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ORIGINAL PAPER

The effect of starter fertilization on the growth of seedlings of European beech *Fagus sylvatica* L.

Jacek Banach✉, Marta Kempf, Kinga Skrzyszewska, Klaudia Olejnik

University of Agriculture in Krakow, Faculty of Forestry, Department of Ecology and Sylviculture, al. 29 Listopada 46, 31-425 Kraków, Poland

ABSTRACT

In this study, the effect of the Yara Mila Complex (YMC) and Osmocote Exact Standard 3-4M (OE) fertilizers on the growth traits of European beech seedlings was examined in four variants of starter fertilization. Growth traits (height, root system length and root-collar diameter) were measured, followed by the scanning of the stems and root systems of the seedlings, which were then analysed using the WinRhizo software. In addition, their dry weight was measured, and the total length, mean diameter and volume of roots and shoots, as well as the length of skeleton roots (diameter>2 mm) and fine roots (diameter≤2 mm) were determined. The most useful variant of starter fertilization turned out to be the mix of the YMC+OE fertilizers applied at a dose of 1.5 and 0.5 kg per 1 m^3 of substrate, respectively. The seedlings grown on the substrate after the application of this starter fertilization variant were characterized by higher growth parameters. They also featured favourable qualitative indices, i.e. Dickson quality index (*DQI*), sturdiness quotient (*SQ*) and shoot-to-root ratio (*S*/*R*), which indicate their better adaptation and growth after planting in a forest plantation. A change of the currently used fertilization variant with the YMC fertilizer applied at a dose of 2.5 kg per 1 m^3 of substrate to a variant demonstrated in the study as optimum, i.e. the mix of the YMC and OE fertilizers at a dose of 1.5 and 0.5 kg, respectively, will increase the cost of seedling growth by no more than 1.2% (approx. PLN 0.007).

KEY WORDS

Yara Mila Complex, Osmocote Exact, dry mass, seedling quality, seedling cost

Introduction

Mineral fertilizers are the main source of nutrients for seedlings growing in forest nurseries affecting their physiological and morphological properties (Kasprzyk *et al*., 2015). Artificial substrates used in nurseries are prepared on the basis of different ingredients, such as: high peat, bark, sawdust, perlite, vermiculite or sand, which are poor in mineral compounds and require fertilization (Bosiacki *et al*., 2009). Nowadays, pre-sowing mineral fertilisers and top dressing are mainly applied to soil and foliage during the growing season (Wesoły *et al*., 2009).

Numerous studies confirm a significant effect of fertilizers on the quality of cultivated seedlings of different forest tree species. A properly selected composition and dose of the fertilizer may have a positive impact on seedling morphology (Traubat *et al*., 2010), or increased reserve of nutrients (McAlister and Timmer, 1998), resistance to fungal pathogens (Tkaczyk *et al*., 2014),

✉Tel. +48 12 6625125, e-mail: rlbanach@cyf-kr.edu.pl

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and increased seedling tolerance to elevated water stress (Glynn and Keary, 2008). An excessive fertilizer dosage may have an unfavourable effect, causing an excessive growth and a decrease in plant resistance as a result of inhibiting the rate of colonization by ectomycorrhizal fungi (Vaario *et al*., 2008). Seedling adaptation after planting in a forest plantation is affected by the interaction between fertilization and production method (Luis *et al*., 2009).

Slow-release fertilizers may have a favourable effect on the growth and nutrition level of plants, as well as simplification of the cultivation technology. Their application enables elimination of re-fertilization during the growing season, and thus workload reduction (Kozik *et al*., 2009). The slow-release fertilizers used once at the beginning of the production period release nutrients evenly throughout the growing period. This contributes to a reduced fluctuation of salt concentration and a limited leaching of mineral compounds outside of the reach of the root system, which results in a more efficient use of the slow-release fertilizer (to 80%), as compared to the traditional fertilizer (30-40%) (Strojny, 2004; Bosiacki *et al*., 2009).

The aim of the study was to assess the effect of fertilization with different doses of the Yara Mila Complex and Osmocote Exact Standard 3-4M fertilizers on the growth of European beech (*Fagus sylvatica* L.) seedlings. The study hypothesis assumed that the type of fertilizer and its doses do not affect the sylvicultural suitability of seedlings.

