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RATE OF SURVIVAL AND GROWTH OF SCOTS PINE (*Pinus sylvestris* L.) IN RECLAMATION PLANTINGS AT THE NITROGEN FERTILISER PLANT ZAKŁADY AZOTOWE „PUŁAWY" S.A.[1]

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Summary. The study was focused on the survival rate, annual height increments and the height of Scots pine in 8-year plantings on chemically degraded industrial soils and urbisols with particle size distribution of loose sand (dunes), in the immediate vicinity of the nitrogen fertiliser plant Zakłady Azotowe „Puławy" S.A. The experimental plantings had been made by the Zakłady using 3 kinds of seedlings (in 4 replicates): 0 – seedlings with uncovered root system, non-mycorrhized; M1 – seedlings with covered root system (in „pots"), mycorrhized; M2 – seedlings with uncovered root system, mycorrhized. It was found that the highest rate of mortality of the trees (survival rate of 71–73%) occurred during the period of 4 years after the planting; in subsequent years of growth there occurred sudden decay of incidental trees (survival rate after 8 years in the range of 63–71%). Higher survival rates and more intensive growth in height (during 3–5 years after planting) were noted for trees from seedlings with covered root system, mycorrhized; no significant differences were observed in the average height increase between trees from mycorrhized and non-mycorrhized seedlings with uncovered root system. On all study areas, throughout the period of observations, there was a very high variation in the annual increments in height and in the height of the individual pine trees. It is necessary to elucidate the continual dying of pine trees (systematic decrease of survival rate) in pine plantations and thickets, and the very strong individual variation in the growth of pine trees in height.

Key words: scots pine, growth, degraded soil

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INTRODUCTION

Due to the immission of gas and dust pollution (primarily fallout of aerosol of ammonium nitrate) and lowering of the ground water table (uptake of subterranean waters for production purposes), a no-forest zone formed in the vicinity of the nitrogen fertiliser plant Zakłady Azotowe „Puławy" S.A. [Adamczyk-Winiarska *et al*. 1969, Jakubczak *et al*. 1969, Gadzikowski 1971, Chojnacki 1975, Dunikowski and Kowalkowski 1980, Kowalkowski 1980] – in 1983 the area of devastation of forest ecosystems reached 5 km^2. The investment projects aimed at reducing the emission of pollution, begun in 1985, contributed to an improvement of the status of the environment. This led to a resumption of attempts at forest reclamation of de-forested soils situated in the immediate vicinity of the emitter of nitrogen pollution and deep-water intakes [Kowalkowski and Kopron 2002, Kopron 2007].

The objective of the study presented here was the estimation of the growth of Scots pine (*Pinus sylvestris* L.), in 8-year plantings, in the zone of the strongest degradation transformations of the environment at the nitrogen fertiliser plant Zakłady Azotowe „Puławy" S.A. (the Plant) based on analysis of survival of annual height increments and the height of the trees.

MATERIAL AND METHOD

The experimental areas are situated at the foot of the windward slope of a dune, at a distance of about 200–300 m to NE from the Plant [Kowalkowski and Kopron 2002]. The soils in the region of the experiment are industrial soils and urbisols with particle size distribution of loose sand (dunes) [Pranagal and Słowińska-Jurkiewicz 2007], developed from forest soils through, among other things, felling and rooting out dead pine stands, construction of roads and underground installations, crop plant cultivation, application of various techniques of soil improvement during earlier attempts at reclamation [Siuta 2002]. The soils are characterised by strongly disordered chemistry [Bielińska *et al*. 2001, Kowalkowski and Kopron 2002] due to long-term chemical immissions, mainly of nitrogen compounds [Chojnacki 1975, Kowalkowski 1980]. The area was overgrown with wood small-reed [Węgorek 2006], cut and processed for compost.

In the spring of 2002 the Plant (Department of Environmental Protection) performed plantings on the experimental areas, after prior preparation of the soil into troughs with width of ca. 0.4 m [Kowalkowski and Kopron 2002]. One-year old seedlings were planted at spacing of 1.0 × 1.5 m. The plantations were established in three variants: 0 – seedlings with uncovered root system, non-mycorrhized; M1 – seedlings with covered root system (in „pots"), mycorrhized; M2 – seedlings with uncovered root system, mycorrhized. Each of the variants was represented by 4 areas (replicates). The numbers of trees planted in the particular variants of the experiment were as follows: 0 – 1267 pcs; M1 – 1146 pcs;

M2 – 1303 pcs; total – 3713 pcs. No corrections or complementary plantings were made in the experimental plantings. Studies of genetic variation of pine on the experimental areas revealed that the intra-population variation is characteristic for the species [Kruk *et al*. 2012].

