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Effects of root pruning and fertilization on biometric traits of 2-year-old seedlings of European beech (*Fagus sylvatica* L.)

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Abstract. The aim of this study was to examine the effects of pruning the root system and different doses of nitrogen fertilization on the height and root collar diameter of 2-year-old beech seedlings (Fagus sylvatica L.). This research was conducted in the forest nursery Muchów (Jawor Forest District, regional directorate of State Forests in Wrocław) and two different pruning treatments (no pruning and at 12 cm depth) and nitrogen fertilization doses (25 and 50 kg×ha^{-1}) were applied. Results from an ANOVA showed statistically significant differences between the two pruning treatments ($p = 0.000$) as well as for the interaction of both treatment factors ($p = 0.019$). Root collar diameter correlated with seedling height, both of which were significantly different for the two pruning treatments ($p = 0.000$). No statistically significant impact by the nitrogen fertilization doses on seedling height could be observed ($p = 0.125$). To conclude, we found that it is reasonable to reduce the doses of nitrogen fertilization to half the recommended amount, 25 kg×ha^{-1}, if the root system is not pruned during the second growth year. Seedlings that do receive pruning should be fertilized using the recommended nitrogen doses.

Keywords: root pruning, fertilization, European beech, forest nursery

1. Introduction

The main goal of nursery production is delivering planting material for needs of renewal, afforestation, repair planting and completing. The planting material should be characterized by strictly defined biometric features, where the basic meaning have height and diameter in root collar of plants, which are a final effect of nursery production.

The root system is essential when it comes to supplying plant in nutrients and water (Atkinson, Wilson 1980). It also supports gas exchange and allows for vegetative reproduction. The survival and further growth of seedlings is dependent largely on properly formed root system (Buraczyk, Kapuścińska 2010). A common practice in nursery production within the forming of root system is pruning of both coniferous and deciduous species.

The basic treatments influencing the growth parameters and success in forest culture should also include properly balanced organic and mineral fertilization (Walendzik, Szołtyk 1990). However, it should be noticed that the modified Liebig's Law of the Minimum today also includes the deficiency or excess of factors different than fertilization and an impact of interaction of factors on each other (Kozłowska 2007). On this basis, the reduction of root system, which takes places during the treatment of root forming, is also a significant factor influencing the basic parameters of planting material. It influences, in particular, the increase in height and thickness in root collar while improving the ratio of dry mass of root system to mass of over-ground part of plant (Kłoskowska 1995; Sobczak et al. 1999). As a consequence of pruning, large reserves of carbohydrates and nutrients are being cut, which would normally be used for root system regeneration and growth of plant after transplantation to forest culture (Canham et al. 1999; McArtney, Ferree 1999). Therefore, after the performance of this treatment, seedlings should be supplied with large amounts of water, and mainly nitrogen fertilizers, in the form of foliar or soil application.

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This process is also intended to form compact and not susceptible to damage during the mechanical lifting of root system (Białobok et al. 1990).

2. Material and methodology of research

The research was conducted on two-year-old seedlings of European beech in forest nursery in Muchów (Muchów forest district, Jawor forest inspectorate). The seeds were sown by hand on May 9, 2013, in an area of 8 acres in the amount of 4,4 kg×ar^{-1}. TL-5 variant of sowing technology was used in the research (ZHL 2003) [Forest Management Practices 2003].

In the second year of seedlings' life, designated were, on 4 acres fragment of area covered with sowing, twenty-four sections with a length of 9 meters each and then randomly they were assigned to four variants of breeding treatments, as described below:

- pruning of root system and providing nitrogen in the amount of 25 kg×ha-1
- pruning of root system and providing nitrogen in the amount of 2x25 kg×ha-1
- no pruning of root system and providing nitrogen in the amount of 25 kg×ha-1
- no pruning of root system and providing nitrogen in the amount of 2×25 kg×ha-1

During the experiment, the forest nursery was equipped in current 'pedology-fertilizer recommendations' developed in March 2014. The recommendations for fragment covered with experiment was limited to use for top-dressing nitrogen fertilization in two doses, that is, 2×25 kg×ha-1. A variant without fertilization was not designed due to the necessity of assigning planting material from the experiment to fulfil the needs of renewal and afforestation.

For each of the variants used, there were six repeats, while maintaining the depth of horizontal cut on the level around 12cm below the soil surface. The pruning treatment was performed in February 2014 using the root pruning machine type BRS from Egedal company that allows for performing horizontal cutting.

