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Impact of low frequency magnetic fields on yield and quality of sugar beet

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A b s t r a c t. Pre-sowing treatment of seeds using a low frequency magnetic field (16 Hz, 5mT) and its impact on the yield and quality of plants were investigated. Magnetic treatments increased the emergence of seeds, especially for low vigour seeds. The chlorophyll content also increased significantly. As a result, the yield of plant roots was increased. The magnetic field also influenced the content of sugar in the root of the beet.

K e y w o r d s: low frequency magnetic field, germination, seed, sugar beet, yield

INTRODUCTION

Sugar beet is the only plant which is used for sugar production in Poland. Sugar beet belongs to the family *Chenopodiaceae*. Its Latin name is *Beta vulgaris* (L.) *ssp. vulgaris conv. crassa* (*Alef.*) *prov. altissima* (*Döll*). It is a biannual plant (Jasińska and Kotecka, 2003). Changes in sugar beet harvest technology, involving complete mechanisation, resulted in a tendency towards a smaller sowing norm with a higher quality requirement. This leads to the necessity of producing seeds with very high quality which means a sowing efficiency of around 100%.

There are many frequently-used methods for improvement of the quality of sowing material (that is conditioning) *eg* seed treatment, matrix treatment, capsule treatment, tape treatment, stimulation and fluid drilling. In agricultural practice, seeds have been impregnated before sowing for several years. The main goal of the seed treatment method is to protect them against particular fungal diseases and pests. The main goal of the matrix treatment of seeds (Domoradzki, 2004) is to increase their size and to adapt the seed shape for sowing. Small seeds with a small mass and with an irregular shape are most frequently subjected to matrix treatment. The composition of the matrix and the course of matrix treatment is a commercial secret of the company and the composition of the matrix is protected by patent (Orzeszko-Rywka and Rochalska, 2004). The composition of the matrix can be considerably influenced by the germination ability (Domoradzki and Kopral, 2004). The capsule treatment is a technological process similar to the matrix treatment, but rarely applied in traditional seed production. This method is most frequently used to help the sowing of artificial seeds. During the capsule treatment, seeds with nutrients, actively physiological or protective, are placed in a hydro-gel capsule which is formed from calcium alginate. The tape treatment consists in putting seeds between two layers of tape. Insecticide, herbicide and fungicide can be added to the tape. The tape method ensures high precision in seed sowing. Seed stimulation is a form of physiological conditioning. It is used to increase the speed of germination of seeds and to increase its uniformity, especially under stress conditions *eg* frost or increased soil wetness) or to break seed dormancy caused by high temperatures or the absence of light. Fluid drilling consists of putting sprouting seeds into a water-based gel. This gel is a medium of water, and can prevent drying out of the sprouts as well as encourage the growth of plants through added substances (Orzeszko-Rywka and Rochalska, 2004).

The increase in quality requirements has caused a search for new and different ways of conditioning which are as yet very rarely used *eg* stimulation with magnetic fields (PEM), ion radiation, laser radiation, UV radiation and visible light. Plants are permanently exposed to the effect of magnetic fields – both natural and artificial, resulting from human activity. During conditioning, both permanent and alternating fields are used.

Magnetic and electric fields are constituent elements of an electromagnetic field. An electric field produces a magnetic field and vice versa. These fields are dispersed and create electromagnetic waves. An electromagnetic field is

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a type of radiation dispersed at the speed of light, and which can cause changes to the strength of the charges (Mikołajczyk, 1990). The natural electromagnetic field of planet Earth can be divided into natural and artificial fields. On Earth, a natural electromagnetic field occurs which consists of a constant electric and magnetic field which is produced by our planet and high-energy cosmic radiation of various frequencies. The artificial electromagnetic fields produced by humans are broadcast by technical appliances and have a frequency of several to 3 kHz. Up to now experiments have been conducted to investigate the positive impact of PEM on the vigour of seeds and plant yield from treated seeds. But not many of those experiments apply to yield quality.

The aim of this study was to determine the impact of pre-sowing treatment of seeds on the yield, quality of plants and the content of sugar.

MATERIALS AND METHODS

Seeds of sugar been cv. Lubelska from the Kutno Sugar Beet Breeding Co. Ltd. were used in the investigation. Seeds were divided into seeds with low and high vigour: raw, matrix treatment (grey context) and matrix treatment (pink context). Seeds were divided according to high and low vigour seeds on the basis of the density of the seeds, using a vibration table. Preliminary conditioning treatments were only used for seeds without a matrix. The control group seeds were not subjected to any conditioning. The seeds were stimulated through soaking in an optimum water volume (30% maximum water capacity of blotting paper) for 24 h at 20°C. Then the seeds were dried. Seeds without matrix (control and stimulated) and with matrix were exposed to the effect of an alternating magnetic field with a frequency of 16 Hz. The seed treatment time was 2 h and the magnetic flux density was 5 mT. The magnetic field generator was constructed by the Technical University in Wrocław. The generator produces a homogenous magnetic field with a frequency of 16 Hz and a strictly determined magnetic flux density. The design of the generator allows the elimination of the electrical component of the field and enables seed treatment with a constant magnetic field. To avoid overheating the internal volume of the seeds, the equipment was cooled by an air stream.

