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EFFECT OF SELECTED FACTORS ON THE VALUE OF FORCE NECESSARY FOR REMOVING INDIVIDUAL SUGAR BEET ROOTS FROM SOIL

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Summary. Force measurements, taken in the process of sugar beet roots removing from soil, served as the basis for determining the effect of selected geometric features of beet roots on the value of that force. The variation of the value of that force was studied on three selected plots depending on cultivar, soil compactness and soil moisture content. Irrespectively of root size, cultivar and plot, the average values of these forces were differed and were within 399–690 N. In several cases these force values exceeded 900 N.

Key words: sugar beet, geometric features, soil, energy

INTRODUCTION

Despite using modern techniques in sugar beet cultivation, especially in the process of beet root harvesting, there is a persistent risk of quantitative and qualitative losses of biological material. According to many authors [Bzowska-Bakalarz 1994, Byszewski *et al*. 1997, Malec 1997, Ostrowska and Wzorek 1998], the level of these losses, as well as that of the energy input during harvest are determined by, in addition to soil and climatic conditions, the physical properties of sugar beet roots. For the economic and strength considerations of harvesting machines, the characteristic of basic importance for the designers is the knowledge about energy consumption/demand in the process of root extraction from the soil [Gorzelany and Noworól 1998].

Soil conditions, such as soil compaction and soil moisture, combined with meteorological conditions during harvest, affect the changes of forces necessary for beetroot extraction most significantly [Bzowska-Bakalarz and Szklarz 1987, Gorzelany and Bzowska-Bakalarz 1999, Gorzelany and Noworól 1998, Gorzelany 2001]. The value of the force necessary for sugar-beetroot pullout is also affected by the differences in their structure, geometric shape characteristics and the height to which they grow above the soil level. The relationships between those characteristics and the sugar-beetroot cultivar, cultivation technology, fertilization, irrigation and environmental conditions have already been studied [Byszewski *et al.*. 1981, 1997], but comprehensive measurements of the effects of these factors on energy demand for beetroot extraction from soil are not available.

RESEARCH OBJECTIVE AND RANGE

The research aimed at defining the effect of soil conditions on the geometric characteristics of sugar beetroots and the value of the force necessary to pull out individual beetroots from soil.

The research was conducted in 2004 on a farm in the Zarzecze village in Podkarpackie province. Three objects *(fields, plots)* with sugar beetroot cultivation of approx. 0.5 ha each, were selected. Plot I was a loess soil of class IIIa on clay substrate, with onion as preceding crop; plot II – silt soil of class IIIb, with winter wheat as the preceding crop, plot III – loess soil of class IIIa, with winter wheat as the preceding crop. Two sugar beetroot cultivars, Andante (Strube Dickmann) and Oktavia (Advanta), were sown on each plot.

Once the preceding crops were harvested on the studied plots, subsoil ploughing was carried to the depth of approx. 50 cm. Mustard, Metex cultivar, was sown at mid August on plots II and III in a quantity of 20 $kg \cdot ha^{-1}$. On the 9th Oct. 2003 all plots were ploughed for winter to a depth of approx. 28 cm. In the spring (9th April 2004), upon fertilizing the field prior to sowing, cultivation aggregator was used to even and loosen the soil. Sugar beetroot seeds were sown with single seeder on the next day. After beetroot sowing (from the 1st May 2004) chemical treatments against weeds, diseases and pests were carried out on the studied plots. The last such treatment (against *Cercospora beticola* Sacc.) was performed on the 7th Aug. 2004.

RESEARCH MATERIALS AND METHODS

In autumn 2004, just before beetroot harvesting, the soil moisture and compaction were measured individually for each plot. The moisture of soil samples was determined with drier method. Manual, spring-load soil probe (compaction meter), designed and made by the Polish Academy of Sciences Institute of Agro-physics in Lublin, was utilized to measure soil compactness at the depth of 0–20 cm.

Then, 60 roots in three sizes (fractions; small roots of 6–9 cm, medium roots of 9–12 cm and large roots of more than 12 cm) from two neighboring rows on each of the studied plots, were topped with the use of manual striper/topper. The height of root head above the soil surface was measured after topping.

