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ORIGINAL PAPER

EFFECTS OF FERTILISER USE AND PRE-SOWING SEED STIMULATION WITH A MAGNETIC FIELD ON THE MINERAL CONTENT AND YIELD OF THREE VARIETIES OF SUGAR BEET ROOTS*

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Abstract

The study investigated the effects of using mineral fertilisers and pre-sowing stimulation of seeds on the yield of roots and the content of selected mineral elements in the roots of three sugar beet cultivars. The treatment consisted of applying a slowly changing magnetic field of 50 mT induction for a period of 60 seconds, so as to avoid heating the research material. The biological material was divided into four groups, taking into account the magnetic field and fertiliser applied. The first group was untreated seeds, the second one comprised seeds stimulated only with a magnetic field, the third one consisted of seeds pre-sowing stimulated with a magnetic field and then treated with mineral fertilisers and the last group was composed of seeds treated with mineral fertilisers. The assessment focused on the total yield of sugar beet roots as well as the content of eleven mineral elements, including three toxic metals analysed on an ICP-OES optical spectrometer. The application of mineral fertiliser resulted in a significant increase in the yield of sugar beet roots, and in a higher content of basic macroelements. On the other hand, stimulation with a magnetic field led to an increase in the yield of sugar beet roots which, although statistically higher than in the control group, was lower than after an application of mineral fertilisers. Additionally, the pre-sowing magnetic stimulation of sugar beet seeds resulted in a mild reduction in the transfer of elements from soil to plant, and a nearly complete blocking of such transfer in the case of harmful elements.

Keywords: sugar beet, pre-sowing stimulation, fertiliser use, mineral content, yield.

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INTRODUCTION

Contemporary agriculture needs top quality seeds, characterised by high vigour and germination capacity. In the finest cultivars, the germination rate may reach a level of nearly 100% (Rochalska, Orzeszko-Rywka 2008). Hence, it is necessary to achieve the highest possible rate of field emergence of plants growing in unfavourable conditions, such as a limited access of seeds to water, poor soil, and temperatures differing from the optimum values (Kenter et al. 2006). The contemporary challenges are to look for methods applicable in such adverse conditions, to facilitate further improvement in the seed germination speed and capacity, to enhance physicochemical properties of plants and, eventually, to obtain an increase in the yield.

The basic methods designed to improve the quality and quantity of sugar beet yield include the use of mineral and organic fertilisers (Werker et al. 1999, Zimny et al. 2005, Malnou et al. 2006), and the optimisation of growing conditions (Rajewski et al. 2008, Kuc, Tendziagolska 2011, Gaj et al. 2015). On the other hand, less conventional and more innovative methods include various pre-sowing treatments applied to seeds. Researchers have investigated the effects of treatments based on laser stimulation (Koper et al. 1996, Dziwulska-Hunek et al. 2009, Sujak et al. 2009, Prośba-Białczyk et al. 2012), ionising radiation (Rybiński et al. 2004), an electric field (Pietruszewski 2002, Pietruszewski, Kornarzyński 2002, Pietruszewski et al. 2003) as well as a static and variable magnetic field of wide ranging induction values (Matsuda et al. 1993, Achremowicz et al. 2002, Frant, Bujak 2010, Zaguła et al. 2010, Marks, Szecówka 2011, Zaguła, Puchalski 2013).

Studies carried out in countries across the world show that a balanced and optimal content of micro- and macronutrients in soil ensures an optimum yield of sugar beet with a low content of toxic metals. Therefore, in addition to efforts aimed at increasing the yield of sugar beet, it is necessary to investigate factors which may eventually enhance the physicochemical content of the crop while reducing the accumulation of harmful metals in the roots due to their transport from the soil into the plant. The study assessed the effects of a slowly changing magnetic field applied to sugar beet seeds before planting and the use of mineral fertiliser on root yield and mineral composition, including the content of harmful metals in the roots.