The experiment yielded eight combinations for seeds with low and high vigour, respectively:
- control group of seeds,
- seeds treated with 16 Hz magnetic field,
- stimulated seeds,
- stimulated seeds treated with 16 Hz magnetic field,
- matrix treatment (grey context),
- matrix treatment (grey context), treated with 16 Hz magnetic field,
- matrix treatment (pink context),
- matrix treatment (pink context), treated with 16 Hz magnetic field.

The field experiments were carried out at the Agricultural Experimental Station in Żelazna near the town of Skierniewice, on podzol soil, in 2005. The sugar beet was sown after bean. Seeds without surrounds before sowing were treated using the Super Homai 70DS seed treatment against black leg of sugar beet, beet fly and aphids.

Seeds were sown on 27.04.2005 using a drill, in 5 repetitions. Each row had 100 seeds. The distance between the rows was 50 cm. Winter ploughing was done in the autumn, followed by harrowing, sowing of fertilizer and mechanical sowing of the seeds in the spring. The fertilizers were potassium salt in autumn with a plough, ammonium phosphate and potassium salt in spring, ammonium – calcium – magnesium nitrate and urea after the harvest. The total dose of fertilizer, per 1 ha, was 110 kg N, 90 kg P, 160 kg K.

In the field experiments the following determinations were made – the germination capacity of sugar beet plants, counted every 2 days from the emergence of the first seedlings, the Pieper coefficient, and the uniformity of ground-germination rate. The Pieper coefficient was determined using the following model:

$$W = \Sigma\, (d_n\, a_n)/\Sigma a_n,$$

where: d_n – day of germintion, a_n – number of germinated seeds on a given day.

The uniformity of the ground germination rate was determined using the Pieper coefficient model.

During the period of sprouting and development of the plants in the field, physiological measurements were done:
- chlorophyll content in leaves (7 and 18.07.2005),
- coefficient of PAR radiation measurement (18.07.2005),
- coefficient of solar energy absorption (τ) (18.07.2005),
- measurement of growth in mass roots and leaves (2 measurements: 11 and 27.07.2005).

The chlorophyll content was determined using a SPAD -520 chlorophyllmeter by Minolta Co. Ltd which made it possible to determine the chlorophyll content in plant leaves using the colorimetric method.

The coefficient of radiation PAR and the coefficient of solar energy absorption (τ) were determined by using the AccuPAR apparatus, produced by the Light Interception Devia Company.

The harvest of sugar beets was done by hand on 24.10.2005. During the harvest, the following features were determined: number of plants during the harvest, fresh mass of leaves, fresh mass of roots, content of sugar in the roots.

The sugar content was measured during the harvest using an RR12 manual refractometer produced by Polish Optical Plant. The weather conditions during the vegetation period are shown in Table 1. During the plant development period, on the 16th of May and on the 29th of July, there were two intense rainfalls: 34.2 mm over 45 min and 56.4 mm over 1 h. The coefficient of Selianinov (Fig. 1) is the ratio of the average monthly sum of rainfall to the average monthly temperature. When the coefficient value is lower than 1, drought occurs.

T a b l e 1. Average month daily temperatures (°C), average monthly amounts of precipitation (mm), long-term average daily temperatures (°C), long-term average amounts of precipitation (mm) during the April-October period

Average	IV	V	VI	VII	VIII	IX	X
Month daily temperatures (°C)	8.9	17.9	16.4	20.0	17.3	15.0	8.9
Month amounts of precipitation (mm)	14.7	100.3	32.0	117.5	32.3	20.5	3.4
Many years daily temperatures (°C)	7.5	13.4	16.5	18.3	17.5	13.4	8.2
Many years amounts of precipitation (mm)	33.9	51.1	77.1	80.0	73.9	48.7	36.9

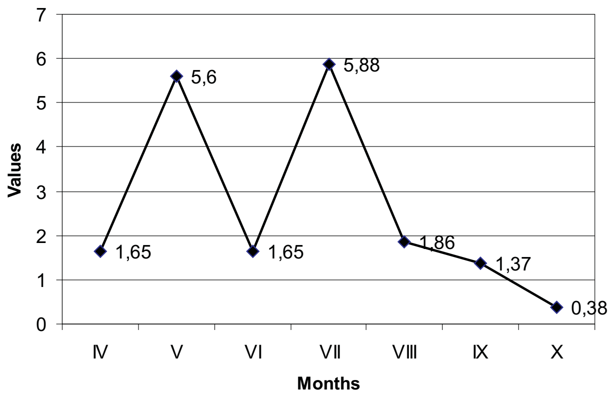

Fig. 1. The coefficient of Selianinow.

T a b l e 2. Ground germination rate of sugar beet

Combinations	Lower vigour	Higher vigour
Control group	59.00	77.75
16 Hz	66.50	84.50
Stimulated	77.00*	71.75
Stimulated + 16 Hz	84.00*	86.25*
Grey matrix	79.75*	80.50
Grey matrix + 16 Hz	86.25*	85.50*
Pink matrix	84.50*	86.00*
Pink matrix + 16 Hz	91.25*	88.25*
LSD	9.68	7.69

*Statistically significant differences in relation to the control group. LSD – least significant difference.

