VERSITA

INTERNATIONAL
Agrophysics
www.international-agrophysics.org

Int. Agrophys., 2012, 26, 271-278
doi: 10.2478/v10247-012-0039-1

Effect of magnetic field on seed germination and seedling growth of sunflower

A. Matwijczuk, K. Kornarzyński, and S. Pietruszewski*

Department of Physics, University of Life Sciences, Akademicka 13, 20-950 Lublin, Poland

Received April 28, 2011; accepted September 7, 2011

A b s t r a c t. The impact of a variable magnetic field, magnetically treated water and a combination of both these factors on the germination of seeds and the final mass at the initial stage of growth sunflower plants was presented. Investigations were carried out in pots filled with sand, tin an air-conditioned plant house with no access to daylight using fluorescent light as illumination. A statistical significance positive impact was achieved for the samples subjected to the interaction of both stimulating factors simultaneously, the magnetic field and the impact of treated water several times on the speed of seed germination and final plant mass. Negative impacts were obtained for the majority of the test cases, for the magnetically treated water, the short duration of activity of the magnetic field and for the connection of the magnetic field and low-flow times.

K e y w o r d s: seed stimulation, magnetic field, magnetically treated water

INTRODUCTION

The most important roles play genetic and environmental factors in the normal process of germination and plant growth. A key role is also played by proper preparation before sowing, which applies to chemicals (seed dressing, growth regulators), scarification, seed stratification and physical factors: fixed and variable magnetic and electrical fields, microwave, ionizing and laser radiation), which usually positively affects germination and plant growth and the height of the yields obtained (Muszyński and Gładyszewska, 2008; Yi-Ping Chen *et al.,* 2005). Four types of fields were applied in the aim of studying the impact of magnetic fields on plants, their germination and growth: weak static fields, homogeneous magnetic fields (up to about 100 μT), with consideration to geomagnetic fields, strong homogeneous magnetic fields (of the order of mT to 1 T), strong inhomogeneous magnetic fields and low frequency magnetic fields (ELF) of mT order (Galland and Talon, 2005). The seeds of many crops were subjected to the activity of physical stimulating factors: onion seeds were stimulated with variable magnetic fields at a frequency of 50 Hz, the greatest yield growths and greatest chive lengths were obtained at a stimulation time of 15 s. For cabbage seeds and radish stimulated with variable magnetic fields at induction of B = 30, 60, and 100 mT for stimulation times from 4 to 60 s, a positive effect on germination rate and yields was obtained for induction of 30 mT (Kornarzyński *et al*., 2004).

Various ways of magnetically treating water are applied in practice, which means varying values of induction of magnetic fields, obtained with the aid of permanent magnets or electromagnets, various configurations of homogeneous and heterogeneous fields as well as various numbers of repetitions of the process (flow revalations) and water flow pressure (Coey and Cass, 2000). Water exposed to the activity of constant magnetic fields changes its conductivity, surface tension and pH (Fathi *et al.,* 2006). The studies demonstrated that the results achieved possess optimal values for specific parameters of magnetic water treatment, where for example a change of content of calcium ions in water depends on the length of the pathway in the field and the flow rate (Gabrielli *et al.,* 2001). Application for water disinfection of permanent magnetic and electrical fields causes a significant decrease of microorganismal and bacterial content (Biryukov *et al.,* 2005). Research carried out over the years concerning the possibility of the application of magnetically treated water in agriculture has generally been concerned with determining of its usefulness for improving seed germination and plant growth (Morejon *et al.,* 2007). Magnetically treated water has been utilized to improve yielding conditions of desert soil in Egypt with high salinity and calcification, where higher yields were obtained for tomato, pepper, maize and wheat (Hilal and Helal, 2003). Likewise, applying drinking water and water of varying salinity (NaCl content from 1 000 to 3 000 mg kg^{-1}) higher yields

*Corresponding author's e-mail: krzysztof.kornarzynski@up.lublin.pl

may be obtained for celery and white peas where the increase was similar to that of drinking water to that containing an admixture of salt (Maheshwari and Rewal, 2009).

