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Comparing Scots pine regeneration established by sowing and planting at various times of year

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Abstract: The aim of this study was to evaluate the practical feasibility of two forest regeneration methods using Scots pine *Pinus sylvestris* L. To this end, comparative experiments were established in the Złotoryja and Legnica Forest Districts. The site in Złotoryja had been clear cut, while the experimental plot in Legnica was established at a location damaged by wind in 2009 and cleared from wind throws and wind-broken trees before the experiment. Four different dates for sowing and two for planting were chosen in order to investigate the potential forest regeneration with respect to time. Both experiments were established according to the same design: a complete random block design with five replication blocks. To each plot we applied approximately 53 g (1.2 kg/ha) of seeds and planted 230 seedlings (10 200 seedlings/ha). In 2017, the height of the pine trees was recorded and their increment in height was measured in 2016 as well as 2017. A preliminary analysis of results was conducted using ANOVA for multiple experiments in order to identify significant differences and to then combine variables to form homogeneous groups to which the Duncan multiple range test could be applied. For growth traits, the ANOVA showed significant differences between experimental sights as well as a significant interaction of factors with the experimental site. In terms of planting, April was the most advantageous resulting in the greatest tree height in both forest districts, while in the Legnica Forest District the saplings planted in April also showed the greatest annual increments. Among the sowing dates, the most advantageous was the winter sowing, while the April sowing date produced the least desirable results. In conclusion, both sowing and planting are effective methods to establish pine cultures in coniferous forest.

Furthermore, both methods may be performed at the currently recommended spring date, but they may also be postponed to summer and winter dates provided favorable weather conditions prevail.

Keywords: methods of forest regeneration, pine growth, density

1. Introduction

Artificial forest regeneration is performed by sowing or planting. Each of these methods has its own advantages, disadvantages and application. Comparing them makes sense only under certain natural, economic and technical conditions. Tyszkiewicz and Obmiński (1963) and Puchniarski (2008) mention a number of advantages of both artificial renewal planting and sowing.

Historically, the oldest method of forest regeneration was self-seeding. When this form of renewal failed, artificial sowing was used, including cone sowing. Sowing and self-seeding were supplemented with planting. Forest regeneration by planting was first performed with seedlings taken from among those that self-seeded and then produced in nurseries (Pfeil 1839; Burckhard 1870). The unreliability of sowing regeneration resulted, in the case of Scots pine (*Pinus sylvestris* L.), in the widespread method of planting one- or two-year-old nursery-produced seedlings in prepared soil in accordance with the guidelines of Pfeil (1839, 1843). This was probably forced by the extensive use of large clearcuts, on which regeneration from the self-sown seeds of adjacent stands was insufficient (Puchalski 1972).

The most reliable and effective method of regenerating pine in terms of the amount of sown seeds is to plant seedlings produced in nurseries. However, sowing regeneration is inexpensive and can be done quickly on large areas with little labour. Therefore, this method is still of interest. Łukaszewicz and

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Gil (2007) reviewed sowing regeneration methods. Silviculture practitioners are constructing new types of seed drills and developing procedures for establishing crops, which are considered to be new silvicultural methods (Walachowski 1985; Niemiec 2003; Niemiec, Sobański 2007, 2009; Borysiewicz 2011). These initiatives are very valuable and contribute to a significant improvement in the quality of the silvicultural work. However, practitioners' research is usually lacking systematic comparisons between different regeneration techniques.

An attempt was made to determine the practical usefulness and possibilities of using artificial sowing and planting as ways of regenerating Scots pine. Additionally, various dates of establishing crops were included in the study. Given rapidly changing and unstable climatic conditions, this information will not only supplement the theoretical deficiencies in this field, but also expand the possibilities of undertaking practical activities.