RESULTS AND DISCUSSION

As can be seen in Table 2, among the seeds with lower vigour, the highest field ground germination rate were seeds with a red matrix and magnetic field treatment – 91.25%. Whereas, the control group of seeds had the lowest rate – 59%. Stimulated seeds had a higher ground germination rate compared to the control group of seeds (about 18%), the stimulated and magnetic field treatment seeds (about 25%), the grey matrix seeds (about 20.75%), the grey matrix and magnetic field treatment seeds (about 27.25%) and the pink matrix (about 25.5%). The magnetic field seed treatment resulted in good benefits for most examined combinations. The ground germination rate for seeds with pink matrix and treated with magnetic field was higher by about 6.75% compared to seeds with the grey matrix treated with magnetic field. The highest ground germination rate among the seeds with higher vigour was seeds with pink matrix treated with magnetic field – 88.25%. However, the lowest stimulated seeds had a rate of 71.75%. The stimulated seeds treated with magnetic fields (about 7.75%) showed a higher ground germination rate. The pink matrix gave about 8.25%. A beneficial impact of the magnetic field was observed for seeds treated with magnetic field, stimulated and treated with magnetic field, with grey matrix and treated with magnetic field. These gave a ground germination rate higher than seeds not treated with magnetic field – at about 6.75, 14.5, and 5%. Essential differences between seeds with higher and lower vigour were only observed for the control group seeds and those treated with a magnetic field. The ground germination rate of seeds with higher vigour was higher by about 18.75% for the control group seeds and about 18% for seeds treated with magnetic field.

The Pieper coefficient of ground germination rate is shown in Table 3. Under field conditions, the average time for a single seed with lower vigour to sprout was shorter than in the case of seeds treated with magnetic field and stimulated: seeds stimulated and treated with magnetic field, and seeds with a pink matrix and treated with magnetic field. The beneficial influence of magnetic field treatment on seeds appeared on all tested seeds treated with magnetic field. Seeds germinated faster by about 0.8 days compared to seeds not suitably treated with magnetic field; about 0.16 days when stimulated and treated with a magnetic field; and about 1.24 days seeds when with grey matrix and treated with magnetic field; and about 0.31 days seeds when with pink matrix and treated with magnetic field. Seeds with pink matrix germinated slower than seeds with pink matrix and treated with magnetic field. For seeds of a higher vigour, the average time for a single seed to sprout in field conditions was lower for stimulated seeds and those treated with magnetic field by about 1.24 days. Stimulated seeds and seeds treated with magnetic field germinated faster, by about 0.75 and 0.76 days, respectively. For seeds with a matrix the differences were not statistically significant. The higher vigour seeds had a positive impact on the control group, those treated with magnetic field, and those with grey matrix. Seeds germinated faster by about: 0.34, 0.29 and 1.05 days, respectively. However, seeds with lower vigour with pink matrix and treated with magnetic field germinated faster, on average by 0.65 days, than with the same treatment and higher vigour.

The uniformity of ground germination rates of sugar beets of the Lubelska variety are shown in Table 4. For seeds with lower vigour, most of the uniformly germinated seeds were stimulated and treated with magnetic field (uniformity coefficient for the ground germination rate – 2.17 days). Stimulated seeds (2.33) treated with magnetic field had better uniformity (2.74). Seeds with grey matrix germinated more slowly and less steadily – the uniformity coefficient of the ground germination rate was 4.06 days. Seeds treated with magnetic field obtained a better uniformity of ground germination rate, for both seeds treated with magnetic field and seeds with grey matrix and treated with magnetic field (the uniformity coefficient was lower about: 0.34 days and 0.82 days, respectively, compared to the control group seeds). Seeds with pink matrix germinated more steadily than seeds with grey matrix by about 0.98 days for seeds with a matrix and 0.5 days seeds with a matrix and treated with magnetic field. Seeds with higher vigour germinated more steadily. Stimulated seeds and seeds treated with magnetic field germinated more steadily – the uniformity coefficient was lower by about 0.96 days in comparison to the control group. Stimulated seeds also germinated more steadily (a drop in the uniformity coefficient of about 0.77 days). The remaining results did not show any statistically significant differences. A beneficial impact of uniformity on the vigour of seeds was observed for seeds treated with magnetic field and for seeds with grey matrix (the uniformity coefficient was lower by about 0.3 and 0.73 days). Seeds with low vigour: control group, with grey matrix and treated with magnetic field, with pink matrix and treated with magnetic field all germinated more steadily than seeds with high vigour (the uniformity coefficient was lower by about 0.12, 0.14 and 0.68 days).

T a b l e 3. The Pieper's coefficient

Combinations	Lower vigour	Higher vigour
Control group	9.69	9.35
16 Hz	8.89*	8.60
Stimulated	8.33*	8.59
Stimulated + 16 Hz	8.17*	8.11*
Grey matrix	10.48	9.43
Grey matrix + 16 Hz	9.24	9.37
Pink matrix	9.05	9.61
Pink matrix + 16 Hz	8.74*	9.39
LSD	0.77	1.14

*Explanations as in Table 2.

T a b l e 4. Uniformity coefficient of the ground germination rates of sugar beets (in days)

Combinations	Lower vigour	Higher vigour
Control group	3.23	3.35
16 Hz	2.89	2.59
Stimulated	2.33*	2.58
Stimulated + 16 Hz	2.17*	2.39*
Grey matrix	4.06*	3.33
Grey matrix + 16 Hz	3.24	3.38
Pink matrix	3.08	3.52
Pink matrix + 16 Hz	2.74*	3.42
LSD	0.42	0.81

*Explanations as in Table 2.