The garden sunflower is a plant which is often utilized for laboratory testing due to its rapid growth, relatively simple construction and low environmental requirements. These properties facilitate observations and rendered them the choice of plants for this study. Research of various crops and their growth in terms of soil packing (Bayhan *et al.,* 2002), sowing date and its density for different conditions of hydration, access to light (Ferreira and Abreu, 2001), parasites (Grenz *et al.,* 2008) and stress conditions were conducted alongside the research of germination and growth of sunflowers. Sunflower kernels are a rich source of oil and may be used for food (Mamat *et al.,* 2005; Smith *et al.,* 2007), as ornamental flowers (Friedman *et al.,* 2007), as an admixture to diesel fuel as well as biodiesel in the form of methyl esters made from sunflower oil (Rashid *et al.,* 2008).

The aim of the experiment was to investigate the influence of a variable magnetic field at a frequency of 50 Hz, magnetically treated water at a constant field at induction of 150 mT, as well as both of these factors simultaneously on the physical characteristics of garden sunflower seedlings.

MATERIALS AND METHODS

Individual samples of seeds were subjected to the influence of a magnetic field and magnetically treated water, which passed between electromagnet pole pieces once, 3 and 10 times. Magnetic seed stimulation took place at a research post, where the seeds were placed between direct current electromagnetic pole pieces at a frequency of 50 Hz for durations of 15 and 30 s. The magnetic water treatment was carried out at a measurement post, where the water flew through a plastic tube placed between direct current electromagnet pole pieces at induction of 150 mT, through a segment length of $d = 0.15$ m, at a constant speed of $v = 0.55$ m s^{-1}.

Three series of measurements were performed, where series I consisted of samples subjected to the activity of varying magnetic fields. The influence of magnetically treated water was investigated in series II. Measurements in series III concerned the combination of both factors (Table 1).

The following markings will be applied in the remainder of the work: MF – variable magnetic field at induction of 30 mT, 15 and 30 s – time of magnetic field stimulation, MWT – magnetically treated water, *x* – revalations of water flow between electromagnetic pole pieces, *C* – control sample.

The investigations were carried out in pots filled with sand, in which 30 sunflower seeds were sown in each pot at a depth of 1 cm in three replications for each sample. The experiment was carried out in air-conditioned plant house without access sunlight, at an average temperature of 24°C and humidity maintained at 50-70%, in day-night conditions (16 h of day, 8 h of night), applying fluorescent light irradiation of about 100 μM m^{-2} s^{-1}. The seeds were watered one time just after sowing with a Hoagland medium at a basic concentration, and then, later in the experiment, watered with magnetized water an average of every two days. Sprouted

T a b l e 1. The parameters characterizing three series of experimental samples

Parameters	Sample	Stimulation time (s)	Revalations of water flow between electromagnetic pole pieces
		Series I	
Varying magnetic field at induction B = 30 mT	P1	15	-
	P2	30	-
	P3	Control sample	-
	P4	-	1
		Series II	
Magnetically treated water	P5	-	3
	P6	-	10
	P7	-	Control sample
	P8	15	1
		Series III	
Combination of both factors: varying magnetic field at induction B = 30 mT and magnetically treated water	P9	15	3
	P10	15	10
	P11	30	1
	P12	30	3
	P13	30	10
	P14	Control sample	

seeds were counted daily by counting the germs which were not removed and which grew to the end of the study, at which time they were cut and weighed as the final mass.

Logistic function has been applied for the mathematical description of seed germination (Torres and Frutos, 1990). The capability of seed germination, N_k (%), was calculated on the basis of the results obtained according to the formula:

$$N_k = \frac{n_k}{n_c} 100\%, \qquad (1)$$

where: n_k – specifies the total number of germinated seeds of a given sample, n_c – the total number of seeds sown. The value of germination rate S_k (% h^{-1}) of studied seeds was calculated on the basis of the relationship:

$$S_k = \frac{n_{max}}{\Delta t}, \qquad (2)$$

where: n_{max} – the maximum percentage of the number of germinated seeds recorded during the counting for the interval time Δt between two successive countings.

The logistic function applied in the work possessed characteristic points and coefficients, thanks to which it is possible to compare and describe the various characteristics:

$$N_T = N_K [1 + exp(\beta - K_t)]^{-1}, \qquad (3)$$

where: N_T – number of seeds that sprouted in the time t (%), N_K – number of final germinated seeds obtained by modeling (germination capability, %), β and K – coefficients, t – time. It is possible to mark the important parameters characterizing the germination process through the application of this version of logistic curve function: $t_{\beta K}$ – time of obtaining the point of inflection of logistic curve ($t_{\beta k} = \beta$/K), $N_{\beta K}$ – the number of seeds germinated for logistical point of inflection of the curve, v_{max} – maximal rate of germination for point of inflection of logistic curve the ($v_{max} = N_K \frac{1}{4}$K).