MATERIAL AND METHODS

A field experiment was carried out in 2014 - 2015. The study was designed to compare concentrations and migrations of micro- and macroelements, including toxic elements, as well as the yield obtained from three sugar beet varieties: Finezja – a Polish cultivar, Sinan – a German cultivar, and Milton – a Danish cultivar. For each cultivar, the experiment was conducted in four types of cultivation plots, with three replicates: a – untreated seeds, b – seeds subjected only to stimulation with a magnetic field, c – seeds subjected to pre-sowing stimulation with a magnetic field and then treated with mineral fertilisers applied in doses balanced for the specific soil, d – seeds treated with fertilisers (P and K – 70 kg P_2O_5 ha^{-1} as a 40% P_2O_5 enriched superphosphate together with 200 kg K_2O ha^{-1} as a 60 % K_2O potassium salt in autumn before ploughing). Also, N – 120 kg ha^{-1} was applied divided into two doses: 84 kg ha^{-1} in first days of April before seed sowing as a ammonium sulphate, and 36 kg ha^{-1} as calcium ammonium nitrate in the phase of 4-6 leaves.

The seeds were exposed to a magnetic field through the use of an air-spaced coil with an inner diameter of 11 cm and length of 15 cm, powered from a single-phase alternating current power source. The coreless coil made of copper wire consisted of 13 layers, with 115 turns per layer (Figure 1).

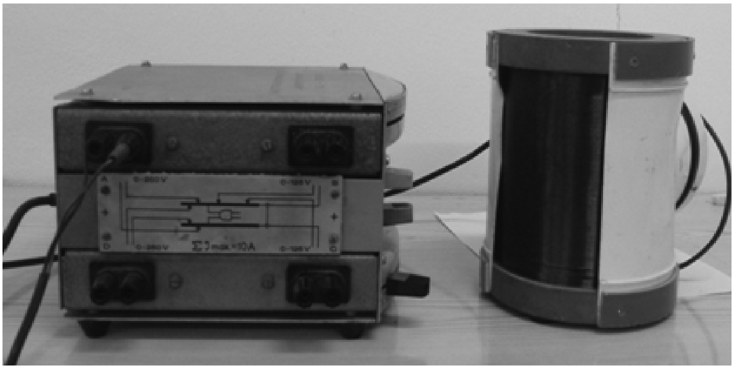

Fig. 1. Station for performing stimulation with a slowly-changing magnetic field of 50 mT magnetic induction

The calculations of such coil parameters as resistance, inductance, reactance, impedance, intensity of current flowing in the coil, and finally the strength of the magnetic field in the central point of the coil were carried out using a technical method of computing based on Ampere's law. Examples of calculations for magnetic field induction at the level of 50 mT, at a frequency of 50 Hz, are shown in Figure 2.

In each case, the stimulation was performed on the day the seeds were planted, and the duration of exposure was defined as 60 s, taking into account the temperature coefficient:

$$R_T = R_0 \, (1 + \alpha \, \Delta T),$$

where: $R_T(\Omega)$ – resistance of the system at the target temp. T,

R_0 (Ω) – resistance of the system at a temp. of 0°C,

α (K^{-1}) – temperature coefficient of resistance,

ΔT (K) – change in temperature resulting from the heating of a current-carrying conductor.

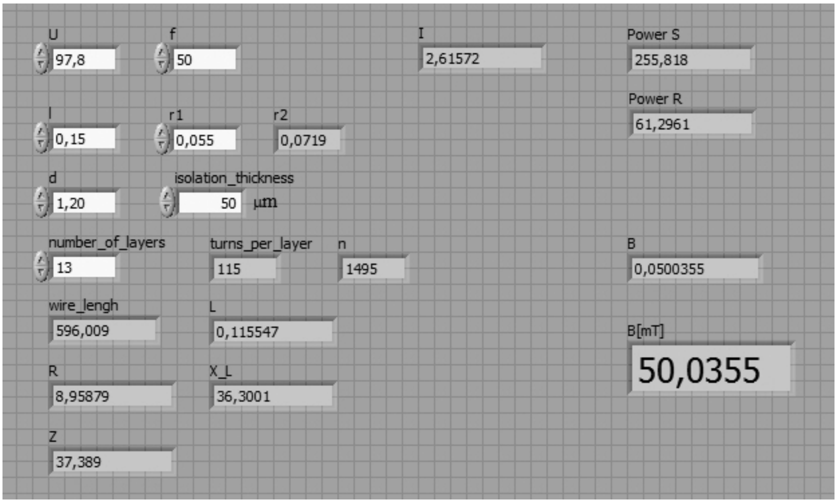

Fig. 2. Counter circuit parameters at the proposed induction of a magnetic field

Table 1

Examples of temperature coefficients of resistance in selected conductors of current (K^{-1})

Iron	Tungsten	Aluminium	Copper	Silver
0.0065	0.0045	0.0044	0.0043	0.0041

In accordance with the above formula, with a change in temperature amounting to 10K, the coil resistance changes by 4.3%, which leads to a change in the current's strength at a constant voltage of 100V of approx. 0.1A.