Material and methods

EXPERIMENT DESCRIPTION. A pot experiment was established in a nursery under controlled conditions (foil greenhouse). A substrate comprising sawdust and peat in the proportion 1:1 was used. In the nursery in which the test was carried out, a sawdust-and-peat substrate had been used for over 40 years for the production of seedlings of the beech and other forest tree species. The application of a mixed substrate was part of the latest research related to the limited use of peat bog areas and the need to replace peat with another faster renewable nursery medium (Humpenöder *et al.* 2020; Manton *et al.* 2021). The substrate was enriched with two fertilizers, most often used in forest nurseries: Yara Mila Complex and Osmocote Exact Standard 3-4M, applied in four variants (Table 1). For each replication, a fertilizer dose suitable for a given variant was each time added to a measured volume of substrate and thoroughly mixed. Such prepared substrate was placed in plastic boxes with a capacity of 30 dm^3. Three replications were used for each variant. On April 26, stratified beech seeds were manually sown in the boxes (110 seeds each) and covered with sand. The boxes were placed in a foil greenhouse, where they remained till the end of September 2020 (foil removed on June 30).

CHARACTERISTICS OF THE FERTILIZERS USED. Yara Mila Complex is a fast-dissolving, multi-component, chloride-free pellet fertilizer with micronutrients. It is available in the form of a prill pellet.

Table 1.
Variants of starter fertilization used in the research and the cost of their application per 1 m^3 of nursery substrate

Variant (symbols)	Fertilizer dose in kg per 1 m^3 of substrate: Osmocote Exact (OE)	Fertilizer dose in kg per 1 m^3 of substrate: Yara Mila Complex (YMC)	Fertilization cost of 1 m^3 of substrate (PLN)	Average price of 1 kg of fertilizer (PLN)
2.5YMC	–	2.5	9.00	YMC=3.60 OE=15.52
1.5YMC+0.5OE	0.5	1.5	12.56	
1YMC+1OE	1.0	1.0	19.12	
2OE	2.0	–	31.04	

The granules are fine, thus covering a greater surface area unit, resulting in a better availability of all nutrients. Fertilizer composition: total nitrogen (N) – 12% (including: 5% of $N\text{-}NO_3$ and 7% of $N\text{-}NH_4$); phosphorus (P_2O_5) – 18.7%; potassium (K_2O) – 18%; magnesium (MgO) – 2.7%; sulphur (SO_3) – 20%; boron (B) – 0.015%; iron (Fe) – 0.20%; manganese (Mn) – 0.02%; zinc (Zn) – 0.02%. The average price of the fertilizer per 25 kg is approx. PLN 90. Osmocote Exact Standard 3-4M is available in the form of a micropellet, and its components are released in a controlled manner. The fertilizer composition includes: total nitrogen (N) – 16% (including: 7% of $N\text{-}NO_3$ and 9% of $N\text{-}NH_4$); phosphorus (P_2O_5) – 3.9%; potassium (K_2O) – 10%; magnesium (MgO) – 1.2%; boron (B) – 0.02%; iron (Fe) – 0.45%; manganese (Mn) – 0.06%; copper (Cu) – 0.05%; molybdenum (Mo) – 0.02%; zinc (Zn) – 0.015%. Price per 25 kg is approximately PLN 388. The first fertilizer is a fast-acting, easily soluble product thanks to the presence of nitrogen in the form of nitrate and the physical properties of the prill pellet. However, its activity is limited only to the initial phase of the growing season and is often combined with top dressing. The second of the used fertilizers is characterized by a controlled release of its mineral ingredients almost throughout the entire growing season (3-4 months at temp. 21°C), which results from the applied encapsulation. The reduced leaching of ingredients from the substrate is an additional advantage of this fertilizer (Zajączkowski, 2004).