2. Methodology

Comparative experimental sites were established in the Złotoryja Forest District, within Chojnów working circle, in the Michałów forest range, compartment 7j, and in the Legnica Forest District, Prochowice working circle t, Mierzowice forest ranget, compartment 45c. The area in Złotoryja was after clearcut. The habitat is categorised as a fresh coniferous forest on rusty podzolic soils made of loose sands. The site index of the removed stand was II, 5. The logged area was adjacent to a mature pine stand on the west side, and from the other sides it was surrounded by forest cultures and pole stands. In Legnica, the experimental site was established in an area that was completely exposed and cleared of wind-broken trees and windthrows from 2009. The habitat is defined as a fresh mixed coniferous forest site on brown podzolic soils.

The selection of the experimental sites resulted from the need to compare not only different regeneration methods, but also their varied timing (Table 1). Hence, the experiment includes both traditional sowing and planting dates as well as potentially possible dates requiring scientific and practical verification. In each location, seeds from one batch were used for sowing and producing seedlings in the nursery. Sowing was planned for November, the so-called sowing under clods. The seeds were to winter over and begin germinating as early as possible in the spring. Unfortunately, the soil was already frozen on the planned sowing date, so the seeds were sown during the closest temporary thaw (i.e. in January 2011).

Both experimental sites were designed similarly: complete random blocks, with five replication blocks. The size of the plots was 225 m^2 with dimensions of 15 m × 15 m. Each experiment consisted of 30 plots – experimental units (6 objects × 5 repetitions), and its size was 0.675 ha. The soil was plowed into furrows with a two-bladed plow at an interval of 1.5 m in both sites. On each plot, about 53 g (1.2 kg/ha) of seed was used. The seeds for the crops were sown with a manual barrow seeder. In the first two years, self-sown seedlings were removed from the site in Złotoryja so that they would not increase the density of the crops. The appearance of self-sown seedlings at the site in Legnica was not possible.

Two hundred and thirty seedlings were planted on a plot (approximately 10,200 items/ha), which survived one, full or incomplete, growing season (1/0).

In 2017, after the tree growth ended, the height of all trees and the height increments for 2016 and 2017 were measured. During the measurements, the trees were qualified (in accordance with the applicable rules for conducting silviculture treatments) for continued growing after late cleaning in 2017. The density (number of trees per hectare) was calculated from the number of trees qualified for further growth.

The results were calculated using analysis of variance (ANOVA) for multiple experiments, in accordance with the following fixed model:

$$y_{ij} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + e_{ij}$$

where
y_{ij} – means for the objects in the experiments,
μ – overall mean,
α_i – effects of the objects,
β_j – effects of the experiments,
$(\alpha\beta)_{ij}$ – interactive effect,
e_{ij} – residuals (errors).

If a significant interactive effect was obtained, which means that the effects of the objects are different in each experiment, the ANOVA for each experiment was performed separately, in accordance with the model:

$$y_{ij} = \mu + \alpha_i + \beta_j + e_{ij}$$

where
y_{ij} – plot average,
μ – average for the experiment,

Table 1. Forest regeneration methods and execution dates

Forest regeneration method and planned execution date	Actual execution date
Sowing VI 2010	28 June 2010
Sowing VIII 2010	26 August 2010
Planting VIII 2010	26 August 2010
Sowing XI 2010	18 January 2011
Sowing IV 2011	31 March 2011
Planting IV 2011	31 March 2011

α_i – effects of the objects,
β_j – effects of the blocks,
e_{ij} – residuals (errors).

If the objects were found to differ significantly, they were combined into homogeneous groups using Duncan's Multiple Range test.

3. Results

The ANOVA of the examined characteristics showed the existence of significant differences between the objects and a significant interaction of the objects with the site. This means that the results of each experiment must be analysed separately. This was done for all characteristics, despite the fact that no differences between the experiments ($p = 0.059$) and no 'objects × experiments' interaction ($p = 0.243$) were demonstrated for tree density. Object averages for the four analysed characteristics and both experiments are summarised in Table 2.

The letters a–f placed next to the values of the characteristics inform about the existence of significant differences between the objects. The presence of the same letter next to two compared means indicates that there is no significant difference and that both means are included in the same group, but only for the experiment being considered.