The first treatment of nitrogen fertilization was conducted on May 12, 2014 using the amount 25 kg N×ha-1. Ammonium nitrate was used for all the variants of experiment. The second treatment of nitrogen fertilization was conducted on June 20, 2014 using the amount 25 kg N×ha-1 only for variants designed for full fertilization in order to supplement the amount of used fertilizer to 50 kg×ha-1. Urea was used as a fertilizer in the second term. All nitrogen fertilizers were used in the form of soil application.

In November 2014, the seedlings were mechanically lifted with the use of a plant lifter type SR2 and then randomly were chosen from each of the experimental plots, from eight to fifteen pieces in order to define its height and diameter in the root collar.

The obtained results were averaged within particular repetitions and each combination of breeding treatments.

The obtained data, in further stage of indoor work, was subjected to a statistical analysis with the use of a two-factor analysis of variance with interaction (Dobek, Szwaczkowski 2003).

$$y_{ijk} = \mu + P_i + N_j + PN_{ij} + e_{ijk}$$

where:
yijk – height/diameter in root collar for i-level of root pruning and j-dose of nitrogen,
μ - grand mean,
P_i – effect of *i*- level of root pruning,
N_j – effect of *j*- level of nitrogen dose,
PN_{ij} – effect of interaction of *i*-level of root pruning and *j*-level of nitrogen dose
e_{ijk} – sampling error.

The groups of homogenous means were designated with the use of Tukey's HSD test. The calculations were made in Statistica 6.0 program (Statsoft 2006).

3. Results

Results of the conducted analysis of variance (Table 1) showed statistically significant differences in the height of seedlings, which was dependent on whether they were subjected to root pruning or not ($p = 0.000$). Significant result was also

Table 1. Analysis of variance for seedlings height

	Sum of squares	Degrees of freedom	Mean square	F	p
Treatment	1556.23	1	1556.23	35.65	<0.001
Dose (N×ha^{-1})	111.72	1	111.72	2.56	0.125
Treatment x Dose (N)	281.95	1	281.95	6.46	0.019
Error	872.99	20	43.65		

obtained for the effect of interaction of activity of both factors ($p = 0.019$) – (Fig. 1). No significant influence of dose of used nitrogen on height of planting material was stated ($p = 0.125$).

The analysis of variance conducted for diameter in root collar (Table 2) showed statistically significant differences in thickness of seedlings, which were dependent on whether they were subjected to a treatment of root forming ($p = 0.000$). Also, statistically significant results were obtained for the used dose of nitrogen fertilization ($p = 0.034$) and for the effect of interaction of activity of both factors ($p = 0.005$) (Fig. 2).

The observed changeability in height and diameter in root collars of seedlings was analysed only for two levels of each of the main factors. Further analysis was focused on the evaluation of effects of joint activity of both factors, which involved dividing the combinations of particular levels of factors to homogenous groups in Tukey's test (Table 3).

The division of variants' combination to homogenous groups for height (Table 3) indicates visibly lower parameters of pruned seedling, while using a reduced dose of nitrogen to 25 kg×ha-1. The highest seedlings were in the unpruned group, regardless of the dose of used nitrogen fertilizer. Also, the combination of pruning and dose of nitrogen in the amount of 25 kg×ha-1 caused a visible reduction in the diameter in root collar. The use of 50 kg×ha-1 dose while root pruning did not influence the thickness in root collar significantly in comparison to the unpruned seedlings, regardless of the given dose of nitrogen (50 or 25 kg×ha-1). The highest variability in terms of height had group of pruned seedlings with dose

