Int. Agrophysics, 2007, 21, 95-100

INTERNATIONAL
Agrophysics
www.ipan.lublin.pl/int-agrophysics

Electromagnetic fields and electromagnetic radiation as non-invasive external stimulants for seeds (selected methods and responses)

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Received October 3, 2006; accepted January 25, 2007

A b s t r a c t. Results obtained in research on the effects of EMF (electromagnetic field) and EMR (electromagnetic radiation) on seeds and seedlings show that it is still impossible to draw coherent conclusions. The seed is an extremely complex system, and its state cannot always be controlled. Biological processes proceed in parallel and they may react in different directions to an EMF stimulus. Therefore, the fundamental role of the researcher is selection of biological material for the investigations and also of appropriate external conditions for running them. This work focuses on some essential factors that must be considered during the experiments. The knowledge of the parameters of seeds (moisture content, growth rate, storage period) and EMF (field strength, frequency, time of exposure, polarity) as well as environmental parameters (temperature, light, moisture content of soil) is necessary to understand the correlations between the physiology and cytology of the growing seedlings and the electromagnetic stimulus. The classification of parameters and quantities which are determined during the research of the influence of electromagnetic and laser treatment of seeds and some basic equations determining the dose of EMF or EMR absorbed by seeds are also presented.

K e y w o r d s: pre-sowing stimulation, magnetic field, electric field, laser radiation

INTRODUCTION

The magneto- and electrobiology are disciplines which are specialized in investigation of the influence of electromagnetic fields (EMF) on biological systems. It is well known that magnetic fields produce biochemical, physical and physiologic changes in cell structures (Wadas, 1992). Due to rapid technological development it is necessary to explore the influence of artificially inducted electromagnetic radiation (EMR), affecting human beings not only directly, but also, as its indirect impact through the environment, especially in agriculture, is still unknown, how EMF affects humans indirectly *ie* via food. The observations the plants growing close to the antenna near-field suggested that electric field did not affect the normal vegetative pattern (Schwan, 1972), but a survey of the plant life near high-voltage transmission lines showed that EMF fields caused a slight influence on plant growth (Hart and Marino, 1977).

Currently there are three main directions of experiments concerning the examination of the influence of EMF on plants. Some scientists are exploring the impact of extremely strong fields (Morgan *et al.,* 2000), others are examining plants growth in absence of the Earth's magnetic field (Negishi *et al.,* 1999). Most of the researchers are studying the influence of EMF and EMR which could be easily generated for various purposes, including future agriculture applications of alternating low magnetic field (LMF).

EMR at very high energies and very short wavelengths, like X-rays and gamma rays, can cause ionization or physical damage to matter that it strikes. X-rays and gamma rays produce effects in living systems because the energy carried by this radiation is so large that it can break molecular bonds and damage cells. The EMF and EMR part of the electromagnetic spectrum discussed here is called non-ionizing radiation because it does not cause physical disruption upon impact with matter, but may, in some situations, cause some types of biological effects. The energy carried in LMF (50 Hz alternating fields) is much too low to break molecular or chemical bonds. Microwaves also do not carry enough energy to break chemical or molecular bonds, but they are absorbed by the water in tissues where they can also set up strong currents, which causes heating of the tissue. While 50 Hz fields can also set up currents in tissues, these currents are much weaker. The amount of heat they generate is negligible compared to the natural heat that comes from the cells of the body. The effects of exposure of seeds to LMF arise from

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non-thermal reactions – 50 Hz is a frequency of many enzymatic reactions and can stimulate the biosynthesis 'stress response' in cells. *In vitro* studies have shown changes in the activity of enzymes as well as stimulation of biosynthetic processes that involve RNA polymerase (Marino and Becker, 1977; Blank, 1995) and free radicals (Gładyszewska, 1998). LMF greatly speeds up the release of enzymes from the bound state and the release of seeds from the dormant state. H-NMR studies have shown that electric polarization of membrane structures of several tissues led to abnormal accumulation of water and the hydration of macromolecules during the imbibition process, which led to irregular organization of tissue structures (Isobe *et al.,* 1999).

Both magnetic and electric fields have been shown to stimulate the same reactions, with similar amplitude, frequency and time dependence. The only – but significant – difference is that the energy needed to induce stimulation with magnetic field is about one thousand times lower than the energy needed with an electric field (Blank, 1995). Changes in cell synthesis, especially in protein synthesis, activated by LMF are similar to those inducted by cellular stress called 'heat shock'. But energy needed to start protein transcription form magnetic field is many orders of magnitude lower than energy needed for thermal stimulation. Biosynthesis response to LMF is similar to cellular response to heat and other physical stress, only cells respond to EMF at very low energy densities. Hirano *et al.* (1998) demonstrated that weak magnetic field had a positive effect on the growth and photosynthesis of the cyanobacterium *Spirulina platensis*, but at a strong field the growth and photosynthesis was inhibited.