In the Złotoryja Forest District, the saplings planted as seedlings in April 2011 reached the highest height. The height increments for 2016 and 2017 were also among the highest in this site. The saplings from the August planting of the previous year were in second place. The height increments of this site belong to the same group as the height increments of the saplings from the April planting. The saplings resulting from the June sowing in 2010 exhibited very similar growth to that of the saplings from the August planting in 2010. The lowest height and the lowest height increments were found in the sapling stand established by winter sowing in Złotoryja. These trees were significantly smaller than the growth characteristics of the young tree stand established from the April sowing, that is, done at the traditional time. The different dates of sowing and planting generated age differences among the trees from winter and spring sowing and the remaining objects, amounting to 1 year. The height difference

Table 2. Results of measurements for experimental sapling stands in the Złotoryja and Legnica Forest Districts recorded in 2017

Object	Age of trees in 2017 [years]	Height in 2017 [cm]	Height increment in 2016 [cm]	Height increment in 2017 [cm]	Density per ha
Experimental site in the Złotoryja Forest District					
Sowing in June 2010	8	239.04 b	42.95 a	55.06 ab	4524 bc
Sowing in August 2010	8	221.83 c	41.81 a	53.60 b	3884 c
Planting in August 2010	8	242.51 b	41.72 a	57.16 ab	4738 b
Sowing in winter 2010	7	201.77 d	29.49 b	44.25 d	5636 a
Planting in April 2011	8	260.75 a	42.90 a	57.44 a	4818 ab
Sowing in April 2011	7	222.88 c	37.18 a	48.05 c	5253 ab
Mean in Złotoryja	-	230.69	38.92	52.22	4809
Experimental site in the Legnica Forest District					
Sowing in June 2010	8	238.16 d	41.05 c	45.58 e	5013 b
Sowing in August 2010	8	236.98 d	42.19 c	46.88 d	4027 c
Planting in August 2010	8	292.38 b	49.62 b	54.76 b	5093 b
Sowing in winter 2010	7	250.83 c	41.50 c	47.75 c	5440 ab
Planting in April 2011	8	301.54 a	52.23 a	60.17 a	5716 a
Sowing in April 2011	7	224.64 e	38.92 d	43.93 f	5173 ab
Mean in Legnica	-	258.93	44.45	50.13	5077

of 59 cm between the trees planted in April and the trees sown in winter can only be due to the age difference, because the eight-year-old objects had height increments of 7–42 cm at the age of 7, and the winter-sown saplings increased in height over 44 cm at the age of 7 (in the next year).

In the Legnica Forest District, the highest height and the largest annual increments were found for saplings planted from seedlings in April and, in terms of grouping objects by growth characteristics using Duncan's Multiple Range test, this group was not linked to any other object. The largest increment achieved in 2017 suggests that the differences may increase in subsequent years. The second object in terms of height and height increment was the sapling stand from the August planting.

Of the sowing dates, winter sowing turned out to be the most beneficial, whereas the least favourable was sowing in April. Winter-sown trees were higher than those sown in June and August, despite the fact that they were younger by one growing season. After comparing the sowing dates, the opposite result was obtained in Legnica from the result in Złotoryja. The differences in tree heights between those sown at the traditional April date and those sown in June and August can be explained by age differences.

4. Discussion

Forest regeneration is a necessity in every managed forest, which is why its methods have been appraised since the beginning of modern forestry, that is, from the 18th century. According to Puchalski (1972), regeneration decisions should be based on three principles: 1) all biological and ecological possibilities of natural regeneration should be used in accordance with the purpose of the renewal, 2) natural regeneration should be rejected when the soil is not functional and when the quality of the regenerated tree stand or its surroundings are deficient or when they are of inappropriate provenance and 3) if natural regeneration is rejected, artificial regeneration should be performed immediately to prevent habitat degradation and losses of growth. According to Jabłoński (2015), the current annual volume increase of Polish forests is on average 9.1 m^3/ha and their market value loses financially for each year of regeneration delay.