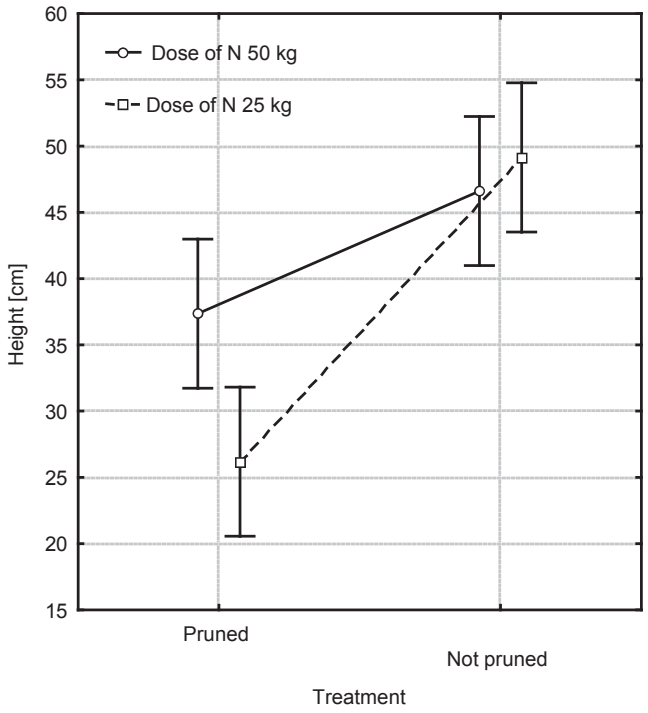

Figure 1. Average height of seedlings for different silvicultural treatment; P – seedlings with pruning root system, N – seedlings without pruning root system

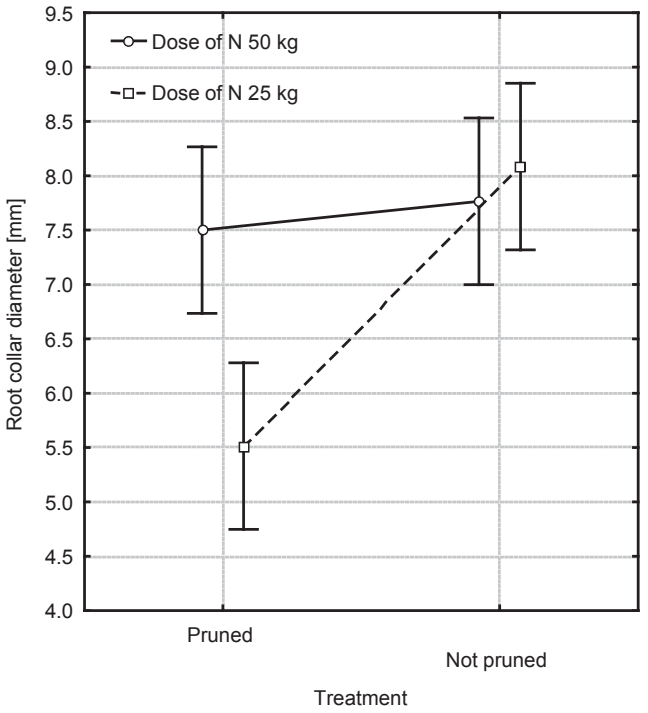

Figure 2. Average of root collar diameter for different treatments; P – seedlings with pruning root system, N – seedlings without pruning root system

Table 2. Analysis of variance of root collar diameter

	Sum of squares	Degrees of freedom	Mean of square	F	p
Treatment	12.07	1	12.07	14.904	0.000975
Dose (N*ha^{-1})	4.167	1	4.167	5.145	0.034544
Treatment x Dose (N)	7.981	1	7.981	9.855	0.005164
Error	16.197	20	0.81		

Table 3. The homogeneous groups of mean height and diameter in root collar. Means with the same letter are not significantly different at $p \leq 0.05$; P – seedlings with pruning root system, N – seedlings without pruning root system

Treatment	Dose [N×ha^{-1}]	Height [cm]	Variability [%]	Root collar diamter [mm]	Variability [%]
P	25 kg	26.2 a	13.54	5.51 a	14.79
P	50 kg	37.3 b	21.36	7.50 b	13.42
N	50 kg	46.6 bc	12.91	7.77 b	11.64
N	25 kg	49.1 c	18.37	8.09 b	9.93

of nitrogen in the amount of 50 kg×ha-1. The smallest variability was observed in the case of unpruned seedlings with nitrogen dose in the amount of 50 kg×ha-1. In the case of thickness in root collar, the group of pruned seedlings treated with reduced dose of nitrogen had the highest variability and the group of unpruned seedlings treated with dose in the amount of 25 kg×ha-1 had the lowest variability.

4. Summary and discussion

An issue concerning the influence of root pruning on biometric features of forest trees' seedlings with regard to the doses of fertilization have not been widely described. Any available literature concerns the fruit trees or agro-forest systems with trees-grain competition (Atkinson, Wilson 1980; Peter, Lehmann 2000).