Given the above, a model was drawn of the magnetic field distribution around the solenoid applied to the seeds using Vizimag software (Figure 3).

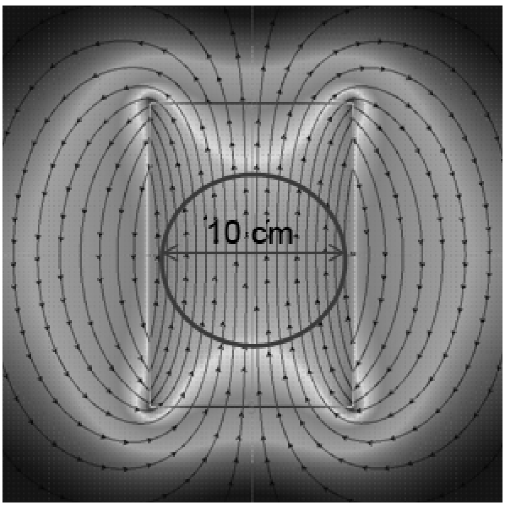

Fig. 3. Model distribution of the magnetic field in the solenoid used in the experiment

The area of uniform induction of the magnetic field comprised a sphere with a radius of 10 cm inside the inducing station.

The field experiments were carried out in soil of medium agronomic quality (soil valuation class III b; order: brown soil; type: brown eutrophic; agricultural complex of suitability: rye, very good) and containing mineral components as indicated in Table 2.

Table 2

The bioavailable constituents and total cadmium, lead and aluminium content of the soil used in the experiment

Constituent assessed and unit	Determination standard	Result of determination
pH in KCl	PN–ISO 10390:1997	4.980±0.180
Reaction		acidic
P (mg kg^{-1})	PN-R-04023:1996	48.00±4.000
K (mg kg^{-1})	PN-R-04022:1996/A	90.01±0.800
Mg (mg kg^{-1})	PN-R-04020:1994/A	95.00±10.00
Al (mg kg^{-1})	PN-ISO 11047: 2001 and PN-ISO 11466:2002	154.0±19.00
Cd (mg kg^{-1})		3.300±1.800
Pb (mg kg^{-1})		8.200±3.500

In each case, the sugar beet cultivars were harvested at the end of October. A representative sample, to be used in laboratory tests, was selected in accordance with the PN-R-74458 standard. Nine representative samples were collected for each type of a cultivar in the experiment (3 plots for each factor), with three replicates.

The course of temperatures and precipitation in 2014 and 2015 is plotted in Figure 4.

The samples of sugar beet roots were mineralised under high pressure, in super pure 65% HNO_3. 5 gram samples were weighed and placed in Teflon

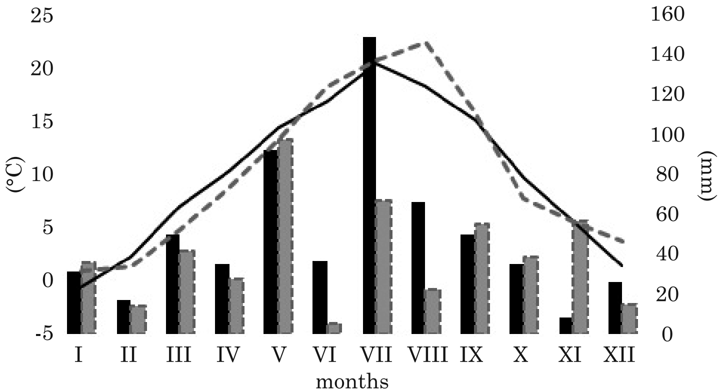

Fig. 4. Monthly temperature (lines) and precipitation (bars) in 2014 (black colour) and 2015 (grey colour) years