The results obtained in research on the effects of EMF and EMR on seeds and seedlings show that it is still impossible to draw coherent conclusions. By analysing results obtained for pre-sowing stimulation of seeds, it is clear that static and variable magnetic field may have a positive, but mostly temporary and impermanent effect on the percentage of germination, growth speed and germination rate (Kornarzyński *et al.,* 2004; Carbonell *et al*., 2000; Pietruszewski, 1993; Pittman, 1977), making EMF and EMR non-invasive external stimulants for seeds. Germination is assumed to be dependent on the concentration of active phytochrome P_r. It is generally supposed that laser effect on the germination capacity may be related to the red light inducted photoinversion of passive phytochrome P_{fr} into its active form P_r (Bewley and Black, 1985). The crop yield increase could also be related to the sterilizing effect of applied stimulants (Wilczek *et al.*, 2005).

In the case of alternating magnetic field, a positive influence on seeds and seedlings of wheat in the first period of germination is observed for almost all values of the magnetic induction applied. Magnetic treatment not only increased yields, but also the percentage of gluten and starch (Bhatnagar and Deb, 1977; Frydemberg and Nielsen, 1965). The results show that bean sprouts growing in an electric field have a better growth rate of the height of stems and the length of roots in comparison to non-exposed seeds (Kiatgamjorn *et al.,* 2002).

PLANNING THE EXPERIMENT

For useful adaptation of those effects for agriculture purposes a systematic essential study is necessary to create a uniform model of all experiments. In previous years numerous methods have been adopted by different scientists in experimentation with pre-sowing EMF stimulation. They used a range of different types of magnets, coils, lasers and EMF generators. To make all of the experiments more coherent, several basic factors should be taken into account, relating to physical parameters of EMF, as well as to physiological and biochemical properties of seeds, such as auxin effect, vigour, respiration rate, heat loss (Lebiedev *et al.,* 1975; Phirke *et al.,* 1996b). This would suggest that the response to EMF treatment may only occur under specific environmental conditions, as yet not clearly known, and that makes the mechanism of influence of artificial electromagnetic fields on plants still unknown.

The organism is an extremely complex system, and its state cannot always be controlled. Biological processes proceed in parallel and they may react in different manner to an EMF stimulus. Therefore, the fundamental role of the researcher is to make a choice of the biological material for the investigations and all of the external conditions for running them. Figure 1 shows a list of some essential factors that must be considered during the experiments, as proposed by Phirke (1996a). The knowledge of the parameters of seeds and EMF is necessary to understand the correlation between the physiology and cytology of the growing seedlings and the electromagnetic stimulus. Future research response to EMF or EMR occurs. Seed could be treated at different combinations of field strength and seed exposure time. For example, increasing magnetic field strength was found to be more effective than increasing seed exposure time in improving the yield of wheat, soybean and cotton when grown in the field (Phirke, 1996b).

CALCULATION OF THE PHYSICAL PARAMETERS OF EM FIELDS

The first step before the stimulation is the determination of the dose of EMF or EMR which is absorbed by seeds. The electric field intensity E_{av} of an ideal homogeneous field can be calculated as follows (Kiatgamjorn *et al.,* 2002):

$$E_{\max} = \frac{U}{d\eta}, \tag{1}$$

$$\eta = \frac{E_{av}}{E_{\max}} \le 1, \tag{2}$$

$$E_{av} = \frac{U}{d}, \quad (3)$$

where: U – voltage between electrodes (V), d – distance between electrodes (m), $E_{\max}$ – the maximum value of electric field intensity (V m^{-1}), E_{av} – average value of electric field intensity (V m^{-1}), η – field utilization factor, η being dependent on the geometry of the electrodes. When the seeds are placed between the electrodes, the magnitude of electrostatic fields drops by the value of dielectric permittivity of the seeds ε_{Seed}, which is determined by the composition and structure of the seed tissues. The actual permittivity is then calculated by multiplying the relative permittivity by electric constant ε_0 (vacuum permittivity):

$$\varepsilon = \varepsilon_0 \varepsilon_{Seed} = \varepsilon_0 \left(1 + \chi_{Seed}\right), \quad (4)$$

where: χ_{Seed} is the electric susceptibility of the seed. The displacement field inside the seeds, which accounts the for the effects of bound charges within the material, is defined by the relation:

$$D = \varepsilon_0 \left(1 + \chi_{Seed}\right) E_{av}. \quad (5)$$

Magnetic field intensity could not be easily calculated from similar equations, and magnetic strength must me measured manually by a teslameter at the seeds level (Pietruszewski, 1999). Electric (ρE) and magnetic (ρM) field energy densities are defined as:

$$\langle \rho_E \rangle = \frac{1}{2} \varepsilon_0 E_m^2, \quad (6)$$

$$\langle \rho_M \rangle = \frac{1}{2} \mu_0 H_m^2, \quad (7)$$

where: E_m – electric field intensity (V m^{-1}), H_m – magnetic field intensity (T), μ_0 – magnetic constant (the permeability of vacuum). The absolute exposure dose $D_{\exp}$ is described as follows:

$$D_{\exp} = \rho\, t, \quad (8)$$

where: ρ – electric or magnetic field energy density, t – time of exposure (s).