Within the scope of our study we measured the height of each tree (using a measuring staff with accuracy of 1.0 cm), and at the end of the vegetation period the annual height increments were calculated as differences in tree height in the current year and the preceding year. In the course of the measurements inventory was taken of living and dead trees. The rate of survival (rate of success of plantings) was calculated as % of living trees in a particular year in relation to the number of trees planted. The tree height measurements and the determination of the rate of survival were made for the first time in June 2005 – after three years of growth of the trees. In subsequent years (2005–2009) the heights and numbers of living trees were determined every year in November. As the first inventory of the trees was made in 2005 and there is no information on the numbers of trees that survived in the years 2002–2004, the first index of survival was determined for 4-year old plantings (in November 2005). Whereas, the height of trees at the end of the vegetation seasons of 2002, 2003 and 2004 was determined by measuring the height of situation of the whorls formed in those years. The height at which the first whorl was situated was adopted as the height of the tree at the end of the vegetation season of 2002.

RESULTS AND DISCUSSION

Table 1 presents the survival rates and annual height increments and height of the trees (mean, maximum, minimum) in the particular variants of the experiment and for the whole population under study.

The rate of survival of the trees after 4 vegetation seasons (in 2005) was 71.1% in the case of plantings of seedlings with uncovered root system (0 and M2), and nearly 73% in plantings of seedlings with covered root system (M1). In the 5th year of growth the rate of survival in variants 0 and M2 decreased by about 5–6%, and in variant M1 by 1%. In subsequent years (especially in 2008 and 2009), in variants 0 and M2 the number of drop outs decreased and the decrease in the rate of survival was similar to that in variant M1. After 8 years (in 2009), in the plantings of seedlings with uncovered root system, non-mycorrhized (0) and mycorrhized (M2), the rates of survival differed by only 1.2%, but it was lower by 7.7 and 6.5%, respectively, with relation to the survival of trees in the plantings of seedlings with covered root system (M1) – Table 1. These observations indicate that under the conditions of the experiment the use of seedlings with covered root system had a greater effect on the survival rates of Scots pine (in the development phase of the plantation) compared to the mycorrhized seedlings. However, it should be emphasised that in the 8-year plantings (thickets) there is ongoing dying of trees, and it is not an effect of damage, e.g.

Table 1. Rates of survival and morphometric features of trees (mean, maximum and minimum values) in the years 2002–2009 (02–09)

Variant	Parameter/Year	2002	2003	2004	2005	2006	2007	2008	2009
0	survival rate, %	100	n.d.	n.d.	71.1	65.0	63.8	63.6	63.2
	increment (cm) mean	n.d.	11	19	27	29	28	34	52
	max	n.d.	30	53	61	72	88	104	93
	min	n.d.	1	1	1	1	1	1	2
	height (cm) mean	5	15	35	62	92	120	154	205
	max	15	39	91	141	185	248	320	375
	min	1	2	4	7	22	24	30	35
M1	survival rate, %	100	n.d.	n.d.	72.9	71.9	71.6	71.5	70.9
	increment (cm) mean	n.d.	26	27	36	24	32	38	51
	max	n.d.	50	56	79	77	68	95	97
	min	n.d.	1	3	5	1	1	1	3
	height (cm) mean	12	37	64	101	137	168	205	256
	max	30	73	112	179	228	287	315	395
	min	1	5	22	42	55	61	55	93
M2	survival rate, %	100	n.d.	n.d.	71.1	66.1	64.9	64.9	64.4
	increment (cm) mean	n.d.	11	19	26	29	26	36	50
	max	n.d.	33	61	58	83	73	77	101
	min	n.d.	0	1	1	0	1	1	2
	height (cm) mean	5	16	35	62	92	119	153	203
	max	19	43	83	127	183	220	280	367
	min	1	1	4	9	27	31	15	40
0 + M1 + M2	survival rate, %	100	n.d.	n.d.	71.7	67.6	66.6	66.5	66.1
	increment (cm) mean	n.d.	15	22	30	27	29	36	51
	max	n.d.	50	61	79	83	88	104	101
	min	n.d.	0	1	1	0	1	1	2
	height (cm) mean	7	22	44	74	107	136	170	222
	max	30	73	112	179	228	287	320	395
	min	1	1	4	7	22	24	15	35