Measurement works. The study material comprised one-year-old European beech seedlings growing under controlled conditions (1/0K assortment). 90 seedlings from each fertilization variant were collected (30 per replication), numbered and cleaned of the substrate; then, the height and length of the root system, as well as the root collar diameter were measured (accuracy ±0.1 cm for both). Each seedling was cut at the root collar and its leaves were removed; then, the shoot and root system was scanned using the Epson Photo V800 scanner. The obtained digital images were analysed using the WinRHIZO 2016 software (Regent Instruments Inc.). The total length, mean diameter and volume of roots and shoots, as well as of coarse roots (diameter>2 mm) and fine roots (=2 mm) were determined (Farahnak *et al.*, 2020). Individual parts of the seedlings were dried at a temperature of 65°C for 72 hours (Memmert UF 110 drier), and then weighed on a laboratory scales (±0.001 g).

Calculations. Three indicators determining silvicultural suitability of seedlings were used. The first one is the sturdiness quotient (SQ), calculated as the ratio of height to diameter at the root collar [1]. The low value of the quotient indicates that the seedlings are stouter and would exhibit higher resistance to the unfavourable abiotic conditions, while its high value points to seedlings, which would be characterized by lower resistance after planting in a forest plantation. The maximum permissible value of the sturdiness quotient for European beech seedlings is SQ=65 (Banach *et al.*, 2020a).

$$SQ=\frac{SH}{RCD}\cdot 10 \qquad [1]$$

where:

SH – seedling height (cm),

RCD – root collar diameter (mm).

The second indicator is the stem-to-root ratio (S/R), which determines the ratio of the dry weight of the above-ground to below-ground parts of the seedling [2]. The root system must be proportional in value to the above-ground part of the shoot, in order to keep up with providing it with water and mineral salts (Iverson, 1984; Banach *et al.*, 2020a). The value of this ratio for the seedlings grown on an artificial substrate should not exceed 2:1 (Thompson, 1985; Haase, 2007).

$$S/R = \frac{SLDW}{RDW} \quad [2]$$

where:

SLDW – shoot with leaves dry weight (g),
RDW – root system dry weight (g).

The third indicator is the Dickson Quality Index (DQI), calculated as a ratio of the seedling dry weight to the sum of the values of both previous indices [3]. The high value of this index shows better adaptive capabilities of the seedling after planting in a forest plantation (Dickson *et al.*, 1960).

$$DQI = \frac{TDW}{0.1 \cdot SQ + S/R} \quad [3]$$

where:

TDW – transplant dry weight (g),
SQ – sturdiness quotient,
S/R – stem/root ratio.

The significance of the differences between the mean values of the analysed growth properties and coefficients determining the sylvicultural suitability of seedlings was established with the application of one-way Analysis of Variance (fixed model). Using Tukey's test, also homogeneous groups were determined at a significance level of p=0.05 for the obtained mean values. Pearson's linear correlation coefficient was used to determine the strength of the relationship between random variables. In order to establish relationships between the tested traits and fertilization variants, the Principal Component Analysis (PCA) was applied. Eigenvalues of the morphological parameters of the seedlings necessary to specify the number of the main components were determined following data standardization. For two indices, *i.e.* SQ and S/R, which demonstrated a pronounced, negative correlation with the second component (–0.8 and –0.7, respectively), each seedling was classified in terms of meeting the criterion of =maximum value for the given index. Three seedling categories were distinguished: A – criterion met for both indices, B – criterion met for one index, C – no criterion met. The significance of differences between the obtained fractions were determined using χ^2 Pearson's test. All calculations were performed using the Statistica 13.3 software (TIBCO Software Inc., 2017).

The difference in the cost of fertilization with the use of individual doses of fertilizers was estimated. The cost of fertilization of 1 m^3 of substrate (Table 1) and the entire nursery bed (36 m^2, 11 m^3 of substrate) was calculated on the basis of the average price of 1 kg of fertilizers. The analysis also included the number of seedlings of the first and second quality classes determined according to the PN-R-67025 (1999) standard. The average value of the first and second class seedlings for a nursery bed (6,000) was corrected on the basis of the share of such seedlings in each experimental variant.

Results

Growth traits. Growth parameters of European beech seedlings, except for the length of the root system and diameter at the root collar, largely depended on the starter fertilization variant. The application of the 1YMC+0.5OE mix at a dose of 1.0 kg per m^3 of substrate turned out to be the most favourable variant, because the mean values for all traits were the highest and typically formed a separate homogeneous group. The mean beech seedling height in this fertilization variant was 34.1 cm and the total biomass was 5.183 g. The lowest values were obtained for the 2.5YMC variant, with 28.6 cm and 3.384 g, respectively (Table 2).