The Grapher program was utilized for the mathematical description. A variation coefficient (%) being the ratio of standard deviation and mean value of the ability to germinate seeds of stimulated sprouts at a given temperature was also utilized to assess the impact of selected factors. The variation coefficient is a measure of diversity and distribution characteristics and determines the absolute differences, thus is a relative measure dependant on the size of the arithmetic mean. The analysis of results of a level statistical significance was explored with the help of the Tukey test in relation to control sample, for level significance $p \leq 0.05$.

RESULTS AND DISCUSSION

Figures 1-3 present the germination of sunflower seeds, where the points on the graphs are the actual number of seeds germinated at a given time obtained from the counting. The various curves are the effect of logistic function fitting to measurement points with the aid of a computer program.

Table 2 shows the experimental data of kinetics of sunflower seed germination. The highest germination capacity, exceeding 90%, were possessed by samples P2 (MF 30 s), P5 (MWT 3x), P7 (C, MWT), P9 (MF 15 s, MWT 3x) and P12 (MF 30 s, MWT 3x), the lowest, below 80% – samples P1 (MF 15 s), P6 (MWT 10x), P11 (MF 30 s, MWT 1x) and P14 (C MF and MWT).

However, the relative seed germination capacity was highest for samples P2 (MF 30 s), P8 (MF 15 s, MWT 1x), P9 (MF 15 s, MWT 3x), P10 (MF 15 s, MWT 10x), P12 (MF 30 s, 3x, MWT) and P13 (MF 30 s, 10x, MWT) for which a positive effect of stimulating factors was obtained. This confirms the results obtained for other seeds, where the positive impact of stimulation with a variable magnetic field at induction of 30 mT, frequency of 50 Hz and activity time of 15-30 s for the majority of applied doses was confirmed. These results were obtained wheat – grain, where yield increases were obtained around twenty, 30% for different times of stimulation and varieties of wheat (Kornarzyński and Pietruszewski, 2005; Muszyński *et al.,* 2009).

Negative impact, being the lowest values occurred for P1 (MF 15 s), P4 (MWT 1x) and P6 (MWT 10x). So with the exception of sample P1, the negative effect concerned samples watered with magnetically treated water without magnetic field stimulation (Table 2).

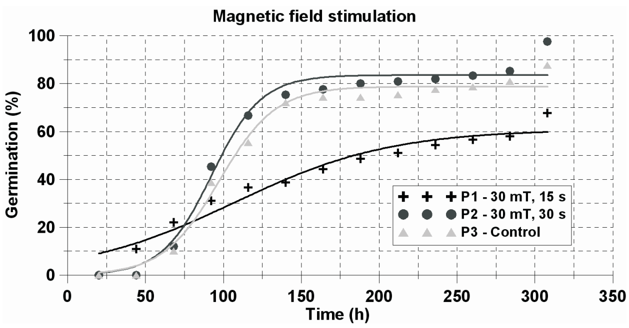


Fig. 1. Germination of sunflower seeds subjected to the activity of a variable magnetic field.

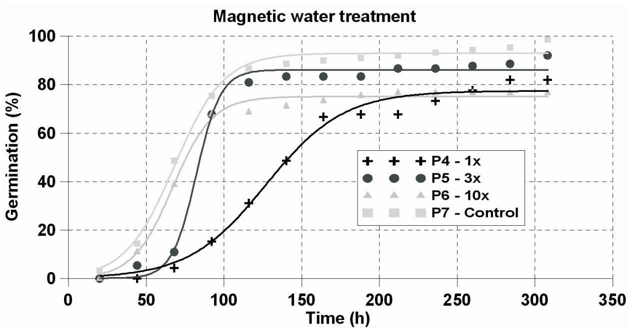
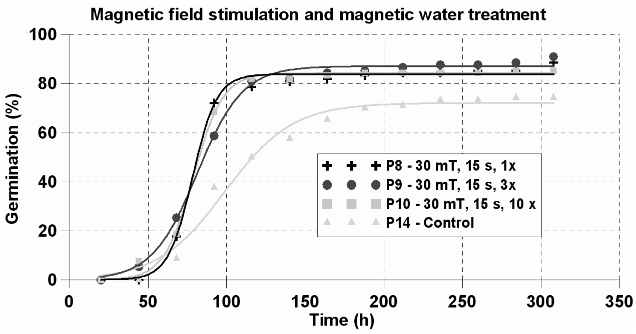


