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DETERMINATION OF THE IMPACT OF SOIL COMPACTION ON GERMINATION AND SEEDLING GROWTH PARAMETERS OF COMMON BEECH IN THE LABORATORY CONDITIONS

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Abstract. The paper presents the results of laboratory research on the effects of different soil compaction caused by varying unit pressure and its impact on germination and growth parameters of common beech. Soil for the research was taken from the forest stand, and then poured into prepared PVC cylinders. Pressure was exerted on the soil with use of the stamp, on a specially prepared static stand. Unit pressure ranged from 50 to 300 kPa with 50 kPa resolution. Each variant of the exerted unit pressure and control without pressure was repeated three times. 21 seeds of common beach were sown into a single cylinder. The cylinders were then placed in controlled conditions and after 2.5 months all seedlings parameters were measured. 234 seedlings were analysed (sown 441). It was found that the seeds were influenced by the place of sowing. There were significant correlations between the exerted unit pressure and the length of root system of plants sown away from direct exposure to the stamp, as well as all the plants together. With the increased unit pressure the length of root system decreased. Sowing place turned out to be important for the root neck diameter, root dry weight and whole plants.

Key words: unit pressure, germination, growth parameters, common beech

INTRODUCTION

In modern forest management, in nursing exertions, at all stages of stands development, as well as their renewal, the range of application of modern technology increases the use of mobile technical resources, first of all tractors, to obtain raw materials. Compared with the existing manual-mechanical methods, they bring about a significant increase in efficiency and safety, simultaneously reducing the risk of injury. Unfortunately, these machines do not always meet the ecological requirements, frequently negatively affecting the basic factor of production, which is forest soil [Lukáč 1997, Porter

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and Porter 1998, Więsik 1996]. According to many authors the forest damage caused by harvesting machines, and specially the skidding ones, can significantly affect the quality of wood, deterioration of forest health and change the forest soil properties [Lukáč 1997, Porter 1998, Ulrich et al. 2003]. Majority of the damages take place close to skidding paths. The growth of trees to 15 m on both sides of the skidding trail according to Porter [1994] can be reduced by 10 to 15%, and according to Becker [Ulrich et al. 2003] loss of production may be at the level of 17% and even more.

The main issue considered in the context of the interaction between machines carriageable system and the ground is the unit pressure. Preferred unit pressure exerted by machines moving in the forest should be, as low as 30-40 kPa, unfortunately only a few of forest machines meet this criterion. That is why the unit pressure of 70 kPa is assumed to be acceptable, in case of a tracked carriageable system and up to 150 kPa, at a wheel carriageable system. In practice, the machines that currently work in the forests exert the average unit pressure from 50 to 150 kPa, but the values up to 250 kPa [Gil 1999, Więsik 1996] are quite common, too. So far, despite the determination of criterion values relating to the unit pressures that should be exerted by the machines on the ground during their forest operation, there are no documented literature studies on the problem of the influence on individual plants of size and distance from the direct impact of stress.

The main aim of this study was to determine the effect of different soil compaction (degree?) caused by exerted unit pressure on germination and seedling growth of common beech under controlled laboratory conditions. It was assumed that variable soil compaction would be established by putting the static unit pressure on to the soil brought from the forest. Unit pressure in the range from 50 to 300 kPa with 50 kPa resolution, reflects a specific unit pressure which exerts a real machine carriageable system during work in the forest [Gil 1999, Więsik 1996].

MATERIALS AND METHODS

A special position stand for compaction of the soil in cylinders (Fig. 1) was constructed to access the assumed unit pressure. With its help, the unit pressure was exerted with use of a compaction stamp on the soil brought from forest and then inserted into specially prepared cylinders, and next common beech seeds were sown. After growing, the seedlings were subjected to analysis.

Soil for measurements, without surface organic layer, was taken from the fresh mixed coniferous forest site of the Niepołomice Forest Complex. The moisture content of the soil was measured during the collection of the soil. Since the soil had been collected prior to the conducted research, a partial loss of moisture was observed, and therefore before the tests it was moistened by spraying and mixing.