Chlorophyll is a basic vegetable dye which is indispensable in the photosynthesis process. The chlorophyll content correlates with the content of nitrogen in a plant and with the intake of nutrients. Among plants grown from seeds with lower vigour, the lowest chlorophyll content was in the sugar beet grown from the control group seeds, while the highest was for sugar beet grown from seeds with grey matrix and magnetic field treatment (Table 5). The pre-sowing treatment of seeds with magnetic field had a beneficial influence on the chlorophyll content in sugar beet leaves. For both dates when the plants were measured, plants grown from seeds treated with magnetic field had higher chlorophyll content than seeds that were not treated. For the first date, the

Table 5. Relative chlorophyll content in leaves of plants grown from seeds with lower and higher vigour, measured on 2 dates – 71 and 82 days after sowing (in SPAD unit)

Combinations	Measurement 1	Measurement 2
	Lower vigour	
Control group	40.90	41.13
16 Hz	47.73*	46.50*
Stimulated	45.07	47.33*
Stimulated + 16 Hz	48.83*	49.27*
Grey matrix	48.13*	47.73*
Grey matrix + 16 Hz	50.17*	51.93*
Pink matrix	46.23	47.33*
Pink matrix + 16 Hz	48.27*	48.47*
LSD	5.88	4.81
	Higher vigour	
Control group	41.93	43.87
16 Hz	43.13	47.63
Stimulated	43.57	45.90
Stimulated + 16 Hz	51.20*	52.43*
Grey matrix	46.00	46.47
Grey matrix + 16 Hz	48.80*	49.57
Pink matrix	47.73	48.27
Pink matrix + 16 Hz	50.23*	52.40*
LSD	6.4	6.08

*Explanations as in Table 2.

chlorophyll content was higher in plants grown from seeds treated with magnetic field, the increase in the chlorophyll content being about 19.06%, while those stimulated and treated with magnetic field showed an increase in chlorophyll content of about 8.34% compared to the control group. However, for the second measurement date, the differences were significant for plants grown from seeds treated with magnetic field (increase in the chlorophyll content of about 8.78%) and seeds with grey matrix and treated with magnetic field (increase in the chlorophyll content of about 13.06%). The matrix process, using a pink matrix, also had a beneficial influence on the chlorophyll content (increase of about 14.1% compared to the control group).The chlorophyll content in leaves in the same combinations did not show any changes between the measurements in the experiments.

In the case of seeds with higher vigour, pre-sowing treatment with magnetic field also had a beneficial influence on the chlorophyll content in sugar beet leaves (Table 5). For both dates, plants grown from seeds treated with magnetic field had higher chlorophyll content than those grown from seeds that were not treated with magnetic field. On the first measurement date, plants grown from stimulated seeds and treated with magnetic field had higher content of chlorophyll than the control group – an increase of 17.51%. On the second date, the measurement of plants grown from seeds treated with magnetic field showed an increase in chlorophyll content of about 8.57%; plants grown from stimulated seeds and treated with magnetic field had an increased chlorophyll content by about 14.23%, while plants grown from seeds with grey matrix and treated with magnetic field had an increased chlorophyll content by about 6.67%. Better results were obtained for plants grown from stimulated seeds and treated with magnetic field than for plants grown from seeds only stimulated or from seeds only treated with magnetic field. The matrix process using a grey matrix also had a beneficial influence on the chlorophyll content – an increase of about 12.98% compared to the control group. For seeds with higher vigour, the differences between the chlorophyll content in sugar beet leaves after 71 and 82 days from sowing were significant only for plants grown from seeds treated with magnetic field – increased chlorophyll content after 11 days from the first measurement of about 10.43%. After 71 days from sowing, the differences in chlorophyll content in plant leaves grown from seeds with higher and lower vigour were observable only in the case of seeds treated with magnetic field. The difference was 10.67% for plants grown from seeds with lower vigour. However, after 82 days from sowing, the differences observed in plants grown from stimulated seeds and treated with magnetic field (plants grown from seeds with higher vigour had a higher chlorophyll content of about 6.41%) and plants grown from seeds with grey matrix and treated with magnetic field (plants grown from seeds with higher vigour showed a lower chlorophyll content of about 4.54%).

Photosynthetically active radiation (PAR) is a type of solar radiation used by plants in the photosynthesis process. The coefficient of PAR radiation indicates the percentage of the PAR radiation absorbed by plants. For plants grown from seeds with higher vigour, only sugar beet with seeds treated with magnetic field had a higher coefficient of PAR radiation than control group plants (an increase of about 2.46%) and plants grown from seeds stimulated only (an increase of about 4.1%). The remaining differences are not statistically significant (Table 6). Plants grown from seeds with lower vigour showed higher differences. Sugar beets grown from seeds treated with magnetic field had a higher coefficient of PAR radiation by about 9.5% over the control group as well as plants grown from stimulated seeds (an increase of about 3.71%). Sugar beet grown from stimulated seeds and treated with magnetic field were characterized by higher absorption of PAR than the control group. Plants grown from seeds with grey matrix had a lower radiation coefficient of about 2.64% over those grown from seeds with grey matrix and treated with magnetic field. Conditioning of seeds with magnetic field had a beneficial influence

T a b l e 6. Coefficient of PAR radiation for plants grown up from seeds conditioned with different methods

Combinations	Radiation coefficient PAR	
	Lower vigour	Higher vigour
Control group	83.13	90.28
16 Hz	91.03	92.50
Stimulated	87.77	88.86
Stimulated + 16 Hz	91.07	90.84
Grey matrix	89.65	86.88
Grey matrix + 16 Hz	92.02	90.92
Pink matrix	88.91	91.88
Pink matrix + 16 Hz	91.31	92.66
LSD	6.70	5.72

*Explanations as in Table 2.