Fig. 2. Germination of sunflower seeds watered with magnetically treated water.

a



b

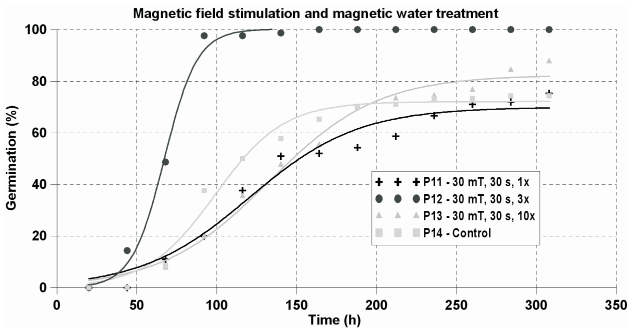


Fig. 3. Germination of sunflower seeds subjected to the activity of a variable magnetic field for: a – 15 s, and b – 30 s, and watered with magnetically treated water.

T a b l e 2. Germination of sunflower seeds

Sample	Final number of germinated seeds	Germination capacity (%)	Variation coefficient of germination capacity (%)	Relative germination capacity of seeds
		Series I		
P1	20.3±1.2	67.7	5.9	0.772*
P2	29.3±0.9	97.7	3.1	1.114
P3	26.3 1.1	87.7	4.2	-
		Series II		
P4	24.6±1.3	82.0	5.3	0.831*
P5	27.6±1.5	92.0	5.4	0.932
P6	23.0±1.9	76.7	8.3	0.777*
P7	29.3 0.7	98.7	2.3	-
		Series III		
P8	26.6±0.8	88.7	1.9	1.194*
P9	27.3±1.2	91.0	4.4	1.225*
P10	25.6±1.5	85.3	5.8	1.148*
P11	22.6±1.5	75.3	6.6	1.013
P12	30.0±0.0	100.0	0.0	1.346*
P13	26.3±0.9	87.7	3.4	1.180
P14	22.3±0.7	74.3	3.1	-

*Samples of statistical significance were marked. Explanations of the names of samples are describes in the Table 1.

Relative capacity of seed germination was also highest for seeds treated with simultaneously subjected to magnetic field stimulation and watered with magnetically treated water samples stimulated for 15 and 30 s, for higher flow revalations 3x and 10x. Studies conducted by other authors, upon magnetic water treatment with the application of water flow magnetizers allowed for the achievement of improved emergence, a significant boost in seed yields (Carbonell *et al.,* 2004). For ground tomato seeds, in studies on Petri dishes and pickles during potting trials (Pietruszewski *et al.,* 2007), the best results were also obtained for induction B = 150 mT at 3 and 10 times the number of flows between electromagnet pole pieces.

For final plant masses subjected to the activity of the stimulation, the greatest relative plant mass, being positive effect (relative to control samples) was achieved for samples P2 (MF 30s), P5 (MWT 3x), P8 (MF 15 s, MWT1x) P9 (MF 15 s, MWT 1x) and P12 (MF 30 s, MWT 3x), lowest for P1 (MF 15 s), P4 (MWT 1x), P6 (MWT 10x) and P11 (MF 30 s, MWT 1x) (Table 3).

Masses of samples after conversion to one plant, the highest exceeding 0.6g was achieved for P1 (MF 15 s), P4 (MWT 1x), P5 (MWT 3x), P9 (MF 15 s, MWT 3x) and P12 (MF 30 s , MWT 3x). The lowest levels of 0.5 g and lower were obtained the P3 (MF C) and P11 (MF 30 s, MWT 1x). Whereas for the relative masses of the samples converted to one plant (obtained after conversion to one plant, relative to control samples), the highest values were achieved by samples: P1 (MF 15 s), P2 (MF 30 s), P4 (MWT 1x), P5 (MWT 3x), P9 (MF 15 s, MWT 3x) and P12 (MF 30 s, MWT 3x), the lowest: P6 (MWT 10x) and P11 (MF 30s, MWT 1x), being similar to those for masses samples converted to one plant.