21 cylinders were prepared (6 types of the assumed unit pressure and control variant, all in triplicate) for the investigations. They were made of PVC plastic 160 mm diameter tube, cut into 20 cm long sections. At the bottom of each cylinder plastic mesh with use of a plastic clamp was placed, and a filter disc made of paper (to prevent soil leaching) was inserted, and then soil was placed. The volume of the soil in the cylinder corresponded to the amount of soil giving the soil density volume measured in the forest. On to the soil prepared in this way, depending on the assumption variant, unit pressure was

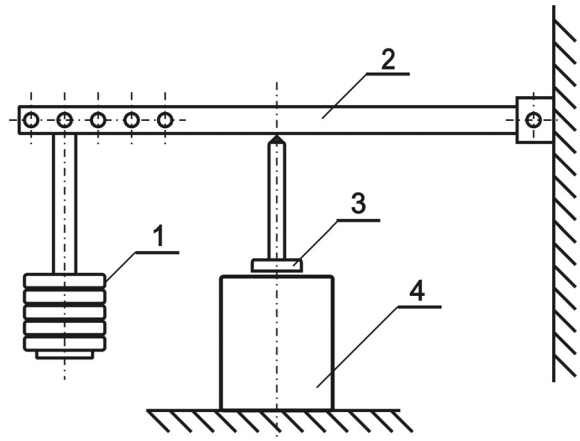

Fig. 1. Stand for exerting the static unit pressure on soil: 1 – fixed weights, 2 – one-armed lever, 3 – stamp for compacting the soil, 4 – cylinder with soil

Rys. 1. Stanowisko do wywierania statycznego nacisku jednostkowego na glebę: 1 – obciążniki stałe, 2 – dźwignia jednoramienna, 3 – stempel zagęszczający, 4 – cylinder pomiarowy z glebą

exerted, with exception of the control cylinders, in which the soil was left in the initial condition. The pressure was exerted on soil by a stamp diameter of 70 mm (Fig. 2), on which the vertical force was exerted by one-arm lever (Fig. 1). The force exerted on the stamp was changed by a modification of distances of hanging static weights from the fulcrum. During the preparation of cylinders, a series of additional cylinders was prepared, in which only compactness of the soil with use of cone penetrometer was measured.

Fig. 2. Process of exerting the pressure on soil with use of the stamp

Rys. 2. Proces wywierania nacisku na glebę za pomocą stempla

Penetrometer was applied with electronic force measurement every 1 cm of the cone insertion into the soil. For each variant of the exerted unit pressure and control cylinders 9 measurements were taken with use of penetrometer in place of the stamp impact and 9 penetrations outside the place of the stamp impact. Figure 3 is a view of the developed cylinders with evenly sown seeds of common beech in an amount of 21 pieces on each of the cylinders, before they were covered with soil. Prepared cylinders were then placed in a chamber with controlled thermal, lighting and humidity conditions. Cylinders were put on a wooden grate made from square strips of 1 cm × 1 cm, which were placed on the bottom of the two plastic dishes of 1.5 m × 0.5 m. Under each of the cylinders, a paper strip was inserted driving water from the bottom of the dish, in case of water deficiency at the cylinder bottom.

Fig. 3. View on the seeds sown in cylinders
Rys. 3. Widok na wysiane nasiona w cylindrach

Above the cylinders, artificial lighting with adjustable height and diurnal cycle (16 h day and 8 h night) was mounted. Between the cylinders PVC tube was fixed, through which heated water was pressed to obtain a constant temperature inside the chamber. The whole chamber was encapsulated with a frame with nursery foil. There was a possibility to remove it while ventilating the chamber. Hand spraying irrigation was conducted in the chamber and the plants were also fertilized. Figure 4, shows a view of the

Fig. 4. View of plants on 76th day from sowing
Rys. 4. Widok na rośliny w 76 dniu od wysiewu nasion

seedlings at the end of the experiment, on 76th day from sowing. After completion of the experiment, plants were pulled out from the cylinder, and then the soil from the individual plants root system was water rinsed. Each plant was individually measured. During the measurements the length of underground and above-ground parts, the neck radicular diameter, numbers and surface area of leaves were determined. The dry mass of the above- and under-ground parts and leaves was measured after drying plants in the oven at the temperature of 70°C.

Surface areas of leaves were measured with the help of image analysis Multiscan 5.0. After all measurements, the results were subjected to statistical processing applying STATISTICA.

RESULTS

Figure 5 shows the average value of the measured soil compaction in all cylinders, depending on where the measurements were taken and depending on the variant of the exerted unit pressure.