vessels, which were then filled with 8 ml of nitric acid and sealed tightly. For each group of nine samples, the rotor of a digestion system was also filled with a blank sample. The samples were digested at an algorithm of temperature increasing as specified for biological samples, never exceeding 200°C. This procedure was carried out in an Ethos One microwave digestion system from Milestone. The vessels were opened after the mineralisation process had been completed and the samples with acid had been brought to room temperature. Afterwards, they were replenished with water to a volume of 50 ml. The detection threshold obtained for each element was not lower than 0.01 mg kg^{-1} (with an assumed detection capacity of the measuring apparatus at a level exceeding 1ppb). The measurements were performed on an ICP-OES spectrometer, Thermo iCAP Dual 6500 with horizontal plasma, and with the capacity of detection being determined both along and across the plasma flame (Radial and Axial). Before measuring each batch of 11 samples, the equipment was calibrated with the use of certified Merck models, with concentrations of 10000 ppm for Ca, Fe, K, Mg, P and 1000ppm for Al, Ba, Cd, Cu, Na, Pb. The measurement result for each element was adjusted to account for the measurement of elements in the blank sample.

In each case, a 3-point calibration curve was used for each element, with optical correction applying the method of internal models, in the form of yttrium and ytterbium ions, at concentrations of 2 mg l^{-1} and 5 mg l^{-1}, respectively. The analytical methods were validated using two independent tests. Certified Reference Material (NIST – 1515) was used and the recovery obtained for specific elements is shown in Table 3. In order to identify the relevant measurement lines and to avoid possible interferences, the method of adding a model with a known concentration was applied (Table 3).

Table 3

The lengths of measurement lines and the recovery obtained for the specific elements examined

Element	Measurement line (nm)	Recovery according to CRM (%)
Al	167.079	98
Ba	455.503	101
Ca	393.366	97
Cd	214.438	102
Cu	324.754	102
Fe	259.940	100
K	766.490	99
Mg	279.553	101
Na	589.592	98
P	177.495	98
Pb	220.353	97

The statistical hypotheses regarding the lack of an effect of the sugar beet cultivar, the experimental factor, on the examined parameters, and the lack of interaction between the cultivar and the factor, were verified with the use of two-way ANOVA with the Fisher's least significant difference (LSD) as a *post-hoc* test in Statistica 12 software. Analyses were made for each year separately. The level of significance was $\alpha \leq 0.05$.

RESULTS AND DISCUSSION

The content of basic mineral components, yield of sugar beet roots, as well as attempts to limit the transfer of biologically harmful metals from soil to biological material, have been investigated by numerous researchers. It has been observed that the transfer of heavy metals from soil to plants is mainly modified by the soil pH. The value of the negative logarithm of the hydrogen ion concentration at a level of 6.5 and above significantly decreases the amount of highly soluble forms of a given metal in the soil, and reduces its absorption and accumulation by plants (Sady 2001). In an acidic environment, plants may absorb large quantities of cadmium, zinc and nickel, even from mildly polluted soils. A decrease in the soil reaction to slightly acidic or acidic produces higher concentrations of the available, mobile forms of toxic metals. This leads to an increased rate of accumulation by crops (Chłopecka et al. 1996, Gębski 1998). Zaniewicz-Bajkowska et al. (2007) demonstrated a significant decrease in the cadmium content of celery roots and leeks cultivated in soil subjected to liming. According to Rosa et al. (2009), liming had a positive impact manifested as a decrease in the content of soluble lead compounds in the soil. This was shown by the values of the solubility rates. In non-limed soil, the content of dissolvable lead was identified at a level of 0.236 mg kg^{-1}, and in soil subjected to liming the rate was 0.208 mg kg^{-1}. It was determined that red beet cultivated in limed soil accumulated significantly less lead in the edible parts than the plants cultivated in non-limed soil. Following an increase in the soil reaction, the quantity of lead in red beets decreased by 7% on average.

Our study examined the effects of magnetic stimulation applied to sugar beet seeds prior to sowing as well as the impact of the application of balanced mineral fertiliser (matching the requirements of the plants and soil) on the yield of sugar beet roots and of selected mineral components. Balanced fertiliser application to sugar beet, which is extremely sensitive to deficiencies in minerals, is very important because any deficiencies lead to a decreased sugar beet yield (Szczepaniak et al. 2012) and to an altered mineral composition of the roots (Rekowska, Jurga-Szlempo 2011).

The results for the specific years in the study are shown in Tables 4-6.

The relationships between magnetic stimulation and the application of fertiliser and sugar beet yield in 2014 and 2015 are presented in Table 4.