There is no complete and uniform theory explaining the function of magnetic fields on the property changes of water. Literature provides only a hypothetical mechanism of this phenomenon, where, according to one theory, there occurs polarization of external electron shells of water molecules and ions under the influence of the magnetic field, which changes the conditions of hydration of ions, which may serve as crystallization germs upon disruption of the hydration shell. Theories which attempt to explain the biological effects of the activity of electromagnetic fields have been based on their possible impact on the permeability of ion channels in the membrane, which may affect the transport of ions into the cells and lead to biological changes in the organism. Another possible effect relates to the formation of free radicals in cells as an effect of the field. Variable magnetic fields may affect the biological functions of organisms through changes of hormone concentrations, changes of enzyme functions or of transport of ions through the cell membrane and through changes in DNA synthesis or transmission (Strasak *et al.,* 2002). If we are dealing with electrical anisotropy of the structure of plant tissues and cells, the magnetic field affects the work of ion pumps for the transport of Ca^{2+} ions (Piacentini *et al.,* 2001).

Magnetically treated water may cause an increase in permeability of cell membranes in the seed, acting on calcium ions and inhibiting the growth of harmful microorganisms for the seed germination and plant growth processes. This may be a result of Lorenz force activity on ions contained in water, which causes their momentary polarization in concord with the external magnetic field. This may have an effect on the transport of ions through cell membranes – upsetting the balance of ion concentration in the cell and changes of intracellular pH. Magnetic water treatment also causes increasing of electrical conductivity and decreasing of surface tension. Applying the 'free dipole' model, in which Lorenz strength acts in the magnetic field, causing the

T a b l e 3. Final plant mass obtained after germination

Sample	Final mass (g)	Variation coefficient of masses (%)	Relative final mass	Mass of samples after conversion to a single plant (g)	Relative mass of the samples after conversion to a single plant
			Series I		
P1	12.66±1.03	8.14	0.951	0.624	1.233*
P2	16.53±1.56	9.44	1.242*	0.564	1.115
P3	13.31±1.22	9.17	-	0.506	-
			Series II		
P4	16.12±0.98	6.08	1.021	0.655	1.229*
P5	16.87±0.97	5.75	1.069	0.611	1.146*
P6	12.69±0.91	7.17	0.804*	0.552	1.036
P7	15.78±1.10	6.97	-	0.533	-
			Series III		
P8	15.91±1.07	6.73	1.090	0.598	1.079
P9	17.54±1.23	7.01	1.202*	0.642	1.126
P10	15.18±0.99	6.52	1.040	0.593	1.070
P11	8.58±0.81	9.44	0.588*	0.380	0.686*
P12	18.84±1.62	8.59	1.291*	0.628	1.134
P13	15.34±1.32	8.60	1.051	0.583	1.052
P14	14.59±1.28	8.77	-	0.554	-

*Explanations as in Table 1.

polarization of the water molecules, it is possible to explained the changes in water properties and impurities contained therein, and the activity of microorganisms present in the water having an impact on seed germination of and plant development (Biryukov *et al.,* 2005).

The largest value of the maximum rate of germination, v_{max}, achieved thanks to logistic curve modeling for interaction with magnetic field occurred for sample P2 (MF 30 s), while for P1 (MF 15 s) it was the lowest, where the impact on germination rate was negative relative to the control sample (Table 4). In the case of seeds watered with magnetically treated water, the highest value v_{max} was achieved for sample P5 (MWT 3x), and the smallest for P4 (MWT 1x). For samples subjected to the activity of a variable magnetic field for 15 s and watered with magnetically treated water, the highest value v_{max} occurred for P8 (MF 15 s, MWT 1x), whereas for stimulation time of 30 s, the highest value v_{max} occurred for P12 (MF 30 s, MWT 3x), and the smallest for P11 (MF 30 s, MWT 1x). No stimulus impact was observed for the remaining samples.

The dependence of sunflower seed germination rates was obtained on the basis of Eq. (2) as a function of time (Figs 4-6).

Table 5 contains the maximum rate of seed germination $S_{k\ max}$ read from the graphs $S_k = f(t)$ and durations of their obtainment t_{kmax}. The accuracy of the reading of the maximum rate value came out to 0.05% h^{-1}, obtainment – 2 h.