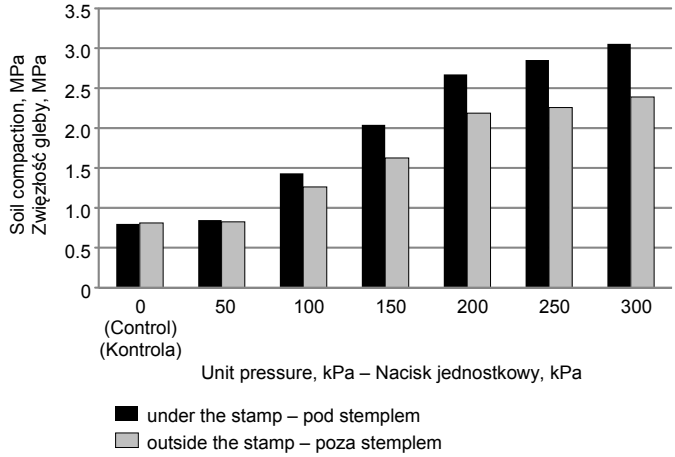

Fig. 5. Average values of compactness measured in cylinders depending on the variant of the exerted unit pressure and place of measurement

Rys. 5. Średnie wartości zwięzłości zmierzone w cylindrach w zależności od wywartego nacisku jednostkowego i miejsca wykonania pomiaru

According to Figure 5, the average soil compactness in the cylinders increased with the increase of the exerted unit pressure independently from the place of the measurement. The compactness ranged from 0.83 MPa, for control cylinders, to 3.1 MPa in 300 kPa variant of the exerted unit pressure. Percentage differences of compactness depending on where the place of measurement ranged from 2.6% for variant 50 kPa of the exerted unit pressure, to 28%, in 300 kPa variant. Compactness measured in the stamp impact place, was higher than those measured near the stamp impact place.

A total of 234 seedlings were grown in the experiment (sown 441). Table 1 shows the number of seedlings grown in terms of the number and percentage depending on the variant of the exerted unit pressure, as well as depending on the place of sowing.

Table 1. Number and percentage of seedlings grown in the experiment, depending on the variant of the exerted unit pressure on soil, and place of sowing

Tabela 1. Liczba oraz procent wyhodowanych sadzonek w doświadczeniu w zależności od wariantu wywartego nacisku jednostkowego na glebę oraz miejsca wysiewu nasion

Place of sowing the seeds Miejsce wysiewu nasion	Unit pressure Nacisk jednostkowy kPa	Number of sown seeds Liczba wysianych nasion	Number of grown plants Liczba wyrosłych roślin	Percent of grown plants Procent wyrosłych roślin
Under the stamp Pod stemplem	control (without pressure) kontrola (bez nacisku)	21	9	42.8
	50	21	8	38.0
	100	21	7	33.3
	150	21	9	42.8
	200	21	10	47.6
	250	21	9	42.8
	300	21	7	33.3
Average value Wartość średnia			8.4	40.1
Outside the stamp Poza stemplem	control (without pressure) kontrola (bez nacisku)	42	20	47.6
	50	42	27	64.3
	100	42	34	80.9
	150	42	23	54.8
	200	42	25	59.5
	250	42	18	42.8
	300	42	28	66.6
Average value Wartość średnia			25	59.5
Whole area Cała powierzchnia	control (without pressure) kontrola (bez nacisku)	63	29	46.0
	50	63	35	55.6
	100	63	41	65.1
	150	63	32	50.8
	200	63	35	55.6
	250	63	27	42.9
	300	63	35	55.6
Average value Wartość średnia			33.4	53.1

The average number of seedlings was 53.1%, and it is a relatively low value, however it does not differ from the actual rising in the ground nursery for this species. Information on the number of plants grown, depending on where they were sown, seems to be interesting (Table 1).

In the case of seeds sown in place of direct stamp impact (beneath it), rising is much lower and amounts to 40.1%, while in the case of seeds sown away from direct stamp impact, it reaches 59.5%. It probably indicates the process of worsening plants germination in the place of direct unit pressure influence.

Table 2 shows the resulting values of the average growth parameters for seedlings grown in the experiment according to the exerted pressure on the soil surface, as well as the place of sowing the seeds.