Similar calculations can be made when calculating the stimulus energy of laser irradiation. In the most popular methods of laser stimulation, irradiated seeds are moved under the divergent laser beam (Koper *et al.,* 1997). The stimulus radiation is He-Ne laser red light (wavelength λ = 632 nm). When the seed is moving through the exposure area with a constant speed, energy reaching the seed can be calculated form the following equation (Gładyszewska 1998):

$$E = S \frac{\sqrt{2\pi}}{v} \sigma P_{\max}, \quad (9)$$

where: E – energy of laser irradiation reaching each seed (J), S – surface area of exposed seed (m^2), v – velocity of the seeds (m s^{-1}), σ – standard deviation of laser power distribution in exposure area, $P_{\max}$ – the maximum value of laser power (mW).

After selection of the radiation dose, clear and concise goals and methods of research must be chosen. Figure 2 shows the scheme of those experiments (Pietruszewski *et al.,* 2004). It contains all the steps of study which must be determined to make it possible to draw complete and clear conclusions about the influence of selected radiation dose or electromagnetic field strength on examined seeds.

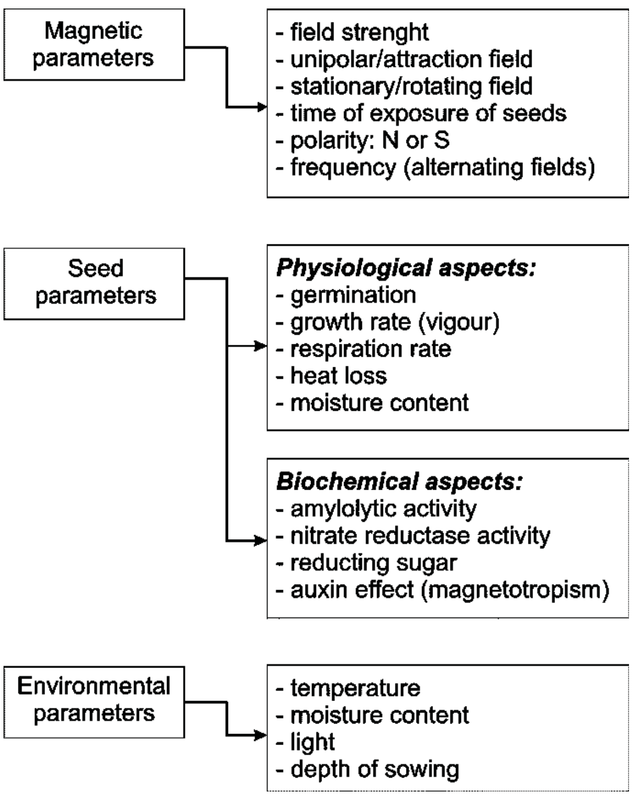

Fig. 1. List of the basic parameters that must be considered during magnetic stimulation.

RESULTS

It must be emphasized that the application of those stimuli not always positively affects plants, and they may cause a decrease of the quality of the sowing material. Table 1 shows results obtained in a study on the effect of pre-sowing stimulation with He-Ne laser light on the yield of two varieties of white lupine seeds (Koper and Dziwulska, 2003). The research was undertaken on two varieties of white lupine: Bardo and Katon. The effect of laser treatment depends on the variety of lupine, but for all of the examined indices there is a significant negative influence of the pre-sowing treatment. Plants and seeds respond to light with a complex variety of reactions that are affected by the