Two methods were applied to determine the maximum rate of sunflower seed germination: with the aid of logistic curve modeling, and reading from the chart of germination rates as a function of time, obtained from direct measurements (Tables 4, 5). Maximum values correspond to the germination rates of samples P2, P5, P8, P9 and P12 for both methods, where the highest values were obtained, and P1, P4 and P11, where the lowest values were obtained, although reaching different values. Results do not overlap only in the case of sample P13. This means that both methods for determining germination rates are satisfactory, and in the case of the logistic curve application it is not necessary to perform graph correlations.

The results for final number of germinated seeds, seed germination ability relative to control samples, final plant masses of products and relative masses of the samples, after conversion to one plant, relative to the control samples achieved positive impact of stimulation for P2 (MF 15 s), P5 (MWT 3x), P9 (MF 15 s, MWT 3x) and P12 (MF 30 s, MWT 3x), which (except P8) achieved a maximum seed germination rate. Negative impact was obtained for P1 (MF 15 s), P6 (MWT 10x) and P11 (MF 30 s, MWT 1x), which is also negative for the sample mass after conversion to a single plant, where the lowest rate of germination was obtained for samples P1 and P11. While relative ability of seed germination in relation to the control samples and relative sample masses, after conversion to one plant, in relation to the control samples was positive for samples P2 (MF 15 s), P8

T a b l e 4. Presents the parameters characterizing the germination of sunflower seeds obtained from the logistic curve modeling

Sample	N_K (%)	β	K (h^{-1})	T_{pk} (h)	$N_{\beta/K}$ (%)	V_{max} (% h^{-1})	R^2
			Series I				
P1	60.82	2.149	0.020	107.45	36	0.304	0.951
P2	83.52	5.786	0.063	91.84	45	1.315	0.978
P3	78.74	5.378	0.055	97.78	43	1.082	0.986
			Series II				
P4	77.32	5.116	0.040	127.9	37	0.773	0.988
P5	86.05	10.496	0.127	82.64	47	2.732	0.992
P6	75.00	5.269	0.078	67.55	38	1.462	0.992
P7	92.87	4.308	0.063	68.38	48	1.463	0.993
			Series III				
P8	83.79	10.034	0.128	78.39	44	2.681	0.995
P9	87.03	5.620	0.069	81.45	46	1.501	0.996
P10	75.00	5.268	0.079	66.68	18	1.481	0.992
P11	69.85	3.553	0.029	122.52	43	0.506	0.969
P12	100.00	6.557	0.097	67.59	48	2.425	0.995
P13	75.00	5.269	0.078	67.55	7	1.462	0.992
P14	92.87	4.309	0.063	68.39	8	1.462	0.993

Explanations as in Table 1.

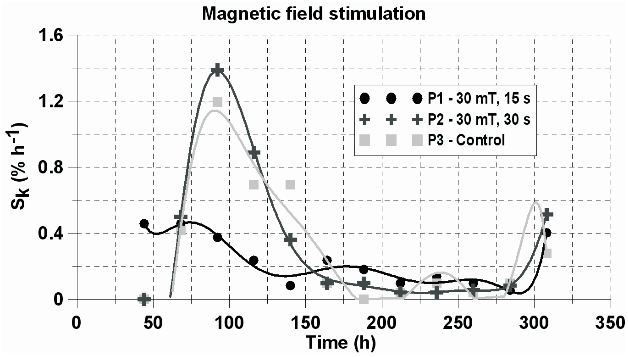


Fig. 4. Germination rate of sunflower seeds subjected to the activity of a variable magnetic field.

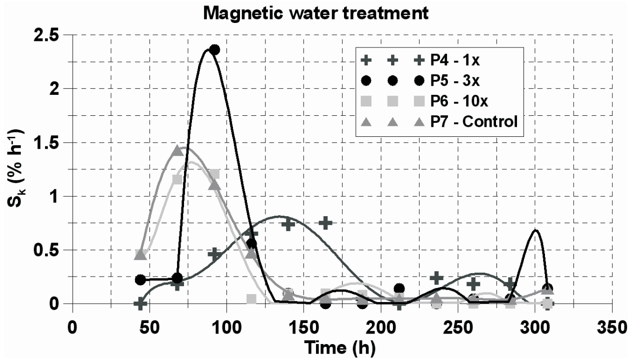


Fig. 5. Germination rate of sunflower seeds watered with magnetically treated water.