The literature on the subject lacks studies that compare the growth of pine regeneration established by sowing or planting, performed on the basis of methodically established experiments. This is an additional gap in knowledge. Existing literature concerns remote geographical regions. Mäkitalo (1999), in an experiment conducted in northern Finland comparing methods of soil preparation and establishing crops, found a height advantage of trees propagated from bare-root seedlings (295 cm) over trees from container seedlings (261 cm) and those sown (186 cm) in a crop of 16-year-old trees. This result is not consistent with the popular belief that container seedlings have a higher quality. The Oleśnica Forest District compared the growth of pines from bare-root seedlings and container-grown seedlings planted in late summer, autumn or spring, and found that the stands grown from container seedlings had no growth advantage over stands from bare-root seedlings if they were planted in the period of August to October (Barzdajn 2010; Barzdajn, Kowalkowski 2016). In the central European part of Russia, in the forests of the Moscow Technical Institute of Forestry, Merzlenko and Muhamedšin (1987) conducted a comparative growth analysis of two Scots pine stands at the age of 110, established in 1874 by sowing and planting. Due to the lack of repetitions, the results are not of full value; however, they indicate more intensive growth increments of the stand that was planted, up to the age of 110 years. After this period, the ongoing growth increment of the sown stand was higher than that of the planted stand. The authors explained these differences only by the higher density of the trees regenerated by sowing and the influence of competition among the trees. In Poland, a number of comparisons were made of crops and seedlings that were sown or planted; however, on the basis of observing business entities established without a research purpose. The results of such comparisons, in which the experimental error (influence of uncontrolled factors) cannot be calculated, are unreliable. In the research of Hawryś et al. (2004) of a site cleared by a fire in 1992 in the Rudy Raciborskie Forest District, planted pine regeneration grew better than self-sown regeneration, and, in the Potrzebowice Forest District, plantings grew better than sown regeneration. The observation of Okoń (2016) from the forests of the Regional Directorate of State Forests in Radom (forest districts of Grójec, Kozienice, Barycz, Włoszczowa, Ruda Maleniecka, Zwoleń and Stąporków) provided a similar result – renewals from plants grew faster than sown renewals, at least until the sapling age. The results of our experiment clearly indicate a more intensive growth of crops resulting from planting than from sowing and are in complete agreement with the data in the literature. The differences in growth remained until sapling age and did not show a tendency to disappear. It follows that the expected growth losses relating to what is known as transplant shock are not justified.

So far, the dates of sowing pine seeds for tree crops have not been studied in the research. Only in Finland in the experiments of Chantal et al. (2003) was sowing date (spring and summer) one of the factors. Summer sowing was not conducive to the good wintering over of pine seedlings and increased mortality was noted in the next growing season due to frost damage to the roots.

Regardless of the date and method of establishing experimental crops in all the sites, the saplings were fully suitable for further cultivation. This is even more valuable information, because unconventional dates of sowing and planting were used in these experiments. Even sowing pine seeds in winter, not used anywhere so far, proved to be useful under the conditions in which both experiments were established. From a practical point of view, this allows pine crops to be established over a much longer timeframe, which is important in situations where regeneration work is extensive and must be performed quickly.

5. Conclusions

1. Both methods of establishing pine forest cultures at coniferous site types, sowing and planting, can be effective and productive.

2. Both sowing and planting can be performed in the previously accepted spring time, as well as extended to summer and winter in the event of favourable weather conditions.

3. The better height increment of crops and saplings resulting from planting compared to regeneration from sowing crops requires deeper analysis.

Conflict of interest

The authors declare that there are no potential conflicts of interest.

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Authors' contribution

W.B. contributed to the concept, methodology, statistical calculations and preparation of manuscript. W.K. involved in experimental design, organising the measurements and preparing the literature. R.T. performed the measurements and prepared the results.

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