n.d. – not determined

inflicted by deer or insects, nor the result of selection caused by competition – increased density of the tree stands. It appears that the cause for the dying of pine trees may lie in the disturbance of the physiological processes of the trees resulting from the disorder in the chemistry of the soils and the continuing (though vastly reduced) immission of pollutants. Dying of Scots pine (40% of the population) during the initial 2 years of growth, in the vicinity of the fertiliser plant Zakłady Azotowe in Włocławek, was observed by Z. Barzdajn *et al*. [2002] who report that the cause is contamination with chlorine due to a breakdown of a PVC pipeline. In subsequent years those authors observed further dying of trees, but also regeneration of a part of the trees damaged by chlorine. This caused that the survival rate of the pine trees after 6 years of growth was at the level of ca. 60% [Barzdajn *et al*. 2002]. Under the conditions of our study, the rate of survival of pine trees after 6 years of growth, for the whole population (0 + M1 + M2), was 66.6% (63.8–71.5), and after 8 years it was 66.1% (63.2–70.9) – Table 1.

The mean annual height increments (means from three variants) displayed an increasing trend, from 15 cm in 2003 to 51 cm in 2009. Analysis of the mean height increments in the particular variants of the experiment shows distinct differences (especially in the years 2003–2005) between the increments of trees from seedlings with covered root system (M1), and those of trees grown from seedlings with uncovered root system, non-mycorrhized (0) and mycorrhized (M2) – Table 1. In variant M1, the mean height increment in 2003 was 2.5-fold greater than in variants 0 and M2. In subsequent years the divergence between the mean annual increments between variants M1 and 0 and M2 decreased, and after 8 years of growth of the trees (2009) practically disappeared – the differences between the mean for the whole population (0 + M1 + M2) and the means for the variants amounted to 0–1 cm (Tab. 1). Up till 2006, the mean tree height increments in variants 0 and M2, in the same years, were identical, as a rule. In 2009 the differences in mean height increments between all variants did not exceed 2 cm (Tab. 1). Throughout the period of growth the ranges of annual height increments were very broad in all the variants. The minimum increments, as a rule, were 1 cm. The maximum values of annual increments increased in the successive years, from 30 cm (0) in 2003 to about 1 m (basically in all the variants) in 2008 and 2009 (Tab. 1).

Already after the first vegetation season of the plantings the mean height of trees in variant M1 (seedlings with covered root system) attained 12 cm and was almost twice as big as in variants 0 and M2 (seedlings with uncovered root system), where it was 5 cm. In subsequent years, the differences in height between trees from seedlings with covered root system (M1) and trees from seedlings with uncovered root system (0 and M2) increased, the mean heights of trees in variants 0 and M2 being nearly identical. E.g. in 2005 the mean height of population M1 was 101 cm, and that of populations 0 and M2 – 62 cm. In 2004, after three vegetation seasons, the mean height of trees in variant M1 was still nearly double that of trees in variants 0 and M2. Since 2007 the difference between the

mean heights of trees from variant M1 and variants 0 and M2 remained at the level of about 50 cm, the mean values in variants 0 and M2 being almost identical all the time (Tab. 1) and in 2009 amounted to 205 and 203 cm, respectively (in variant M2 – 256 cm) – Table 1. In all variants of the experiment (and in all areas – replicates), throughout the period of the experiment, there was a very strong variation in the height of the trees. This was due to systematic development of the smallest annual increments on the smallest trees and, as a rule, the maximum increments on the tallest trees. After 8 years of growth the difference in the height of the tallest and the smallest trees in variant M1 was a little above 3 m, and in variants 0 and M2 – 3.4 and 3.3 m, respectively (Tab. 1). Good growth of Scots pine in height in areas under the influence of nitrogen immissions is confirmed by a study performed in the vicinity of the nitrogen fertiliser plant Zakłady Azotowe in Włocławek – 8-year old plantings of the species had heights of about 1.2 m, and when at the age of 14 years their height exceeded 3.5 m [Barzdajn *et al*. 2002]. Good growth of young pine tree stands on the degraded soils at the Zakłady Azotowe in Puławy is indicated by comparisons with the results of studies on the growth of Scots pine on non-degraded forest soils. In a provenience study established in a mountain mixed forest habitat, 6-year old pine tree stands, depending on their origin, had heights of 97–128 cm [Chodzicki 1975] (in Puławy 119–168 cm). In turn, in a dry coniferous forest habitat, depending on the time and manner of soil preparation, 10-year old pine thickets attained average tree heights of 156 to 210 cm.