Shoot and root parameters. Mean values of parameters for the roots and shoots of European beech seedlings were significantly higher in the variant with YMC 1.0 kg + OE 1.0 kg mixed fertilization, forming a homogeneous group. Also in the case of these traits, the lowest values were obtained for the 2.5YMC variant, except for the root diameter, which was comparable to the 1YMC+1OE variant (Table 2).

Production suitability indices. Mean sturdiness quotient (SQ) for European beech seedlings was the highest in the mixed variant of starter fertilization YMC 1.0 kg + OE 1.0 kg and amounted to 74.9, exceeding the maximum permissible value of 65. In the case of the remaining fertilization variants, the mean values of the SQ coefficient were similar and ranged from approx. 61 to 63, forming the same homogeneous group. For this coefficient, a statistically significant effect of fertilization variant was obtained (Table 1).

A significant effect of fertilization variant was also demonstrated for the Dickson Quality Index (DQI), and all variants with OE formed one homogeneous group with the values ranging from 0.592 to 0.633, while seedlings fertilized with YMC 2.5 kg were characterized by a significantly lower DQI value of 0.462. High values of this index for European beech seedlings in variants with the OE fertilizer indicate that they will feature higher performance and better adaptation after planting in a forest plantation (Table. 2).

A statistically significant effect of fertilization variant on the value of the stem-to-root ratio (S/R) was determined. The coefficient was at its lowest (best) for both variants with mixed starter

Table 2.

Mean values (±SE) of the traits of European beech seedlings grown in different variants of starter fertilization (a-c – homogeneous groups determined by Tukey's test, $p<0.05$)

Seedling trait	Fertilization variant			
	2.5YMC	1.5YMC+0.5OE	1YMC+ 1OE	2OE
SH (cm)	28.6 ±0.6c	31.0 ±0.7bc	34.1 ±0.8a	32.1 ±0.8ab
RLen (cm)	37.1 ±1.0a	35.9 ±1. 0a	37.4 ±1.0a	35.7 ±1.1a
RCD (mm)	4.77 ±0.09a	5.04 ±0.10a	4.86 ±0.14a	5.13 ±0.11a
TSDW (g)	3.384 ±0.150c	4.320 ±0.196b	5.183 ±0.251a	4.647 ±0.214ab
SDW (g)	1.317 ±0.067c	1.590 ±0.081bc	2.010 ±0.108a	1.811 ±0.092ab
RDW (g)	1.344 ±0.066b	1.846 ±0.087a	2.082 ±0.098a	1.796 ±0.091a
LDW (g)	0.722 ±0.029c	0.885 ±0.039b	1.091 ±0.055a	1.040 ±0.045ab
TRLen (cm)	728.0 ±33.4b	850.8 ±38.4ab	886.7 ±40.4a	871.1 ±37.4a
RDia (mm)	0.41 ±0.01ab	0.38 ±0.01 c	0.42 ±0.01a	0.39 ±0.01bc
RVol (cm^3)	0.944 ±0.048b	0.989 ±0.048b	1.247 ±0.065a	1.035 ±0.048b
TRLen ≤ 2mm (cm)	711.8 ±33.2b	832.6 ±38.2ab	866.6 ±40.0a	853.3 ±37.1a
TRLen > 2mm (cm)	15.9 ±0.5 c	17.8 ±0.5b	19.8 ±0.6a	17.5 ±0.5bc
SLen (cm)	56.4 ±2.0b	59.3 ±2.0ab	64.8 ±2.3a	65.1 ±2.1a
SDia (mm)	2.24 ±0.03b	2.27 ±0.03b	2.43 ±0.04a	2.29 ±0.03b
SVol (cm^3)	2.235 ±0.095 c	2.447 ±0.111bc	3.091 ±0.148a	2.765 ±0.125ab
SQ	60.8 ±1.2a	62.2 ±1.3a	74.9 ±2.6b	63.3 ±1.3a
S/R	1.60:1 ±0.05bc	1.39:1 ±0.03a	1.51:1 ±0.03ab	1.66:1 ±0.04 c
DQI	0.462 ±0.024b	0.592 ±0.031a	0.633 ±0.037a	0.603 ±0.031a