T a b l e 7. Coefficient of solar radiation absorption, τ (%)

Combinations	Lower vigour	Higher vigour
Control group	16.86	9.72
16 Hz	*8.97	7.50
Stimulated	12.23	11.18
Stimulated + 16 Hz	*8.53	9.12
Grey matrix	10.35	13.12
Grey matrix + 16 Hz	*7.98	9.08
Pink matrix	11.09	8.12
Pink matrix + 16 Hz	*8.69	7.34
LSD	6.70	5.72

*Explanations as in Table 2.

on the absorption of photosynthesis active radiation. The differences are more visible in plants grown from seeds with lower vigour. Hence, magnetic field improves the quality, particularly in seeds with lower initial parameters.

The coefficient of solar radiation absorption (τ) was equal to the transmission of PAR radiation used by plants. All sugar beets grown from seeds treated with magnetic field had a lower coefficient of solar radiation absorption than plants grown from seeds not treated with magnetic field (Table 7).

The fresh mass of plants was examined on two dates (75 and 91 days after sowing), separately for leaves and for roots (Table 8). At the same time, the length of plants in cm (Table 9) was determined. The fresh mass of root plants grown from seeds with lower vigour was considerably lower than the mass of leaves (as low as half). After 75 days from sowing, the differences were the greatest for plants grown from stimulated seeds. The mass of leaves was about 2.71 times higher than the mass of roots. The lowest differences were observed for plants grown from seeds with pink matrix and treated with magnetic field (the mass of leaves exceeded the mass of roots by about 1.55 times). After 91 days from sowing, the differences decreased and the proportion of root mass to the mass of leaves was between 1.44 for plants grown from seeds with pink matrix and treated with magnetic field, and 1.12 for plants grown from seeds with pink matrix and treated with magnetic field.

After 75 days, statistically significant differences in fresh mass were observed for the roots and leaves of plants grown from stimulated seeds and treated with magnetic field, stimulated seeds, and plants grown from seeds with pink matrix and seeds with pink matrix and treated with magnetic field. Plants grown from seeds treated with magnetic field had a higher mass. It was found that plants grown from seeds treated with magnetic field, and stimulated seeds treated with magnetic field, had a higher mass of leaves than plants grown from seeds with grey and pink matrixes. Plants grown from seeds with pink matrix had a lower mass of leaves.

After 91 days from sowing, plants grown from seeds with lower vigour had a fundamentally lower mass of roots and leaves than was obtained for stimulated seeds and those stimulated and treated with magnetic field. The magnetic field treated seeds with pink matrix had fundamentally higher masses of roots and leaves than plants grown from seeds with grey matrix. The rest of the differences were not statistically significant. Among plants grown from seeds with higher vigour, for most combinations, the fresh mass of leaves was higher than the mass of roots. After 75 days from sowing, the highest proportion of fresh mass of roots to the mass of leaves was observed for plants grown from seeds with pink matrix (3.06). However, the lowest fresh mass ratio was observed for plants grown from the control group seeds (0.83). After 91 days from sowing, the ratio of root mass to leaf mass was between 0.93 for plants grown from seeds treated with magnetic field and 1.39 for plants grown from seeds with grey matrix.

After 75 days from sowing, the masses of roots and leaves of plants grown from the control group seeds and seeds treated with magnetic field were lower than masses of plants grown from stimulated seeds. Plants grown from seeds with grey matrix and treated with magnetic field had a lower mass of roots than the control group plants and plants grown from seeds with grey matrix. The mass of plant roots grown from seeds with pink matrix was significantly lower than the mass of roots of the control group plants and plants grown from seeds with grey matrix. Plant leaves grown from

Table 8. Fresh mass (kg) of roots and leaves of sugar beet plants grown from seeds with lower and higher vigour. Measurement 1 was taken 75 days from sowing. Measurement 2 was taken 91 days from sowing

Combinations	Measurement 1		Measurement 2	
	Roots	Leaves	Roots	Leaves
		Lower vigour		
Control group	0.21	0.41	0.88	1.10
16 Hz	0.17	0.35	0.80	1.08
Stimulated	0.14	0.38	0.62*	0.77*
Stimulated + 16 Hz	0.27	0.47	0.62*	0.79*
Grey matrix	0.25	0.49	0.44*	0.59*
Grey matrix + 16 Hz	0.24	0.49	0.68	0.85*
Pink matrix	0.19	0.33	0.75	0.84*
Pink matrix + 16 Hz	0.33	0.51	0.55*	0.79*
LSD	0.16	0.16	0.26	0.23
		Higher vigour		
Control group	0.24	0.20	0.62	0.70
16 Hz	0.24	0.24	0.67	0.62
Stimulated	0.37*	0.57*	0.74	0.79
Stimulated + 16 Hz	0.24	0.46*	0.86	0.81
Grey matrix	0.29	0.53*	0.62	0.86
Grey matrix + 16 Hz	0.18	0.39*	0.75	0.75
Pink matrix	0.16	0.49*	0.61	0.77
Pink matrix + 16 Hz	0.19	0.44*	0.79	0.89*
LSD	0.10	0.13	0.36	0.19

*Explanations as in Table 2.

seeds with higher vigour had significantly lower masses than plant leaves grown from the control group seeds and from seeds treated with magnetic field. The fresh mass of roots and leaves grown from seeds with lower vigour, when compared to seeds with higher vigour, differed significantly from several combinations.