Table 4

Impact of magnetic stimulation and fertiliser use on mean sugar beet root yield in 2014 and 2015

Year	Cultivar	Factor*	Mean root yield ($Mg\ h^{-1}$)
2014	Finezja	C	55.10^{a**}
		MS	59.50^{f}
		MS+F	69.30^{b}
		F	69.70^{bc}
	Sinan	C	50.20^{e}
		MS	56.20^{a}
		MS+F	73.90^{d}
		F	73.20^{d}
	Milton	C	55.10^{a}
		MS	62.30^{g}
		MS+F	70.20^{bc}
		F	71.90^{cd}
2015	Finezja	C	40.10^{b}
		MS	45.10^{c}
		MS+F	56.20^{a}
		F	56.20^{a}
	Sinan	C	38.50^{b}
		MS	45.00^{c}
		MS+F	54.10^{d}
		F	55.10^{ad}
	Milton	C	39.20^{b}
		MS	44.20^{c}
		MS+F	56.30^{a}
		F	56.70^{a}

* C – control, MS – magnetic stimulation, MS+F – magnetic stimulation and fertiliser use, F – fertiliser use;
** according to LSD test means with the same Arabic letter are not significantly different with $\alpha \leq 0.05$; analysis was performed for each year separately;

Significantly higher yields were observed in 2014 mainly because of the favourable weather conditions (Figure 4). The mineral fertiliser applied increased the total root yield for each cultivar by 34% on average when compared to the control. The pre-sowing stimulation treatment alone improved the sugar beet root yield by 4-6 t ha^{-1}. Similar findings were observed by other authors, e.g. Pietruszewski, Wójcik (2000) and Wójcik (2006). Combined application of pre-sowing stimulation and mineral fertiliser did not lead to a significant improvement in sugar beet root yield in comparison with the sample treated only with mineral fertiliser. This is consistent with studies by other authors (Kornarzyński, Pietruszewski 2008) who report that pre-sowing stimulation of biological material is effective if there are deficiencies in mineral components or poor weather conditions. Seeds stimulated with a magnetic field are more vigorous during the first stage of growth; they germinate more rapidly, and in this way achieve a greater advantage at the start (Pietruszewski, Kornarzyński 1999). Therefore, magnetic stimulation may be treated as a kind of "magnetic scarification" by reference to the classic scarification methods. Mechanical and chemical scarification has been discussed by a number of Polish and foreign researchers (Tworkowski et al. 1999, Martin, De la Caudra 2004).

Table 5 presents the effects of magnetic stimulation and fertiliser used on the content of selected micro- and macroelements in sugar beet roots in the 2014 and 2015 seasons. It was observed that there were only slight, statistically significant differences between the content of mineral components in the specific sugar beet cultivars. Likewise, magnetic stimulation did not lead to a statistically significant change in the content of macro- and microelements in sugar beet roots. The mean results for the content of the elements in the roots from seeds pre-stimulated with magnetic field were lower than in the control sample. This situation was particularly pronounced in the case of ions with the highest concentrations. On the other hand, mineral fertilisers contributed to a slight increase in the content of basic macroelements in sugar beet roots, in particular magnesium, potassium, phosphorus and calcium.

Table 6 presents the influence of magnetic stimulation and fertiliser use on the content of harmful metals in sugar beet roots in 2014 and 2015. It was observed that the transfer of toxic metals from the soil to sugar beet roots was reduced following magnetic stimulation and after an application of the optimum dose of mineral fertilisers, as well as the combined use of both treatments. The statistically significant differences confirm the feasibility of using the application of pre-sowing magnetic stimulation as a means of reducing transfer of harmful metals. Thus far, it has only been possible to reduce such transfer by modifying the soil pH (Gębski 1998), achieved through liming, and by optimising the content of micro- and macroelements. The sugar beet roots from the plots treated with mineral fertilisers were characterised by a lower content of accumulated toxic elements, which is consistent with the findings published by other authors (Łukowski, Wiater 2009), who reported that a balanced optimum content of micro- and macronutrients in soil resulted in producing crops with low concentrations of harmful elements. Fertiliser use should be adjusted to the soil and climatic conditions prevailing in a given area, and they should match the nutritional requirements of the plants as well as the purpose for which the crops are intended. The most effective treatments are based on concentrated mineral fertilisers with a high nutrient content (triple superphosphate, potassium

Table 5

Impact of magnetic stimulation and fertiliser use on the content of selected micro- and macroelements in sugar beet roots in 2014 and 2015