Traits: SH – seedling height, RLen – length of the root system, RCD – root collar diameter, TSDW – seedling dry weight, SDW – shoot dry weight, RDW – root dry weight, LDW – leaves dry weight, TRLen – total root length, RDia – average root diameter, RVol – total root volume, TRLen ≤ 2mm – total length of fine roots, TRLen > 2mm – total length of skeletal roots, SLen – total length of shoots, SDia – average shoot diameter, SVol – total shoot volume, SQ – sturdiness quotient, S/R – stem/root ratio, DQI – Dickson quality index fertilization, *i.e.* YMC and OE and at different doses, and remained below 1.5:1. The ratio for the two remaining variants was slightly lower – approx. 1.6:1. However, in spite of the significant differences, the mean *S/R* ratio obtained for the grown seedlings was below 2:1 for all fertilization variants. This means, that the ratio of the above-ground part (transpiration area) to the below-ground part (absorption area) of the seedlings was correct in all the used fertilization variants (Table 2).

Principal component analysis. The analysis of the first two principal components showed a total of 57.36% of variance in seedling traits. The eigenvalues of the first component was 10.110 (45.96%), while of the second one it was 2.508 (11.40%). The first principal component was mostly linked to the seedling dry weight (TSDW), shoot dry weight (SDW), root dry weight (RDW) and leaf dry weight (LDW), as well as to the Dickson Quality Index (DQI) and total shoot volume (SVol). For the second component, the highest resources were characteristic of shoot height (SH) and root volume (RVol). Root and shoot traits were strongly correlated with each other and negatively correlated (except for shoot height – SH) with shoot-to-root ratio (S/R) and sturdiness quotient (SQ), which is presented in Fig. 1 by the value of angles between vectors of individual traits. The highest, but least sturdy seedlings were obtained primarily from the 1YMC+1OE and partially from the 2OE fertilization variants. Seedlings from the 1.5YMC+0.5OE variant were characterized by longer and thicker roots, while those from the 2.5YMC variant featured the lowest values of growth traits (Fig. 1).

The lowest share of seedlings (<5%) not meeting the SQ and S/R criteria was obtained for the 1.5YMC+0.5OE and 1YMC+1OE fertilizer variants. The difference between the obtained

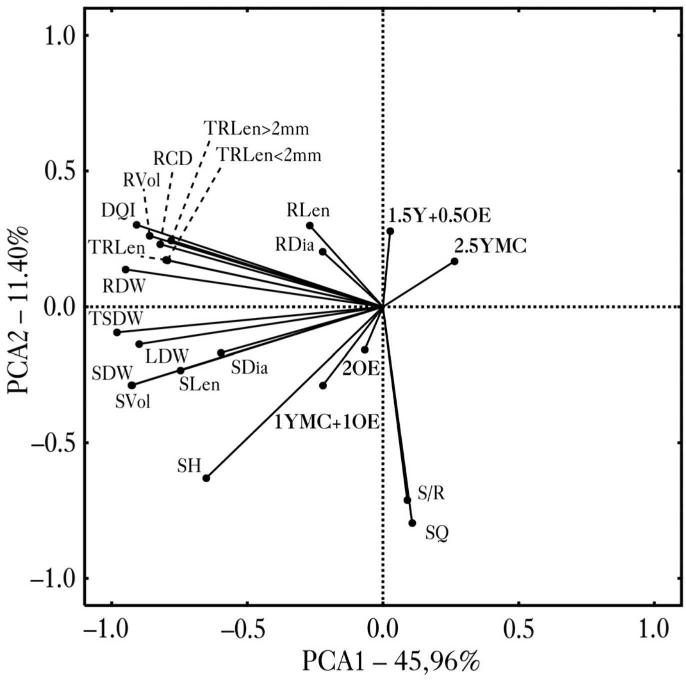

Fig. 1.

A biplot showing the first two variables of the Principal Component Analysis (PCA1 and PCA2) for seedling traits and fertilization variants. The vector length is a weighting parameter that defines the main component. The symbols of the traits are given in Table 2.

fractions determined via χ^2 Pearson's test turned out to be statistically significant (p=0.002), and the share of seedlings meeting both criteria was higher (60%) for the 1.5YMC+0.5OE variant (Fig. 2).