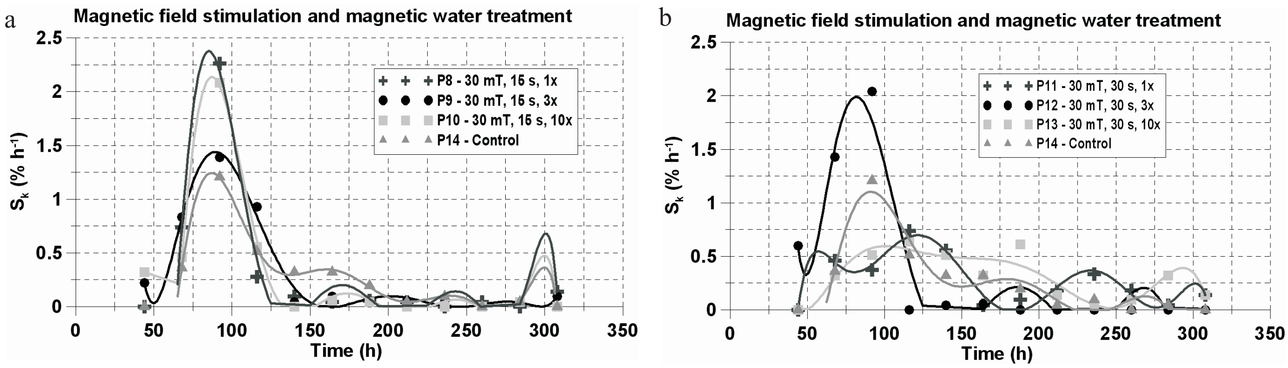


Fig. 6. Germination rate of sunflower seeds subjected to the activity of variable magnetic field for: a – 15 s, and b – 30 s, watered with magnetically treated water.

T a b l e 5. Maximum value of sunflower seed germination rate and obtainment time

Series	Sample	$S_{k\,max}$ (% h^{-1})	t_k (h)
I	P1	0.45	68
	P2	1.40	95
	P3	1.20	92
II	P4	0.80	155
	P5	2.40	92
	P6	1.25	85
	P7	1.45	72
III	P8	2.25	92
	P9	1.40	92
	P10	2.05	92
	P11	0.75	120
	P12	2.05	88
	P13	0.65	116
	P14	1.20	92

Explanations as in Table 1.

(MF 15 s, MWT 1x), P9 (MF 15 s, MWT 3x), P10 (MF 15 s, MWT 10x) and P12 (MF 30 s, MWT 3x). It means that positive effects were achieved for these same stimulations, in terms of both impact, both germination ability and final sample mass. In most cases this relates to positive effects of combining both stimulations.

For magnetically treated water, the short duration of activity of the magnetic field for the combining of the magnetic field and low revelations of MWT obtained a negative effect for most of the indicators characterizing sunflower seed germination and plant growth.

CONCLUSIONS

1. It may be asserted that for the same doses of stimulation, a positive impact was achieved on both germination capacity and final sample masses. In most cases this relates to the positive effect of a combination of both factors, being the magnetic field and the activity of magnetically treated water.

2. For seeds watered with magnetically treated water, the short duration of magnetic field activity and the combination and magnetic field and low revelations of MWT, a negative effect was obtained for most of the indicators characterizing sunflower seed germination and plant growth.

REFERENCES

Bayhan Y., Kayisoglu B., and Gonulol E., 2002. Effect of soil compaction on sunflower growth. Soil Till. Res., 68, 31-38.

Biryukov A.S., Gavrikov V.F., Nikiforov L.O., and Shcheglov V.A., 2005. New physical methods of disinfection of water. J. Russian Laser Res., 26, 1, 1913-1925.

Carbonell M.W., Martinez E., Diaz J.E., and Florez M., 2004. Influence of magnetically treated water on germination of signal grass seeds. Seeds Sci. Technol., 32, 617-619.

Coey J.M.D. and Cass S., 2000. Magnetic water treatment. J. Magnetism Magnetic Materials, 209, 71-74.

Fathi A., Mohamed T., Claude G., Maurin G., and Mohamed B.A., 2006. Effect of magnetic water treatment on homogeneous and heterogeneous precipitation of calcium carbonate. Water Res., 40, 1941-1950.