After 75 days from sowing, plants grown from stimulated seeds had a higher root mass (by about 0.23 kg), whereas, plants grown from seeds with pink matrix and treated with magnetic field had a lower mass (by about 0.03 kg). The leaf mass of plants grown from seeds with higher vigour was lower than the mass of leaves grown from seeds with lower vigour. In the case of the control group plants, the difference was about 0.21 kg, treated with magnetic field by about 0.11 kg, and with pink matrix by about 0.07 kg. A higher mass was only obtained for leaves of plants grown from stimulated seeds (by about 0.19 kg). After 91 days from sowing, a lower mass was observed for roots of plants grown from seeds with pink matrix and treated with magnetic field (by about 0.24 kg), and higher for plants grown from the control group seeds (about 0.26 kg). After 91 days from sowing, the mass of leaves was lower compared to the mass of leaves of plants grown from seeds with higher vigour. In the case of plants grown from the control group seeds (by about 0.4 kg), treated with magnetic field (by about 0.46 kg) and with pink matrix (by about 0.1 kg). The higher mass of leaves was only observed for sugar beets grown from seeds with grey matrix (by about 0.27 kg).

The methods of seed conditioning which had a positive influence on the fresh mass of plant roots had a negative influence on the fresh mass of leaves and the other way round. The length of plant leaves grown from seeds with the lowest vigour was considerably higher than the length of roots after 75 days as well as 91 days from sowing. In this case, only in sugar beets grown from seeds with grey matrix after 75 days from sowing the length of roots was equal to the length of leaves and was about 20 cm.

After 75 days from sowing, plants grown from seeds treated with magnetic field, stimulated, stimulated and treated with magnetic field, had significantly shorter roots than plants grown from the control group seeds. However, the longest roots were recorded for plants grown from seeds

T a b l e 9. Height of plants (cm) grown from seeds with lower and higher vigours. Measurement 1 was taken 75 days from sowing. Measurement 2 was taken 91 days from sowing

Combinations	Measurement 1		Measurement 2	
	Roots	Leaves	Roots	Leaves
		Lower vigour		
Control group	20.80	43.40	22.80	57.00
16 Hz	18.60	47.20	21.60	55.80
Stimulated	15.60*	34.00*	23.00	56.00
Stimulated + 16 Hz	19.40	46.80	23.00	54.20
Grey matrix	20.00	20.00*	18.20*	50.00
Grey matrix + 16 Hz	18.80	54.40*	18.80*	55.80
Pink matrix	19.60	47.60	21.20	54.80
Pink matrix + 16 Hz	25.40*	47.80	21.40	56.00
LSD	2.66	4.93	3.24	7.6
		Higher vigour		
Control group	19.80	40.20	21.80	54.20
16 Hz	24.40	43.80	25.00	52.60
Stimulated	21.20	54.40*	22.60	61.40*
Stimulated + 16 Hz	18.00	52.40*	24.00	57.80
Grey matrix	19.80	48.60*	21.00	60.20*
Grey matrix + 16 Hz	16.80	45.80	25.20*	49.60
Pink matrix	18.40	50.00*	22.40	56.40
Pink matrix + 16 Hz	15.40	54.20*	23.00	62.60*
LSD	6.64	6.74	3.29	5.82

*Explanations as in Table 2.

with pink matrix and treated with magnetic field. The roots of sugar beets grown from stimulated seeds were shorter (with average length of 15.60 cm). The length of leaves and roots of plants grown from stimulated seeds was the smallest and significantly lower than of sugar beets grown from seeds treated with magnetic field and from stimulated seeds treated with magnetic field. Plants grown from seeds with grey matrix and stimulated seeds had a lower length of leaves than the control group. However, longer leaves compared to the control group were only observed for sugar beets grown from seeds with grey matrix and treated with magnetic field. The leaves of sugar beets grown from seeds with grey matrix were significantly shorter than leaves of sugar beets grown from seeds compared to the rest of the combinations (with a matrix, and with a matrix treated with magnetic field).

After 91 days from sowing, differences between the lengths of roots decreased. The roots of sugar beets grown from seeds treated with magnetic field were shorter than both roots grown from the control group seeds as well as stimulated, stimulated and treated with magnetic field. The roots of plants grown from seeds with grey matrix were significantly shorter than of those grown from seeds with pink matrix. However, the length of leaves after 91 days from sowing only differed from the control group in the case of plants grown from seeds with grey and pink matrix.

Among seeds with higher vigour, longer roots compared to the control group plants after 75 days from sowing were found in plants grown from seeds treated with magnetic field and from stimulated seeds. The roots of these plants were longer than the roots of sugar beets grown from stimulated seeds treated with magnetic field. Plants grown from seeds with pink matrix had longer roots than plants grown from seeds with pink matrix treated with magnetic field. The length of plant leaves compared to the control group was significantly higher for plants grown from seeds of all combinations of seeds without a matrix and for seeds with pink matrix. The length of leaves grown from stimulated seeds and stimulated and treated with magnetic field was higher than in plants grown from seeds only treated with magnetic field. The length of sugar beet leaves grown from seeds with pink matrix was lower by about 4.2 cm from the length of sugar beet leaves grown from seeds with pink matrix and treated with magnetic field.