The measurements of the force necessary for pulling individual beetroots from soil were taken with an instrument designed in the Department of Agricultural Engineering of Rzeszow University. The instrument consists of a stand supported on four vertical supports with a pulley and steel line connected to servo-cylinder of 0–1 KN range. Roots are pulled out of soil with a screw that is screwed into root head and connected, through a holder, with a force gauge. Individual roots were pulled out manually using a crank with slow force incrementing. Once the roots were removed from soil the value of the used force was read from the force-gauge scale and their length and diameter was measured with a slide caliper.

On the basis of the measurements, the mean height of beetroot head above the soil surface, mean root length and the mean soil penetration by beetroots were determined.

Also, the number of plants per hectare and the theoretical sugar beetroot crop yield on the studied plots were determined.

RESEARCH RESULTS

The soil moisture, as measured and calculated at the depth of 0–15 cm, was found to be the highest on the plot II (silt soil) with mean level of 21.6%. The lowest soil moisture was recorded on plot I (loess on clay) – 16.4%. The mean value of soil moisture on plot III (loess soil) was at 19.3%. The subsoil ploughing of the studied plots in autumn, as well as favorable climatic conditions on the harvest day, contributed to soil loosening, with the resulting low soil compaction of 0.5 MPa. Table 1 presents the number of plants per hectare on individual plots and the theoretical sugar beetroot crop yield, with seeds sown in rows, 18 cm from each other, with row spacing of 45 cm.

Table 1. Planting (density) and theoretical yield of sugar beet roots

Object	Variety	Density tys. szt·ha^{-1}	Yield t·ha^{-1}
Object I	Andante	95.3	68.4
	Oktavia	86.6	64.5
Object II	Andante	82.5	54.1
	Oktavia	80.3	49.9
Object III	Andante	91.8	66.7
	Oktavia	87.0	63.8

At harvest time the highest number of plants per hectare was recorded for the Andante cultivar on plots I and III (more than 91 thousand plants per hectare). These same plots produced also the highest crop yield per hectare for that cultivar. Plot I – 68.4 t·ha^{-1} and plot III – 66.7 t·ha^{-1}. The lowest number of plants per hectare and crop yield per hectare was found on plot II with the Oktavia cultivar, 80.3 and 49.9 t·ha^{-1}, respectively.

Refer to Table 2 for selected geometric characteristics of sugar beetroots on the studied plots, as well as mean values of forces necessary for pulling them out of soil.

Roots on plot III had the longest mean lengths (33.4 cm), while those on plot II were the shortest (with the mean of 23.5 cm). On plots I and III the differences in root lengths between cultivars were small, whereas on plot II the roots of the Oktavia cultivar were observed to be longer on average by 13.4%, compared to the Andante cultivar.

The mean value of root diameter for both cultivars on the three plots differed slightly and ranged within 10.4 and 10.7 cm. The height of sugar beetroot head projection above the soil surface ranged from 3.0 cm on plot II to 4.0 cm on plot I. The greatest root penetration depth was recorded on the plot III – 21.3 cm for the Andante cultivar, whereas on plot II beetroots of the Andante cultivar penetrated their soil to the mean depth of 14.2 cm.

The mean depth of root penetration on the studied plots was 18.3 cm for the two analyzed cultivars. Independently of the plot and the root size the mean values of force necessary for their extraction differed widely within 399 and 690 N. In several cases the recorded force exceeded 900 N (the maximum force was 920 N). A large standard deviation from the mean value of force for a certain fraction of roots and penetrations are the evidence to a wide range of forces necessary for pulling beetroots from soil (Fig. 1, 2).

Table 2. Geometrical characteristics of sugar beetroots on the objects and average values of *F* force required for extracting sugar beetroots from the soil.