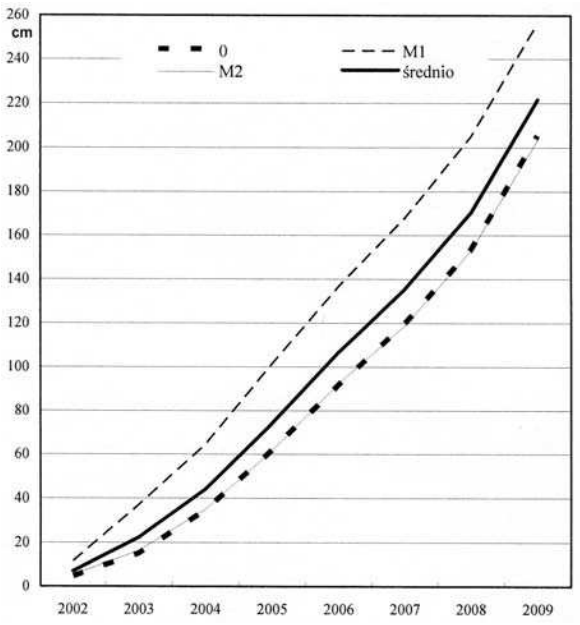

Fig. 1. Increase of the mean height of pine trees in the experimental variants and in the whole population (average)

The differences in the dynamics of growth between tree stands grown from seedlings with covered root system, mycorrhized (M1), and the stands from seedlings with uncovered root system, mycorrhized (M2) and non-mycorrhized (0), are clearly visible on the graph – Figure 1. In variant M1 the trees displayed a stronger dynamics of growth until 2006 (5 years), in the years 2007 and 2008 the dynamics of growth was fairly uniform in all variants, and in 2009 there appeared a slight increasing tendency in the dynamics of growth of the trees in variants 0 and M2. The curves of increase in the mean heights of the trees in variants 0 and M2 are nearly identical in shape (Fig. 1).

CONCLUSIONS

1. The highest rates of mortality of Scots pine (survival rates of 71–73%) occurred during the period of 4 years from planting. The sudden dying of incidental trees in the successive years of growth (rate of survival after 8 years 63–71%) is a cause of concern.

2. The results of the study indicate clearly higher rates of survival and more intensive growth in height (during the period of 3–5 years from planting) in the case of trees grown from seedlings with covered root system, mycorrhized.

3. No differences were observed in the increase of mean heights between trees from seedlings with uncovered root systems, mycorrhized and non-mycorrhized.

4. On all experimental areas, over the whole period of observations, there was a very strong variation in the annual height increments and in the heights of individual pine trees.

5. Further research is required for the elucidation of the cause of continued dying of pine trees (systematic decrease of the rate of survival) in the plantings and thickets, and of the very strong individual variation in the growth of the pine trees in height.

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PRZEŻYWALNOŚĆ I WZROST SOSNY ZWYCZAJNEJ (*Pinus sylvestris* L.) W ZALESIENIACH REKULTYWACYJNYCH PRZY ZAKŁADACH AZOTOWYCH „PUŁAWY" S.A.

Streszczenie. Badano przeżywalność, roczne przyrosty wysokości oraz wzrost wysokości sosny zwyczajnej w 8-letnich zalesieniach na zdegradowanych chemicznie industrioziemach i urbanoziemach o składzie granulometrycznym piasku luźnego (wydmy), w bezpośrednim sąsiedztwie Zakładów Azotowych „Puławy" S.A. Zalesienia doświadczalne wykonały Zakłady, stosując 3 rodzaje sadzonek (w 4 powtórzeniach): 0 – sadzonki z odkrytym systemem korzeniowym, niemykoryzowane; M1 – sadzonki z zakrytym systemem korzeniowym (w „doniczkach"), mykoryzowane; M2 – sadzonki z odkrytym systemem korzeniowym, mykoryzowane. Stwierdzono: największa śmiertelność drzewek (przeżywalność 71–73%) nastąpiła w okresie 4 lat po posadzeniu, w kolejnych latach wzrostu wystąpiło nagłe zamieranie przypadkowych drzewek (przeżywalność

po 8 latach 63–71%); większą przeżywalność oraz intensywniejszy wzrost na wysokość (w okresie 3–5 lat po posadzeniu) miały drzewka z sadzonek z zakrytym systemem korzeniowym, mykoryzowanych; nie stwierdzono różnic we wzroście średnich wysokości pomiędzy drzewkami z sadzonek mykoryzowanych i niemykoryzowanych, z odkrytym systemem korzeniowym; na wszystkich powierzchniach badawczych, w ciągu całego okresu obserwacji występowało bardzo duże zróżnicowanie rocznych przyrostów wysokości oraz wysokości poszczególnych drzewek sosny. Wyjaśnienia wymagają przyczyny ciągłego obumierania drzewek sosny (systematycznego zmniejszania się przeżywalności) w uprawach i młodnikach oraz bardzo silnego osobniczego zróżnicowania wzrostu sosny na wysokość.

Słowa kluczowe: sosna zwyczajna, wzrost, gleby zdegradowane