Ferreira A.M. and Abreu F.G., 2001. Description of development, light interception and growth of sunflower at two sowing dates and two densities. Mathematics Comp. Simulation, 56, 369-384.

Friedman H., Bernstein N., Bruner M., Rot I., Ben-Noon Z., Zuriel A., Zuriel R., Finkelstein S., Place N., and Hagiladi A., 2007. Application of secondary-treated effluents for cultivation of sunflower (*Helianthus annuus* L.) and celosia (*Celosia argentea* L.) as cut flowers. Scientia Hort., 115, 62-69.

Gabrielli C., Jaouhari R., Maurin G., and Keddam M., 2001. Magnetic water treatment for scale prevention. Water Res., 35(13), 3249-3259.

Galland P. and Talon A., 2005. Magnetoreception in plants. J. Plant Res., 118, 371-389.

Grenz J.H., Istoc V.A., Manschadi A.M., and Sauerborn J., 2008. Interactions of sunflower (*Helianthus annuus*) and sunflower broomrape (*Orobanche Cumana*) as affected by sowing date, resource supply and infestation level. Field Crops Res., 107, 170-179.

Hilal M.H. and Helal M.M., 2003. Application of magnetic technologies in desert agriculture. Seed germination and seedling emergence of some crops in a saline calcareous soil. Proc. II Int. Conf. Impact of electromagnetic fields in the agricultural environment, Agrolaser, September 8-10, Lublin, Poland.

Kornarzyński K. and Pietruszewski S., 2005. The effect of large doses of alternating magnetic fields on seed germination of durum wheat (in Polish). Acta Scientiarium Polonorum, Technica Agraria, 4(2), 11-20.

Kornarzyński K., Pietruszewski S., and Segit Z., 2004. Preliminary studies of variable magnetic field on the growth rate of wheat germ (in Polish). Acta Agrophysica, 112, 521-528.

Maheshwari B.L. and Rewal H. S., 2009. Magnetic treatment of irrigation water: Its effects on vegetable drop field and water productivity. Agric. Water Manag., 96, 1229-1236.

Mamat H., Aini I.N., Said M., and Jamaludin R., 2005. Physicochemical characteristics of palm oil and sunflower oil blends fractionated at different temperatures. Food Chem., 91, 731-736.

Morejon L.P., Castro Palacio J.C., Velazquez Abad L., and Govea A.P., 2007. Simulation of *Pinus Tropicalis* M. seeds by magnetically treated water. Int. Agrophysics, 21, 173-177.

Muszyński S., Gagoś M., and Pietruszewski S., 2009. Short-term pre-germination exposure to ELF magnetic field does not influence seedling growth in durum wheat (*Triticum durum*). Polish J. Environ. Study, 18(6), 1065-1072.

Muszyński S. and Gładyszewska B., 2008. Representation of He-Ne laser irradiation effect on radish seeds with selected germination indices. Int. Agrophysics, 22, 1-7.

Piacentini M.P., Fraternale D., Piatti E., Ricci D., Vetrano F., Dacha M., and Accorsi A., 2001. Senescence delay and change of antioxidant enzyme levels in *Cucumis sativus* L. efoliated seedlings by ELF magnetic fields. Plant Sci., 161, 45-53.

Pietruszewski S., Kornarzyński K., and Łopucki M., 2007. The magnetic water, some of its physical characteristics and uses (in Polish). Przegląd Telekomunikacyjny, 80(8-9), 675-682.

Rashid U., Anwar F., Moser B.R., and Ashraf S., 2008. Production of sunflower oil methyl esters by optimized alkali-catalyzed methanolysis. Biomas Bioenergy, 32, 1202-1205.

Smith S.A., King R.E., and Min D.B., 2007. Oxidative and thermal stabilities of genetically modified high oleic sunflower oil. Food Chem., 102, 1208-1213.

Strasak L., Veterl V., and Smarda J., 2002. Effects of low-frequency magnetic fields on bacteria *Escherichia coli*. Bioelectrochem., 55, 161-164.

Torres M. and Frutos G., 1990. Logistic function analysis of germination behaviour of aged fennel seeds. Environ. Experim. Botany, 30(3), 383-390.

Yi-Ping Chen, Ming Yuea, and Xun-Ling Wanga, 2005. Influence of He-Ne laser irradiation on seeds thermodynamic parameters and seedlings growth of *Isatis indogotica*. Plant Sci., 168, 601-606.