Table 2. Average growth parameters of the analysed seedlings depending on the value of the exerted unit pressure on soil and place of sowing

Tabela 2. Średnie wartości parametrów wzrostowych analizowanych sadzonek w zależności od wartości nacisku jednostkowego wywartego na glebę oraz miejsca wysiewu nasion

Place of sowing the seeds Miejsce wysiewu nasion	Unit pressure Nacisk jednostkowy kPa	Growth parameter – Parametry wzrostowe			
		length of seedling długość sadzonki cm	length of root system długość systemu korzeniowego cm	length of above-ground part długość części nadziemnej cm	thickness in root neck grubość w szyi korzeniowej mm
1	2	3	4	5	6
Under the stamp Pod stemplem	control (without pressure) kontrola (bez nacisku)	35.6	24.2	11.4	2.6
	50	29.4	19.1	10.3	2.1
	100	28.6	18.1	10.5	2.3
	150	26.4	15.1	11.2	2.1
	200	25.9	16.5	9.4	2.2
	250	26.6	16.3	10.3	2.6
	300	29.5	17.9	11.6	2.2
Outside the stamp Poza stemplem	control (without pressure) kontrola (bez nacisku)	33.7	23.0	10.6	2.3
	50	33.1	21.1	12.0	2.5
	100	29.4	18.7	10.8	2.5
	150	29.9	19.0	10.9	2.4
	200	27.2	16.4	10.8	2.5
	250	28.8	17.3	11.5	2.8
	300	26.9	16.8	10.1	2.2

Table 2 – cont. / Tabela 2 – cd.

1	2	3	4	5	6
Whole area Cała powierzchnia	control (without pressure) kontrola (bez nacisku)	34.3	23.4	10.9	2.4
	50	32.2	20.6	11.6	2.4
	100	29.3	18.6	10.7	2.4
	150	28.8	17.8	11.0	2.3
	200	26.7	16.4	10.3	2.4
	250	28.0	16.9	11.1	2.7
	300	27.5	17.1	10.5	2.2

Figure 6 shows a plot of the length of the under (roots) and above-ground (stems) parts for all the analysed plants.

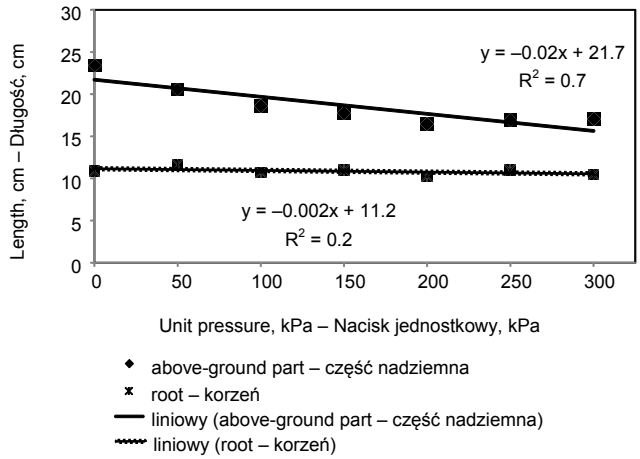

Fig. 6. Average length of the above- and underground plants parts, depending on the variant of the exerted unit pressure on soil and place of sowing

Rys. 6. Średnie długości części nadziemnej i podziemnej sadzonek w zależności od wariantu nacisku jednostkowego wywartego na glebę oraz miejsca wysiewu nasion

According to Table 2 and Figure 6 the length of the underground plants part (roots) decreases with the increase of the exerted unit pressure.

This is also confirmed by statistical analysis (Table 3), which in relation to plant growth parameters indicated a significant correlation between the root system length, and the exerted unit pressure value. According to Table 3, a significant and high correlation occurred between the root system length, and the exerted unit pressure value on the measurement carried out on plants growing outside the direct stamp impact ($r = –0.911$), as well as taking into account all the examined plants ($r = –0.878$).

Table 3. Correlations coefficient between growth parameters and the value of the exerted unit pressure on soil and place of sowing

Tabela 3. Korelacje pomiędzy mierzonymi średnimi parametrami wzrostowymi sadzonek a wartością nacisku jednostkowego wywartego na glebę oraz miejscem wysiewu nasiona

Place of sowing the seeds Miejsce wysiewu nasion	Growth parameter – Parametry wzrostowe			
	length of root system długość systemu korzeniowego	length of above-ground part długości części nadziemnej	length of seedling długość sadzonki	thickness in root neck grubość szyi korzeniowej
Under the stamp Pod stemplem	–0.677	–0.050	–0.618	–0.114
Outside the stamp Poza stemplem	–0.911*	–0.312	–0.905*	0.272
Whole area Cała powierzchnia	–0.878*	–0.470	–0.885*	0.172

*The coefficient of the significant correlation for $p < 0.05$.

*Współczynnik korelacji istotny dla $p < 0,05$.