After 91 days from sowing, the control group plants had shorter roots than plants grown from seeds treated with magnetic field, stimulated and treated with magnetic field, and with grey matrix and treated with magnetic field. However, leaves of the control group plants were shorter than sugar beet leaves grown from stimulated seeds with grey and pink matrix treated with magnetic field. The leaves of plants only treated with magnetic field were shorter than leaves grown from stimulated seeds and from seeds that were stimulated and treated with magnetic field. Plants grown from seeds with grey matrix had longer leaves than plants grown from seeds with grey matrix treated with magnetic field. Plants grown from seeds with pink matrix gave opposite results.

Sugar beets grown from seeds with higher vigour compared to sugar beets grown from seeds with lower vigour had longer roots for plants grown from seeds treated with magnetic field after 75 days from sowing (by about 5.8 cm), or stimulated (by about 5.6 cm). However, the results were lower for sugar beets grown from seeds with pink matrix treated with magnetic field (about 10 cm). After 91 days from sowing, longer roots were observed for sugar beets grown from seeds treated with magnetic field (by about 3.4 cm), with grey matrix (by about 2.8 cm), with grey matrix treated with magnetic field (by about 6.4 cm), and with pink matrix treated with magnetic field (by about 1.6 cm).

Among sugar beets grown from seeds with higher vigour, longer leaves compared to the control group grown from seeds with lower vigour were observed in sugar beets grown from stimulated seeds (about 20.4 cm), with grey matrix (28.6 cm), and with pink matrix (about 6.4 cm). However, shorter leaves were observed in sugar beets grown from seeds with grey matrix and treated with magnetic field (by about 8.6 cm). After 91 days from sowing, shorter leaves were recorded in sugar beets grown from seeds treated with magnetic field (by about 3.2 cm), but longer leaves for plants grown from seeds with grey matrix (about 10.2 cm) and seeds with pink matrix treated with magnetic field (about 5.8 cm). The methods of seed conditioning had a positive influence on the length of roots but a negative influence on the length of leaves, and vice versa.

The field stand at the moment of harvest and the yields are shown in Table 10. It can be concluded that the field stand and its mass was low. The reason for the low yield was the loss of large numbers of seedlings several days after emergence. The seeds used in the experiments had sugar-beet black leg. In addition, during plant development in the field, unfavourable atmospheric conditions occurred: ground frost and long-term drought. The highest field stand at harvest time was for plants grown from seeds with lower vigour with pink matrix treated with magnetic field, at 30.25%. Whereas, the lowest were observed for sugar beets grown from seeds with lower vigour treated with magnetic field, at 10.50%. For seeds with lower vigour, treatment of seeds with magnetic field had a positive influence on the field stand grown from seeds with a matrix. In the case of seeds with higher vigour, a positive influence of seed treatment with magnetic field was only observable for plants grown from seeds with grey matrix. Because of the big differences in the field stand, the sugar beet crop was converted into the mass of one plant – the results are presented in Table 11. For sugar beets grown from seeds treated with magnetic field, the mass of roots converted into one plant was higher than in the case of plants where seeds were not exposed to this factor, both in the case of the control group seeds as well as stimulated seeds.

Table 10. Field stand at the moment of harvest – the number of sugar beet plants per piece in 400 sowing seeds and the yield of collected roots and leaves

Combinations	Seeds with lower vigour			Seeds with higher vigour		
	No. plants (%)	Roots (kg)	Leaves (kg)	No. plants (%)	Roots (kg)	Leaves (kg)
Control group	13.25	97.7	66.90	58	102	66.90
16 Hz	10.50	83.5	47.50	43	88.7	47.50
Stimulated	17.25	119.9	56.10	75	116.4	56.10
Stimulated + 16 Hz	14.50	119.9	39.60	45	77.6	39.60
Grey matrix	14.25	91.6	53.20	66	104.3	53.20
Grey matrix + 16 Hz	18.00	107.8	56.30	73	112.5	56.30
Pink matrix	16.00	100.4	73.20	78	136.3	73.20
Pink matrix + 16 Hz	30.25	131.3	87.70	76	122.7	87.70

T a b l e 11. Mass (kg) of roots and leaves converted into one plant

Combinations	Seeds with lower vigour		Seeds with higher vigour	
	Roots	Leaves	Roots	Leaves
Control group	1.84	1.26	1.76	1.55
16 Hz	1.99	1.13	2.06	1.14
Stimulated	1.74	0.81	1.55	0.88
Stimulated + 16 Hz	2.07	0.68	1.72	0.93
Grey matrix	1.61	0.93	1.58	0.87
Grey matrix + 16 Hz	1.50	0.78	1.54	1.07
Pink matrix	1.57	1.14	1.75	0.90
Pink matrix + 16 Hz	1.09	0.72	1.61	0.83

The mass of roots for plants grown from seeds treated with magnetic field was higher by about 0.15 kg for lower vigour and about 0.30 kg for higher vigour. The plants grown from stimulated seeds and treated with magnetic field gave higher crop of roots than plants grown from stimulated seeds, by about 0.33 kg (lower seed vigour) and about 0.17 kg (higher seed vigour). The mass of sugar beets grown from only stimulated seeds was lower than that of sugar beets grown from seeds not exposed to any conditioning methods, by about 0.10 kg for lower vigour and 0.21 kg for higher vigour.