Fertilization cost. An important aspect of the conducted study of European beech is the comparison of the effect of using a given fertilization variant on the cost of production of one seedling. A difference in the fertilization cost of 1 m^3 of substrate between the fertilization variant with YMC at a dose of 2.5 kg, currently used in the nursery under study, and the fertilization variant with YMC 1.5 kg + OE 0.5 kg, presented as the most useful, taking into account the average pricing of fertilizers at the end of 2020, was PLN 3.56 (Table 1). The substrate fertilization cost per nursery bed in the foil greenhouse (area 36 m^2, approx. 11 m^3 of substrate) would then amount to approx. PLN 40. The Seedling Quality Analysis carried out in accordance with the PN-R-67025 standard [1999] demonstrated that the share of non-classed seedlings ranged from 3.3 for the 1.5YMC+0.5OE variant to 5.6% for the 2OE and 1YMC+1OE variants, and the difference determined with a fraction test turned out to be insignificant (df=3, χ^2 Pearson's=0.6791, p=0.878). Therefore, considering the performance from 1 bed amounting to 6 thousand seedlings on average, the increase in the cost of producing 1 seedling will amount to approx. PLN 0.007.

Discussion

The analysis of individual traits of European beech seedlings demonstrated that the application of the Osmocote Exact and Yara Mila Complex fertilizers had a significant impact on production effects. Starter fertilization with the mix of both fertilizers at a dose of 1.0 kg Yara Mila Complex and 1.0 kg Osmocote Exact resulted in clearly increased values of growth traits of European beech seedlings, with the exception of root collar diameter. In this fertilizer variant, the highest values of root system and shoot parameters were also obtained, and the total length of roots and fine roots, i.e. with diameter of ≤2 mm, demonstrated a well-developed absorption surface in the grown seedlings. The latter element is of high significance for seedling adaptation after

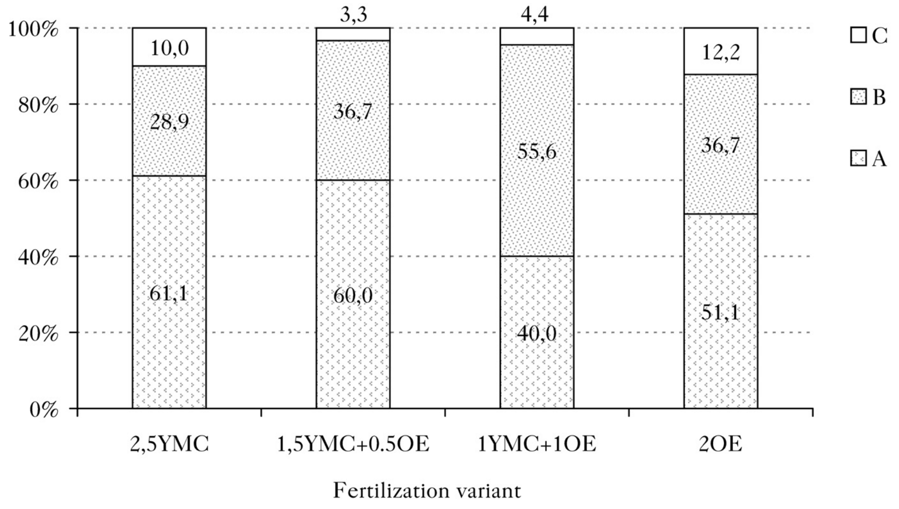

Fig. 2.

Share of seedlings meeting the sturdiness quotient criterion (SQ≤65) and shoot-to-root ratio (S/R≤2:1)
A – both criteria are met, B – one of the criteria is met, C – neither of the criteria is met (χ^2=20.321, df=6, p=0.002)

planting in a forest plantation because a poorly developed root system due to an incorrectly selected nitrogen dose increases seedling sensitivity to drought (Dziedek *et al.*, 2016) and determines their survival rate (Davis and Jacobs, 2005). A similar result was obtained in a study conducted in Croatia. An increased fertilizer dosage resulted in increased parameter values of European beech seedlings, *i.e.* height, root collar diameter and biomass, but the root length, surface and number of root apexes was the highest when an intermediate fertilization dose was used. The root system showed the poorest development at the highest fertilizer dose applied (Potočić *et al.*, 2009). According to Jurásek *et al.* (2008), application of a correctly selected fertilizer dose has a positive effect not only on the initial height of beech seedlings, but also on their later growth in a forest plantation.