The lack of impact of nitrogen dose differentiation on the examined biometric features in the group of unpruned seedlings shows that in case of abandonment of root forming treatment, there is a possibility of reduction of used doses of nitrogen to 25 kg×ha-1 in the second year of seedlings' life already on the stage of nursery production. The pruned seedlings, due to the necessity of reconstruction of the lost part of root system, should be fertilized with recommended doses of nitrogen. It is confirmed by the statistically significant effect of interaction between forming treatment and dose of nitrogen in group of pruned seedlings for both examined features. Research made by Andersen (2001) concerning the influence of root pruning on survivability and growth of beech seedlings in the condition of strong competition indicates that in the case of beech with strongly reduced root system (to 7 cm), the seedlings' mortality reached 99% regardless of growth conditions. Dry mass of shoot and roots was also reduced. Similar results were obtained by Andersen et al. (2000) in the case of seedlings of pedunculate oak. Pruning strongly reduced the growth and the allocation of dry mass of shoot and roots. The used treatment had more influence on total dry mass of shoot than on root. Regarding the conditions of herbaceous plants, it was stated that the ratio of aboveground to underground part changed in favour of the root system. In Buraczyk et al. (2011) research, the reduction of skeletal roots of two-years -old Norway spruce seedlings for transplanting caused a significant and proportional to size of reduction (5, 10 and 15 cm) of joint length of roots and number of tips. For practice, the authors also recommended the use of two-year-old seedlings with skeleton roots reduced to 10 cm. It results from the fact that the stronger reduction of root system may lead to the reduction of survivability, especially during droughts.

The obtained results clearly show a strong influence of performed pruning while using the dose of nitrogen in the amount of 25 kg×ha-1 on the reduction of height and diameter in the root collar. In some cases, like the surfaces of cultures with covers liable to weed-growing or strongly permeable soils, such results should encourage the use of seedlings with quite long roots and substantial height of aboveground part (Wesoły et al. 2009). Therefore, the use of unpruned seedlings, regardless of the used dose of nitrogen, or the seedlings possibly pruned but fertilized with full dose of nitrogen. The influence of competition between forest trees' seedlings and weeds should be particularly considered in the case of afforestation of difficult grounds. The roots of European beech are more sensitive to drying than the roots of pedunculate oak (McKay et al. 1999).

An interesting research on the impact of root pruning on the quality of seedlings of Japanese larch was conducted by Morrissey and O'Reilly (2002). The treatment was performed in June, July, August and October with additional fertilization. The influence of root pruning on growth, spring growth and buds was evaluated. Also, the evaluation of morphology after the end of vegetation season and the root growth capability was carried out. The early performance of treatment (in June) caused an increase in height in comparison to the treatment performed in July and August. The pruning in October did not have any influence on the pace of growth. According to these authors, early pruning of roots caused the increase of diameter in root collar and dry mass of root. Also, an increment in root growth capability occurred (twice, three-times in comparison to control variant). The presented analysis of research does not answer an important question regarding the influence of

used on the stage of nursery production variants of breeding treatments on further growth and survivability of seedlings in the condition of forest culture. The preliminary results of proposed combinations' application in conditions of artificially renewed forest culture does not show, after one year of experiment, diversification in terms of increment in height. However, lower survivability of unpruned seedlings treated with reduced to 25 kg×ha-1 dose of nitrogen (unpublished data) was visible. It was stated by Buraczyk and Kapuścińska (2010), who examined the influence of different depth of root pruning on growth of Scots pine after transplanting, that seedlings with least pruned root systems had the highest survivability. According to these authors, the root pruning has a bigger influence on diameter in root collar than on the growth of seedlings in first vegetation season after transplanting. Any queries or doubts regarding the legitimacy of root system forming treatment in the context of, among others, the possible susceptibility of seedlings to fungi infections (Tkaczyk et al. 2014), should result in running multi-stage research covering. There should not only be an evaluation of the final effects of the production in forest nurseries, but also the influence of methods of production used should be evaluated to understand their impact on growth, development, sanitary conditions and on adaptability of planting material in diversified conditions of forest cultures (Wesoły et al. 2009).

Conflict of interest

The authors declare lack of potential conflicts.

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Authors' contribution

W.K. – concept of research, statistical analysis, engravings, discussion, writing an article; S. J. – concept article, discussion, proofreading, writing an article

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