For seeds with a matrix, in the case of sugar beets grown from seeds treated with magnetic field, the mass of roots, when converted into one plant, was lower than the mass of plant roots where seeds were not treated with magnetic field. Plants grown from seeds with pink matrix and treated with magnetic field gave the lowest yield of roots (1.09 kg). Roots of plants grown from seeds with higher vigour with grey matrix had a mass about 0.04 kg higher than from seeds with pink matrix. Roots of plants grown from seeds with grey matrix treated with magnetic field had a higher mass, by about 0.41 kg, than plants grown from seeds with pink matrix treated with magnetic field. The results were reversed for sugar beets grown from seeds with higher vigour. Roots of plants grown from seeds with pink matrix had a higher mass when converted into plants grown from seeds with a grey matrix. Both for plants grown from seeds with a matrix as well as with a matrix and treated with magnetic field, the mass was about 0.17 and 0.07 kg higher. The mass of sugar beet leaves grown from seeds treated with magnetic field was lower. Only plants grown from seeds with higher vigour and seeds with grey matrix treated with magnetic field had larger masses of leaves.

In the case of seeds without a matrix, the treatment with magnetic field had a positive influence on the mass of roots; at the same time, the mass of leaves was decreased. Except for sugar beets grown from seeds with higher vigour, stimulated and treated with magnetic field – the mass of leaves was increased. For sugar beets grown from seeds with a matrix and treated with magnetic field, both the mass of roots as well as the mass of leaves decreased.

The content of sugar in sugar beets was from 17.11 to 21.20% of the fresh mass (Table 12). Among plants grown from seeds with lower vigour, the lowest content of sugar was found in sugar beets grown from stimulated seeds, at 17.61%. The pre-sowing seed treatment with magnetic field had a positive influence on plants grown from stimulated seeds and treated with magnetic field, in which the content of sugar increased by about 3.17 % compared to plants that were not treated with magnetic field. Among plants grown from seeds with higher vigour, the lowest content of sugar was found in sugar beets grown from stimulated seeds and treated with magnetic field (lower by about 0.75 % than the control group) and lower by about 3.42 % than the content of sugar in plants grown from only stimulated seeds. However,

T a b l e 12. Content of sugar in sugar beets (% fresh mass)

Combinations	Lower vigour	Higher vigour
Control group	20.78	17.86
16 Hz	21.20	20.20
Stimulated	*17.61	*20.53
Stimulated + 16 Hz	19.70	17.11
Grey matrix	20.03	20.03
Grey matrix + 16 Hz	19.78	18.86
Pink matrix	20.03	*20.78
Pink matrix + 16 Hz	19.36	20.36
LSD	2.38	2.63

*Explanations as in Table 2.

a higher content of sugar was found in sugar beet grown from stimulated seeds and seeds with a pink matrix, at about 20.53 and 20.78%, respectively. Sugar beet grown from seeds treated with magnetic field and with a grey matrix had a higher content of sugar than the control group seeds – at about 2.34 and 2.17%, respectively. Among seeds with higher vigour, a positive influence on the content of sugar was found in stimulated seeds – a higher content of sugar by about 2.92%. In the case of sugar beets grown from the control group seeds, treated with magnetic field and stimulated and treated with magnetic field, sugar beets grown from seeds with lower vigour had a higher content of sugar than seeds with higher vigour - at about 2.95, 1, and 2.59 % respectively.

The seed biostimulation with magnetic field before sowing considerably increased the speed of the germination process, especially concerning seeds with low vigour. Among seeds without a matrix, the best were germinated stimulated seeds that were exposed to the effect of a magnetic field. The differences were generally lower in the extension of the germination process.

The results obtained by different authors confirmed the beneficial influence of a magnetic field with a low frequency has on the laboratory germination capacity (Aksyonov *et al*., 2001; Raciuciu *et al*., 2008a, b; Rochalska, 2001, 2008; Soltani *et al*., 2006) as well as the germination speed of a single seed (Gozdowski, 1999; Podlesny *et al*., 2004, 2005; Akira *et al*., 2004; Fischer *et al*., 2004; De Souza *et al*., 2006). Stimulation and treatment of a magnetic field obtains better effects than when applying these treatments separately (Soja *et al*., 2006). The magnetic field for sugar beet seeds is an effective 'agent' to improve vigour especially in seeds that are old or damaged (Rochalska, 2001; Pietruszewski and Wojcik, 2000; Pietruszewski and Wojcik, 2000; Pietruszewski *et al*., 2007; Rochalska and Orzeszko-Rywka, 2005).

In an excessively wet substrate, the germination of the matrix seeds stopped. Under this condition, the matrix spread and then created an oily mass plastered with seeds, which limited the supply of oxygen and seeds did not germinate. The reason for this could be the properties of materials which were used to create the matrix (Domoradzki, 2004). The plant seedlings were faster and more evened out than the control group seeds, which could have an impact on the yield rise as well as the field stand increasing the chance of seedlings to produce normal plants and yield.

CONCLUSIONS

1. The seed biostimulation with a low frequency magnetic field before sowing increases the germination capacity of sugar beet and shortens the speed of germination of single seed.

2. Seeds with lower vigour are more susceptible to the effect of magnetic field than seeds with higher vigour.

3. Magnetic field speeds up the ground germination rate of sugar beet.

4. Magnetic field increases the content of chlorophyll in leaves and growth of root mass during growing period and, as a consequence, results in the obtainment of higher yields.

5. Magnetic field has a positive impact on seeds without a matrix, increasing the sugar content in roots.

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