Forecasting seedling growth in a forest plantation on the basis of the seedling height attained in a nursery will not always bring the desired adaptation effect (Banach *et al.*, 2020b), and the application of lower seedlings sometimes produces superior results (Cortina *et al.*, 2013; Oliet *et al.*, 2019). Root collar diameter turned out to be a considerably better indicator for Monterey pine and Douglas fir (Chavasse, 1977). Also Khanal *et al.* (2018) pointed to an improved survival rate in the initial stage of growth of seedlings with a greater root collar diameter. European beech seedlings grown in the 1YMC+1OE variant demonstrated the lowest value of this trait, suggesting a possibility for their poorer adaptation after planting in a forest plantation. Although the difference was not statistically significant, yet with the highest mean height the obtained value of the sturdiness quotient SQ exceeded the permissible level by approx. 15% and differed significantly from the values for the seedlings from other variants, for which the SQ value was below maximum.

The applicability of synthetic indices calculated with the inclusion of growth traits and dry weight (Dickson *et al.*, 1960; Iverson, 1984; Thompson, 1985) for the assessment of seedlings after planting in a forest plantationwas demonstrated in numerous studies (del Campo *et al.*, 2010; Grossnickle, 2012; Ivetić *et al.*, 2016). The Dickson Quality Index turned out to be the best determinant of seedling adaptation to water deficiency occurring after plantation establishment (Bayala *et al.*, 2009). In the present study, the index did not differentiate variants with the Osmocote Exact fertilizer; only the seedlings fertilized solely with the Yara Mila Complex fertilizer had significantly lower values. The best average value of the stem-to-root ratio (S/R), characterizing the proportion between transpiration area (stems + leaves), and the absorption area of the root system characterized seedlings in both mixed fertilization variants, and a slightly better outcome was obtained for seedlings from the 1.5YMC+0.5OE variant.

Analysis of the three indices of production suitability demonstrated that the potentially best adaptation after planting in a forest plantation (high value of the Dickson quality index (DQI) and low values of the stem-to-root ratio (S/R) and sturdiness quotient (SQ) would characterize seedlings grown on the mixed fertilization variant with Yara Mila Complex 1.5 kg + Osmocote Exact 0.5 kg. This variant can be considered optimum for the growth of European beech seedlings under controlled conditions on a sawdust-and-peat substrate.

Conclusions

- Nursery material grown on the sawdust-and-peat substrate with an addition of the Yara Mila Complex and Osmocote Exact fertilizers at a dose of 1.0 kg was characterized by the highest mean values for the majority of the analysed growth traits, with the exception of the root collar diameter.
- When the Yara Mila Complex 1.5 kg + Osmocote Exact 0.5 kg fertilizer variant was used, a high share of seedlings meeting the criterion of the stem-to-root ratio (S/R=2:1) and sturdiness

quotient (SQ=65), combined with the lowest share of seedlings not meeting these criteria, was observed.

- The greater mean parameters of the seedlings from the 1YMC+1OE variant did not translate into the values of production suitability indices, which were most favourable for the seedlings from the 1.5YMC+0.5OE variant. This variant can be considered optimum for the production of European beech seedlings cultivated under controlled conditions on a sawdust-and-peat substrate, and the obtained nursery material will be characterized by a superior adaptation after planting in a forest plantation.
- Analysis of the change in starter fertilization in the nursery fertilized with Yara Mila Complex at a dose of 2.5 kg per 1 m^3 of the sawdust-and-peat substrate to fertilization with Yara Mila Complex 1.5 kg + Osmocote Exact 0.5 kg would increase the cost of production of one seedling by 1.2%, i.e. by approx. PLN 0.007.

Author's contributions

J.B. – study concept, statistical analysis of the results, literature review, graphics preparation, manuscript writing, manuscript editing; M.K.- statistical analysis of the results, manuscript writing; K.S. – analysis of the results, literature review, manuscript editing; K.O. – conducting the research, analysis of the results, manuscript writing.