Year	Cultivar	Factor*	Nutrients							
			Ca	Ba	Cu	Fe	K	Mg	Na	P
			(mg kg^{-1})							
2014	Finezja	C	685.0^{ab**}	1.070^{cd}	0.500^{ab}	11.73^{d}	8720^{ab}	2350^{abd}	400.0^{a}	2100^{a}
		MS	604.0^{eg}	1.010^{abcd}	0.510^{ab}	11.56^{d}	8690^{ab}	2250^{a}	395.0^{a}	2100^{a}
		MS+F	740.0^{bcd}	1.090^{d}	0.500^{ab}	12.03^{b}	9100^{f}	2500^{ce}	410.0^{a}	2500^{b}
		F	770.0^{d}	1.050^{bcd}	0.480^{b}	12.05^{be}	9115^{f}	2510^{ce}	410.0^{a}	2560^{b}
	Sinan	C	690.0^{abc}	0.990^{abc}	0.560^{ab}	13.26^{cf}	7800^{d}	2300^{ab}	395.0^{a}	2010^{a}
		MS	675.0^{ab}	0.950^{a}	0.530^{ab}	13.20^{c}	7700^{d}	2280^{ab}	390.0^{a}	2000^{a}
		MS+F	755.0^{cd}	1.020^{abcd}	0.580^{b}	12.98^{c}	8140^{e}	2410^{bde}	400.0^{a}	2540^{b}
		F	721.0^{abcd}	0.980^{abc}	0.550^{ab}	13.65^{f}	8150^{e}	2450^{cde}	395.0^{a}	2500^{b}
	Milton	C	545.0^{fg}	1.050^{bcd}	0.540^{ab}	12.56^{a}	8500^{ac}	2310^{abd}	415.0^{a}	2150^{a}
		MS	530.0^{f}	1.040^{abcd}	0.520^{ab}	12.42^{ae}	8410^{c}	2300^{ab}	410.0^{a}	2100^{a}
		MS+F	660.0^{ae}	1.010^{abcd}	0.490^{b}	12.48^{a}	8620^{abc}	2560^{c}	415.0^{a}	2400^{b}
		F	661.0^{ae}	0.970^{ab}	0.500^{ab}	12.56^{a}	8759^{b}	2580^{c}	410.0^{a}	2450^{b}
2015	Finezja	C	690.0^{ab}	1.050^{a}	0.450^{a}	12.01^{cd}	8800^{bc}	2300^{abc}	420.0^{a}	2100^{a}
		MS	670.0^{abc}	1.040^{a}	0.410^{a}	11.99^{c}	8752^{abc}	2250^{ac}	415.0^{a}	1990^{a}
		MS+F	625.0^{abc}	1.040^{a}	0.450^{a}	12.11^{cde}	9210^{e}	2450^{bd}	410.0^{a}	2450^{bc}
		F	645.0^{abc}	1.060^{a}	0.480^{a}	12.40^{cde}	9200^{e}	2560de	410.0^{a}	2500^{c}
	Sinan	C	650.0^{abc}	1.110^{a}	0.510^{a}	13.25^{b}	8250^{df}	2290^{abc}	395.0^{a}	2050^{a}
		MS	630.0^{abc}	1.020^{a}	0.490^{a}	13.24^{b}	8200^{f}	2200^{c}	390.0^{a}	2010^{a}
		MS+F	710.0^{a}	1.050^{a}	0.520^{a}	12.98^{ab}	8650^{ab}	2350^{abc}	400.0^{a}	2350^{bc}
		F	715.0^{a}	1.060^{a}	0.530^{a}	13.02^{ab}	8700^{ab}	2350^{abc}	405.0^{a}	2300^{b}
	Milton	C	610.0^{bc}	1.000^{a}	0.550^{a}	12.56^{ae}	8500^{ad}	2410^{abd}	405.0^{a}	2050^{a}
		MS	580.0^{c}	0.980^{a}	0.520^{a}	12.54^{ade}	8510^{ad}	2400^{abd}	400.0^{a}	2030^{a}
		MS+F	689.0^{ab}	0.980^{a}	0.520^{a}	13.01^{ab}	8900^{bc}	2560de	400.0^{a}	2450^{bc}
		F	701.0^{ab}	1.020^{a}	0.510^{a}	13.02^{ab}	9001^{ce}	2680^{e}	405.0^{a}	2490^{bc}

* C – control, MS – magnetic stimulation, MS+F – magnetic stimulation and fertiliser use, F – fertiliser use;
** according to LSD test means with the same Arabic letter are not significantly different with $\alpha \leq 0.05$; analysis was performed for each year separately;

sulphate, potassium salt 60%) and complex multi-component fertilisers, particularly those which contain magnesium and microelements in addition to the basic nutrients.