Table 4. Average values of dry weight seedlings parts depending on the variant of the unit pressure exerted on soil and place of sowing (the seeds)

Tabela 4. Średnie wartości suchej masy poszczególnych części analizowanych sadzonek w zależności od wariantu wywartego nacisku jednostkowego wywartego na glebę oraz miejsca wysiewu nasion

Place of sowing the seeds Miejsce wysiewu nasion	Unit pressure Nacisk jednostkowy kPa	Weight parameter – Parametry masowe				Number of leaves Liczba liści	Surface area of leaves Powierzchnia liści cm^2
		dry mass of root system sucha masa system korzeniowy mg	dry mass of above-ground system sucha masa części nadziemnej mg	dry mass of leaves sucha masa liście mg	dry mass of whole seedlings sucha masa całej sadzonki mg		
1	2	3	4	5	6	7	8
Under the stamp Pod stemplem	control (without pressure) kontrola (bez nacisku)	254.4	116.6	117.1	488.1	4.0	44.9
	50	164.8	102.5	95.	362.3	3.5	33.6
	100	203.4	106.7	101.6	411.7	2.6	34.3
	150	119.3	82.1	71.3	272.8	2.0	30.2
	200	125.5	67.9	76.0	269.4	3.7	41.5
	250	192.2	109.3	80.1	381.7	2.0	29.3
	300	186.1	120.7	96.1	403.0	2.9	32.5

Table 4 – cont. / Tabela 4 – cd.

1	2	3	4	5	6	7	8
Outside the stamp Poza stemplem	control (without pressure) kontrola (bez nacisku)	171.6	91.3	76.7	339.6	2.3	27.7
	50	269.6	138.8	142.0	550.3	4.4	44.1
	100	228.6	117.2	105.3	451.0	3.6	36.0
	150	205.1	109.4	96.3	410.7	2.3	33.5
	200	211.3	114.7	101.3	427.3	2.6	36.9
	250	263.5	146.0	124.1	533.6	3.9	40.3
	300	167.8	93.3	76.0	337.1	2.2	26.5
Whole area Cała powierzchnia	control (without pressure) kontrola (bez nacisku)	198.2	99.4	89.7	387.3	2.9	33.2
	50	242.5	129.4	129.8	501.8	4.2	41.4
	100	224.1	115.3	104.6	444.0	3.4	35.7
	150	177.5	100.6	88.3	366.4	2.2	32.4
	200	181.7	98.6	92.6	372.9	3.0	38.5
	250	236.8	132.3	107.6	476.6	3.2	36.2
	300	172.1	99.7	80.7	352.5	2.3	27.9

There was no significant correlation between the root system length and the exerted unit pressure in case of plants grown in place of direct stamp impact.

The reasons for this can be found in a relatively low number of seedlings grown in a stamp-affected place, as well as a significant volatility of the parameters analysed for the resulting seedlings. Table 4 shows the results of average values measurements of the dry mass of the analysed plants parts, and average values of the number and surface area of the leaves, all depending on the value of the exerted unit pressure and place of sowing.

Table 5 shows the results of the statistical correlations between the exerted unit pressure, and the parameters of the dry weight for each plant part, and the number and surface area of leaves.

According to Tables 3, and 5 the correlation between the exerted unit pressure and measured parameters proved to be significant only in relation to the length of the whole plants and the root system of the plant, in the variant of the analysed seedlings growing outside the direct impact of the stamp punch, as well as for all the analysed plants.

An analysis was also carried out of the correlation between the location of sowing the seeds and parameters analysed. The results are presented in Table 6.

According to Table 6, the place of sowing had a significant effect on the diameter of the root neck, as well as the dry weight of the root system and the dry weight of the whole plant. The parameters which were measured in the direct stamp impact place were significantly lower than those for the seedlings grown outside of the direct stamp impact.

Table 5. Correlations coefficient between dry weight of the seedlings parts and for number and surface area of leaves with the value of the exerted unit pressure on soil and place of sowing

Tabela 5. Korelacje pomiędzy mierzonymi średnimi parametrami suchej masy poszczególnych części sadzonek, liczby oraz powierzchni liści a wielkością nacisku jednostkowego wywartego na glebę oraz miejscem wysiewu nasiona

Place of sowing the seeds Miejsce wysiewu nasion	Weight parameter – Parametry wagowe				Number of leaves Liczba liści	Surface area of leaves Pole powierzchni liści
	whole seedling cała sadzonka	root system system korzeniowy	above--ground part część nadziemna	leaves liście		
Under the stamp Pod stemplem	–0.355	–0.376	–0.308	–0.565	–0.498	–0.510
Outside the stamp Poza stemplem	–0.059	–0.078	–0.042	–0.135	–0.196	–0.125
Whole area Cała powierzchnia	0.295	–0.346	–0.238	–0.390	–0.477	–0.413

*Coefficient of the significant correlation for $p < 0.05$.
*Współczynnik korelacji istotny dla $p < 0,05$.