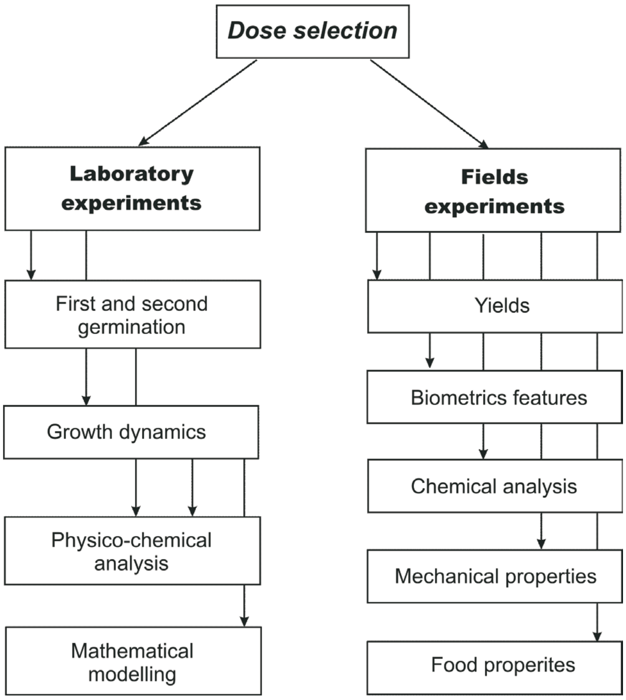

Fig. 2. Methodological structure of the research on the influence of electromagnetic and laser treatment of seeds.

duration (photoperiod), intensity, and wavelength of the light. The effect of laser stimulation at various environmental conditions may be limited by the partial process coupled to the embryo development.

The results presented in Table 2 show the influence of pre-sowing treatment of seeds with low-frequency (50 Hz) alternating magnetic field (AMF). The purpose of the research was to describe the effect of AMF on the yields and chemical composition of sugar beet roots. The research was undertaken on two varieties of sugar beet: Polko and Kaliwia (Pietruszewski and Wójcik, 2000). Basing on undertaken research we can state that the influence of the pre-sowing magnetic treatment depends on beet seed variety and seed preparation (seed dressing). The perceptible, positive influence of the magnetic stimulation was recorded mostly on normal seeds, as compared to dressed seeds growing under similar environmental conditions. All the examined features, both concerning yield and some chemical elements of the root, fundamentally depended on the pre-sowing magnetic stimulation, and this influence, for the applied exposure dose, was finally positive.

It should be highlighted that field experiments on crop plants, in which yield is used as the primary criterion for measuring the effect of stimulus, seldom provide unequivocal results from year to year: environmental conditions during the growing season still have the main influence on final seed yield. Future research should con- centrate of defining the conditions under which a response to RMF or EMR occurs.

CONCLUSIONS

1. It can be seen that pre-sowing EMF treatment of seeds may have a positive effect at low EMF frequencies.

2. The application of EMF and EMR stimulation may be a good tool for improving the yield and plant growth for agricultural production.

3. Analysing the results obtained for pre-sowing stimulation of seeds, it is clear that electromagnetic fields and electromagnetic radiation may have a positive, but mostly temporary and impermanent effect on the percentage of germination, growth speed and germination rate. It is a very important observation because low germination activity of many seeds is a significant problem in agriculture.

4. The economics of those physical methods of improving the quality of sowing material must be calculated.

5. With the positive effects of stimulation on yield, some simple and cost-effective devices must be designed to standardize pre-sowing treatment on a wide range of plants, but without the qualitative description of the influence of those stimulants on the quality of sowing material there is no possibility for their practical application on the grand scale.

T a b l e 1. Results of pre-sowing laser treatment of white lupine - percentage content of protein and fat in yield of white lupine seeds. Seeds of laser treated plants were irradiated with He-Ne laser beam with maximum laser power P_{max} = 3 mW before sowing (Koper and Dziwulska, 2003)

Examined ingredient in seeds	*cv.* Bardo			*cv.* Katon		
	Control plants (%)	Laser treated plants (%)	P	Control plants (%)	Laser treated plants (%)	P
Protein	21.69 ± 0.26	20.96 ± 0.44	< 0.05	21.06 ± 0.64	22.78 ± 2.69	–
Fat	8.77 ± 0.04	8.26 ± 0.25	< 0.05	8.28 ± 0.15	8.02 ± 0.12	< 0.05

T a b l e 2. Results of pre-sowing magnetic treatment on yield of sugar beet root. Exposure dose D = 67200 Jm^3s (B = 75 mT, t = 15 s) (Pietruszewski and Wójcik, 2000)

Index	Seed dressing	Control plants	MF-treated plants	P
		cv. Kaliwia		
Yield of roots ($t\ ha^{-1}$)	n. s.	46.4	49.5	< 0.05
	c. s.	52.9	52.5	—
Sugar (%)	n. s.	16.5	17.7	< 0.05
	c. s.	16.5	17.4	—
Biological yield of sugar (%)	n. s.	7.72	8.74	< 0.05
	c. s.	8.79	9.11	—
		cv. Polko		
Yield of roots ($t\ ha^{-1}$)	n. s.	59	61	—
	c. s.	56.7	60.6	< 0.05
Sugar (%)	n. s.	52.3	54.1	—
	c. s.	55.4	55.3	—
Biological yield of sugar (%)	n. s.	9.96	11.21	< 0.05
	c. s.	9.91	10.96	< 0.05

n.s. – normal seeds, c.s. – coated seeds.

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