Stimulation with a slowly changing magnetic field of 50 mT induction contributed to an improved yield of sugar beet roots in plants with a poorer

Table 6

Impact of magnetic stimulation and fertiliser use on the content of toxic metals in sugar beet roots in 2014 and 2015

Year	Cultivar	Factor*	Nutrients		
			Al	Cd	Pb
			(mg kg^{-1})		
2014	Finezja	C	14.83^{j**}	0.050^{cd}	0.020
		MS	4.800^{e}	0.030^{b}	<0.010
		MS+F	5.740^{a}	<0.010	<0.010
		F	7.880^{h}	<0.010	<0.010
	Sinan	C	12.03^{i}	0.060^{d}	0.020
		MS	3.210^{c}	0.020^{a}	<0.010
		MS+F	2.390^{b}	<0.010	<0.010
		F	5.810^{a}	<0.010	<0.010
	Milton	C	18.90^{k}	0.050^{c}	0.020
		MS	4.440^{d}	0.020^{ab}	<0.010
		MS+F	6.480^{g}	<0.010	<0.010
		F	5.190^{f}	<0.010	<0.010
2015	Finezja	C	13.45^{i}	0.050^{b}	0.020
		MS	5.810^{b}	0.020^{a}	<0.010
		MS+F	6.510^{g}	<0.010	<0.010
		F	5.820^{bc}	<0.010	<0.010
	Sinan	C	12.07^{h}	0.080^{c}	0.020
		MS	4.420^{a}	0.030^{a}	<0.010
		MS+F	4.400^{a}	<0.010	<0.010
		F	4.880^{e}	<0.010	<0.010
	Milton	C	17.88^{j}	0.060^{b}	0.020
		MS	5.090^{f}	0.020^{a}	<0.010
		MS+F	6.020^{cd}	<0.010	<0.010
		F	6.090^{d}	<0.010	<0.010

* C – control, MS – magnetic stimulation, MS+F – magnetic stimulation and fertiliser use, F – fertiliser use;
** according to LSD test means with the same Arabic letter are not significantly different with $\alpha \leq 0.05$; analysis was performed for each year separately;

access to nutrients due to the lack of mineral fertilisers. When balanced mineral fertilisers were applied, the effect of pre-sowing stimulation was cancelled and the sugar beet yield did not differ significantly from the yield of roots recorded in the case of sugar beet plants treated exclusively with mineral fertiliser. On the other hand, the magnetic field applied affected the mineral element content in sugar beet roots, which was particularly visible in the case of harmful metals which accumulated from soil. A magnetic field applied before planting the seeds reduced the accumulation of aluminium, cadmium and lead, beneficially affecting the mineral composition of sugar beet roots. Therefore, the authors filed a patent application titled "Method of reducing absorption of heavy metals by root crops", which was assigned number P.411721 by the Polish Patent Office.

Hypotheses regarding the possible effects of magnetic fields in the transfer of metals from soils of a specific profile to plants may be drawn from reports published by numerous researchers who have examined the interaction between magnetic fields and biological membranes. A change in the cell membrane's potential may lead to the opening and closing of ion channels, through which metal ions may penetrate into the cell (Berton 1993). However, it is necessary to conduct further research at the molecular level in order to confirm such effects precisely, using analytic equipment designed for conducting research at the cellular level.

CONCLUSIONS

1. Use of balanced mineral fertiliser significantly impacted sugar beet yield and mineral composition, and reduced the transfer of toxic metals from the soil to roots in the three cultivars examined.

2. Pre-sowing stimulation of seeds with a magnetic field positively affected the root yield of sugar beet plants growing in soil with an insufficient supply of mineral nutrients.

3. Stimulation of sugar beet seeds contributed to reducing the transfer of mineral compounds such as aluminium, lead and cadmium into sugar beet roots, at the same time only insignificantly decreasing the contents of macroelements.

4. Magnetic pre-stimulation of planting material may be treated as a kind of magnetic scarification, which improves crop yields, particularly in soils with a lower content of nutrients.

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