Table 6. Effect of place of sowing on the analysed parameters

Tabela 6. Wpływ miejsca wysiewu nasion na analizowane parametry sadzonek

Place of sowing the seeds Miejsce wysiewu nasion	Growth parameter – Parametry wzrostowe			
	length of root system długość systemu korzeniowego	length of above-ground part długość części nadziemnej	length of seedling długość sadzonki	thickness in root neck grubość w szyi korzeniowej
	–0.116	–0.066	–0.125	–0.161*
	Weight parameter – Parametry wagowe			
	root system	above ground without leaves	leaves	whole seedlings
	–0.156*	–0.139	–0.123	–0.151*
	Leaves – Liście			
	number of leaves – liczba liści		surface area of leaves – pole powierzchni liści	
	–0.027		0.011	

*Coefficient of the significant correlation for $p < 0.05$.
*Współczynnik korelacji istotny dla $p < 0,05$.

CONCLUSIONS

1. Unit pressure exerted on the surface of the soil in the cylinders with use of a stamp caused a change of the average value of soil compaction measured with use of cone penetrometer. Increase of the compactness for the exerted unit pressure of 300 kPa, in relation to the control variant (without pressure), was 260% in the case of measurement made directly in the place of action of the stamp, and 230% in the place outside the direct action of the stamp.

2. There were differences between the average value of soil compaction measured both in the place of the direct impact of the stamp and outside of the direct impact of the stamp. In the lowest variant i.e. 50 kPa, percentage difference of compaction under the stamp was 2.6%, compared to that measured outside the stamp and it reached 28% in case of 300 kPa.

3. The sowing position affected the number of plants grown. In the place of the direct impact of the stamp, the effectiveness of the sown seeds rose to 40.1%, while outside the impact to 59.5%.

4. There were significant correlations between the exerted unit pressure and length of root system of seedlings sown outside of direct impact of the stamp ($r = –0.911$), and for all seedlings ($r = –0.878$). With the increase of the exerted unit pressure, the value of the length of root system decreased.

5. Place of seeds sowing turned out essential for seedling parameters such as the root neck diameter ($r = –0.161$), root dry weight ($r = –0.156$), and dry weight of whole seedling ($r = –0.151$). All these parameters were lower in the case of seeds sown in place of direct stamp impact, compared to those sown outside of the direct stamp impact.

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WYZNACZENIE WPŁYWU ZAGĘSZCZENIA GLEBY NA KIEŁKOWANIE I WZROST SIEWEK BUKA POSPOLITEGO W WARUNKACH LABORATORYJNYCH

Streszczenie. W artykule przedstawiono wyniki badań laboratoryjnych nad wpływem różnego zagęszczenia gleby, wywołanego zmiennym naciskiem jednostkowym, na kiełkowanie i parametry wzrostowe buka pospolitego. Glebę do badań pobrano z lasu, a następnie wsypano do specjalnie przygotowanych cylindrów z PCV. Na glebę w cylindrach wywierano nacisk jednostkowy stemplem na stanowisku do statycznego zagęszczania gleby. Wywierano naciski jednostkowe o wartościach od 50 do 300 kPa, z rozdzielczością 50 kPa. Każdy wariant nacisku oraz kontrol bez wywieranego nacisku powtórzono trzykrotnie. W każdym cylindrze wysiano po 21 nasion buka pospolitego, a cylindry umieszczono w warunkach kontrolowanych. Po upływie 2,5 miesiąca mierzono parametry uzyskanych sadzonek. Przeanalizowano 234 sadzonki (wysiano 441). Stwierdzono, iż na rośliny miało wpływ miejsce wysiewu w cylindrze. Wystąpiły istotne korelacje pomiędzy wartością wywartego nacisku jednostkowego a długością systemu korzeniowego zarówno sadzonek wysianych poza miejscem bezpośredniego oddziaływania stempla, jak i wszystkich rozpatrywanych sadzonek łącznie. Ze wzrostem wartości nacisku jednostkowego malała długość systemu korzeniowego. Miejsce wysiewu nasion okazało się również istotne dla średnicy szyi korzeniowej, suchej masy korzenia oraz całej sadzonki.

Słowa kluczowe: nacisk jednostkowy, kiełkowanie, parametry wzrostowe, buk pospolity

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