Object Variety	Root size	Measurement of roots			Height topping	Soil penetration	Force *F* max
		Lenght cm	Diameter cm	Weight g	cm	cm	N
Object I Andante	Small	30.8	8.4	515	3.6	20.0	505
	Medium	29.6	10.4	835	3.3	20.8	572
	Big	30.8	12.9	1613	4.2	20.6	655
Object I Oktavia	Small	26.5	7.9	486	4.2	16.9	406
	Medium	30.5	10.6	911	4.3	19.5	501
	Big	32.9	13.1	1638	4.7	19.4	557
	Average value	30.2	10.5	997	4.0	19.5	533
Object II Andante	Small	19.1	8.0	401	2.4	12.6	408
	Medium	23.1	10.4	796	3.2	15.1	478
	Big	23.3	12.8	1496	3.4	14.9	533
Object II Oktavia	Small	22.8	8.0	361	2.48	14.4	399
	Medium	27.7	10.2	758	3.1	16.8	481
	Big	25.2	13.0	1493	3.3	16.1	532
	Average value	23.5	10.4	884	3.0	15.0	472
Object III Andante	Small	32.6	8.0	499	2.9	20.2	420
	Medium	32.6	12.1	894	3.2	20.3	570
	Big	36.0	12.9	1679	4.5	23.3	690
Object III Oktavia	Small	32.2	8.0	459	3.1	19.3	404
	Medium	32.3	10.4	849	3.4	19.2	473
	Big	35.0	12.7	1627	4.7	20.7	585
	Average value	33.4	10.7	1001	3.6	20.5	524
Overall	Small	27.3	8.0	453	3.1	17.2	424
	Medium	29.3	10.7	840	3.4	18.6	512
	Big	30.5	12.9	1591	4.1	19.2	592
	Average value	29.0	10.5	961	3.5	18.3	509

The trend lines for the force *F* necessary for pulling individual beetroots from soil, depending on their diameter and soil penetration on the studied plots, are presented in Fig. 4. The curve of the relationship of force necessary for pulling beetroots from soil versus beetroot diameter and soil penetration is described with the square function of the second degree. The analysis of the relationship between the force *F* necessary for pulling individual beetroots from soil and their diameters on three studied plots (Fig. 3) shows that the determination coefficients, R^2, were high and ranged from 0.72 for the Oktavia cultivar on plot I to 0.97 for the Andante cultivar on plot III. The effect of root penetration on the value of force necessary for pulling beetroots from soil on the studied plots was also significant, as reflected by the values of the determination coefficients, R^2, within 0.46 and 0.75.