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Conflicts of interest

The authors declare the absence of potential conflicts of interest.

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STRESZCZENIE

Wpływ nawożenia startowego nawozami wieloskładnikowymi na wzrost sadzonek buka zwyczajnego *Fagus sylvatica* L.

Sztuczne podłoża szkółkarskie przygotowuje się z różnych komponentów, takich jak: torf wysoki, kora, trociny, perlit, wermikulit czy piasek, które są ubogie w składniki mineralne i wymagają nawożenia przedsiewnego. W pracy zbadano wpływ zastosowania nawozów Yara Mila Complex (YMC) i Osmocote Exact Standard 3-4M (OE) w czterech wariantach nawożenia startowego na cechy sadzonek buka zwyczajnego (tab. 1). Doświadczenie wazonowe założono w szkółce, w warunkach kontrolowanych (namiot foliowy). Pod koniec września z każdego wariantu nawożeniowego pobrano po 90 sadzonek (po 30 w powtórzeniu). Pomierzono cechy wzrostowe (wysokość, długość systemu korzeniowego i grubość w szyjce korzeniowej), a następnie zeskanowano pędy i systemy korzeniowe sadzonek i przeanalizowano je w programie WinRhizo. Określono również ich suchą masę oraz wyznaczono sumaryczną długość, przeciętną średnicę i objętość korzeni oraz pędów, a także długość korzeni szkieletowych (średnica >2 mm) i korzeni drobnych (średnica ≤2 mm). Zastosowano trzy wskaźniki określające przydatność hodowlaną sadzonek. Pierwszy to współczynnik wytrzymałości (SQ), liczony jako iloraz wysokości i średnicy w szyjce korzeniowej. Drugi to współczynnik pędowo-korzeniowy (S/R), który określa stosunek suchej masy części nadziemnej do podziemnej sadzonki, natomiast trzeci stworzony z wykorzystanych wskaźników to indeks jakości Dicksona (DQI), liczony jako iloraz suchej masy sadzonki do sumy wartości obydwu wcześniej opisanych wskaźników. Istotność różnic między średnimi wartościami analizowanych cech wzrostowych i współczynników określających przydatność hodowlaną sadzonek sprawdzono jednoczynnikową analizą wariancji. Aby ocenić zależności występujące między badanymi cechami i wariantami nawożenia, przeprowadzono analizę składowych głównych (PCA).

Nawożenie startowe mieszaniną obydwu nawozów w dawce 1,0 kg Yara Mila Complex i 1,0 kg Osmocote Exact spowodowało wyraźnie wyższe wartości większości cech wzrostowych sadzonek buka zwyczajnego. W tym wariancie nawożeniowym uzyskano także najwyższe wartości parametrów systemu korzeniowego. Wyższe przeciętne wartości parametrów sadzonek z wariantu nawożenia 1YMC+1OE nie przełożyły się jednak na wartości wskaźników świadczące o lepszej przydatności hodowlanej (tab. 2). Analiza trzech wskaźników przydatności hodowlanej wykazała, że potencjalnie najlepszą adaptacją na uprawie – wysoka wartość indeksu jakości Dicksona (DQI) i niska współczynnika pędowo-korzeniowego (S/R) oraz współczynnika wytrzymałości (SQ) – będą charakteryzowały się sadzonki wyhodowane w wariancie nawożenia mieszanego Yara Mila

Complex 1,5 kg + Osmocote Exact 0,5 kg (ryc. 1-2). Wariant ten można uznać za optymalny dla hodowli sadzonek buka zwyczajnego w warunkach kontrolowanych na podłożu trocinowo-torfowym.

Ważnym aspektem przeprowadzonej oceny hodowli sadzonek buka zwyczajnego jest porównanie wpływu zastosowania danego wariantu nawożenia na koszt wyhodowania jednej sadzonki. Zmiana obecnie stosowanego nawożenia nawozem YMC w dawce 2,5 kg na 1 m^3 podłoża na wariant wykazany w badaniach jako optymalny, tj. mieszaniną nawozów YMC i OE w dawce odpowiednio 1,5 i 0,5 kg, zwiększy koszt wyhodowania sadzonki zaledwie o 1,2% (ok. 0,7 grosza).