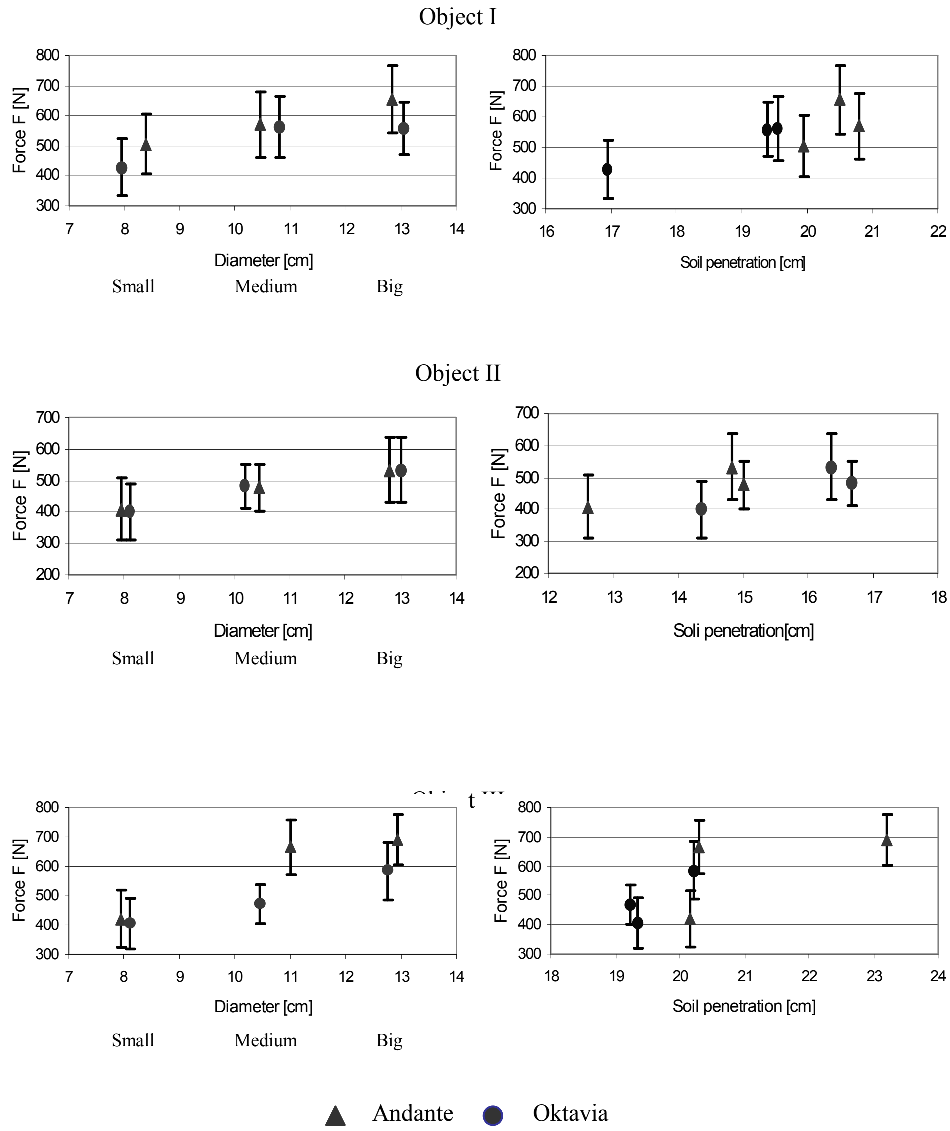

Fig.1. The average values of force F necessary to remove individual roots from soil as well as standard deviations from their average values depending on root diameter and root soil penetration

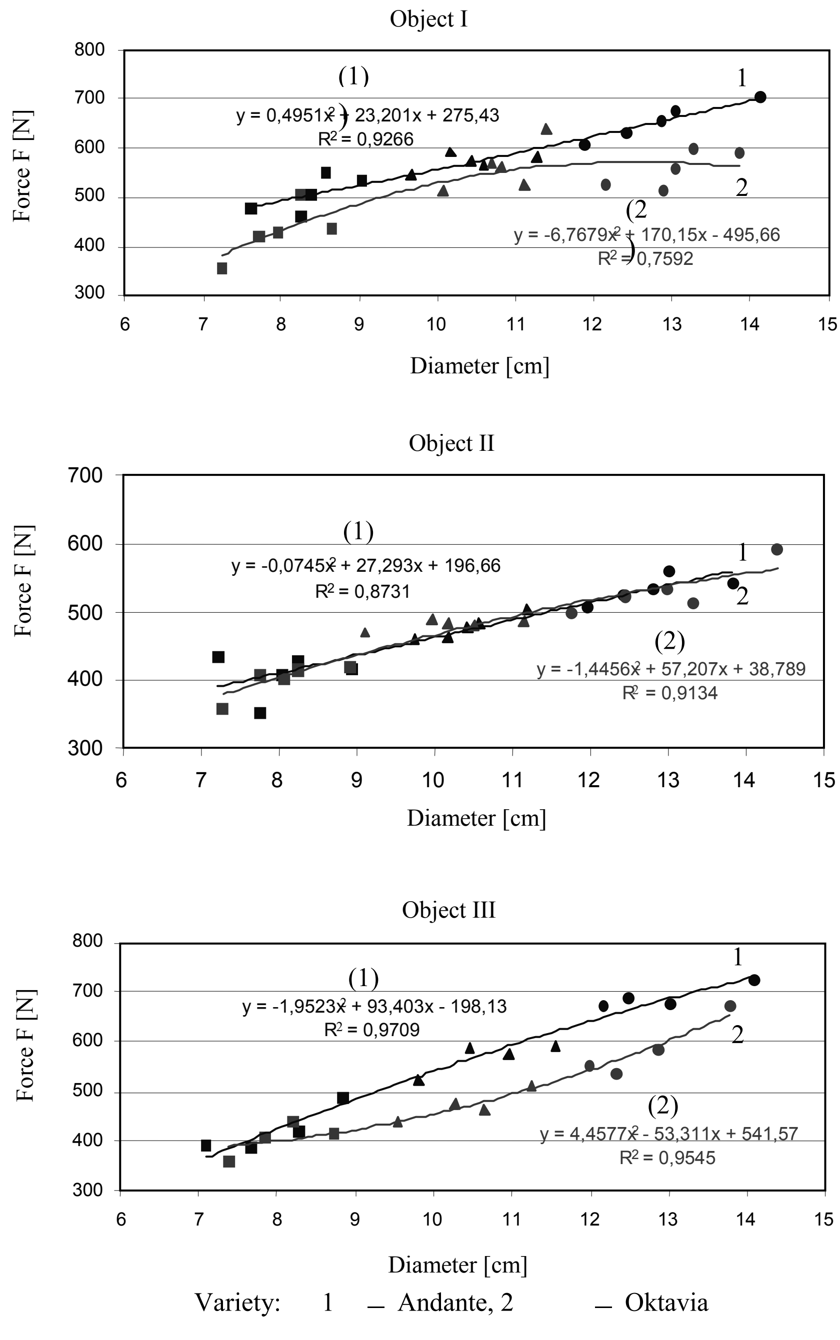

Fig. 2. Force *F* necessary for removing individual sugar beetroots from soil on the selected plots versus root size and cultivar.

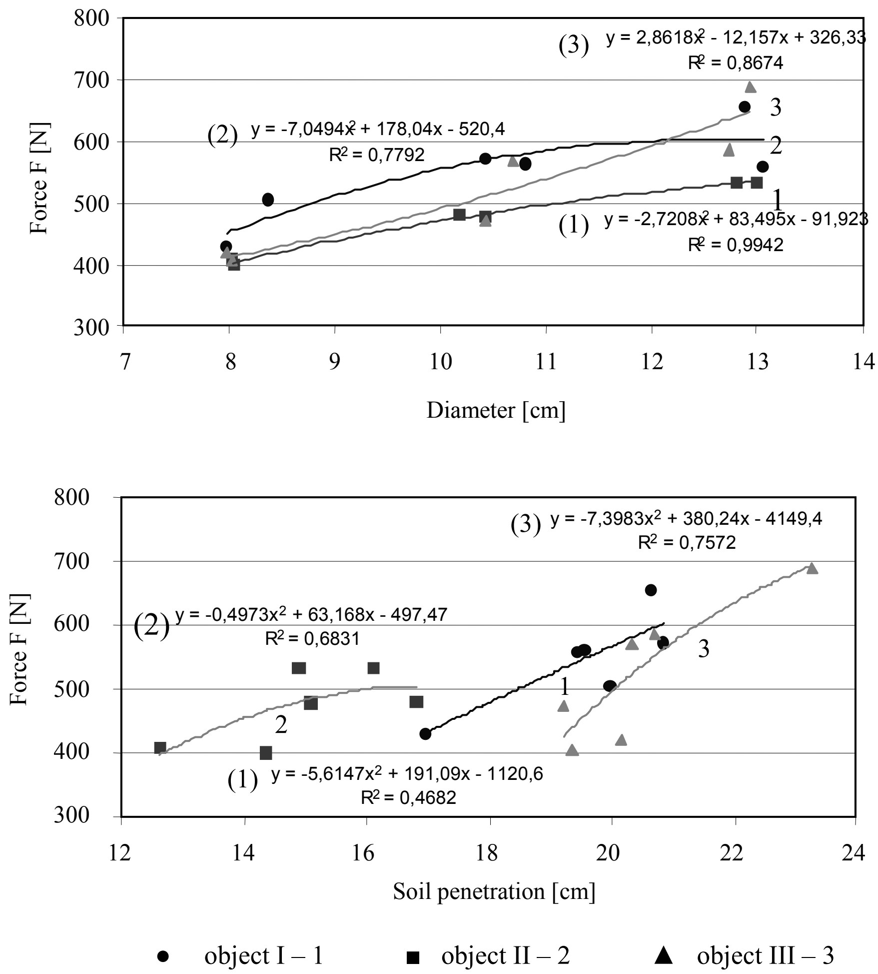

Fig. 3. Trend lines of the values of force F necessary for removing individual sugar beetroots from soil depending on root diameter and root soil penetration

CONCLUSIONS

1. The soil compaction on the studied plots to a depth of 25 cm did not exceed 0.5 MPa, whereas the mean values of soil moisture at the depth of 10 cm were: 16.4, 21.6 and 19.3% for plots I, II and III, respectively.
2. Roots of sugar beets of the two studied cultivars differed in their geometric characteristics. Roots from plot III were the longest, 33.4 cm on average, while those from plot II had the shortest average of 23.5 cm. Roots from plot III exhibited the maximum mean soil penetration of 20.5 cm and those from the plot II penetrated the soil only by 15 cm (the minimum mean).

3. The mean values of forces necessary to pull out individual undisturbed roots of sugarbeets from soil were within the range of 399 and 690 N. In single cases the values of these forces exceeded 900 N.

4. The value of force necessary to pull a beetroot out of its soil was affected by root diameter (correlation coefficients were 0.88, 0.99 and 0.92 on plots I, II and III, respectively) as well as the soil penetration (correlation coefficients of 0.68, 0.82 and 0.86 for plots I, II and III, respectively).

5. On plots I and III beetroots of Andante cultivar were found to penetrate the soil deeper and required higher mean forces for pulling them out.

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