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Electromagnetic field impact on annual medics and dodder seed germination

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Abstract. Differences in seed germination characteristics of three annual medic species and dodder were studied after treating with different intensities of electromagnetic field and exposure times. There were significant effects among treatments for germination percentage, shoot length and mass, seedling dry mass and seedling vigour index in dodder seeds ($P \leq 0.01$). Seedling vigour index and dry mass decreased in *Cuscuta monogyna* seeds under different electromagnetic intensity. Electromagnetic intensity enhancement increased germination rate and percentage and shoot length in annual medic species, as that the highest germination rate and percentage were observed at 128 µT electromagnetic intensity with 10 min of exposure. Therefore, electromagnetic field application can be applied in annual medic farms for greater crop growth and to control the important weeds such as *Cuscuta monogyna* in them.

Keywords: *Cuscuta monogyna*, germination, *Medicago* spp., electromagnetic field, seedling

INTRODUCTION

All plants on Earth live in an electric and magnetic field because the Earth is a magnet and there is an electric field between clouds and the Earth. Investigations into electromagnetic effects on plants have already been carried out with some remarkable results. The optimal external electromagnetic field could accelerate the activation of seed germination (Maeda, 1993; Oomori, 1992), but the mechanism of these actions is still poorly understood (Morar *et al*., 1988; Xiyao *et al*., 1988). Electric and/or magnetic treatments are assumed to enhance seed vigour by influencing the biochemical processes that involve free radicals and by stimulating the activity of proteins and enzymes (Kurinobu and Okazaki, 1995).

Studies on magnetic field effects on seeds are most often concerned with the effects on germination (Bovelli and Bennici, 2000; Hirota *et al*., 1999; Pietruszewski, 1999a) or yield increase (Phirke *et al*., 1996; Pietruszewski, 1999b; Podleśny *et al*., 2004; Vakharia *et al*., 1991). Hypotheses used to try to explain this phenomenon are based on fragmented studies (Tugulea, 2000). It is supposed that magnetic field influences the structures of cell membranes and in this way increases their permeability and ion transport through the ion channels, which then affects various metabolic pathway activities (Labels, 1993). Seeds treated by magnetic stimulation seem to show higher enzyme activities which control the particular stages of seed germination (Aksyonov *et al*., 2000). An important factor determining the magnetic field effect *in vivo* is the amount of water in the tissue and the environment. Water is necessary for all vital processes and is very sensitive to magnetic field influence, even if it is a field with low energy (Wojtusiak and Majlert, 1992).

There have been reports of greater than 10% increase in field emergence of maize and wheat after submitting the seeds to carefully controlled electric fields (Morar *et al*., 1993, 1999). These effects were mainly attributed to field-induced intensification of the biological processes in seeds. The field emergence increase could also be related to the sterilizing effect of high-voltage application (Morar *et al*., 1999).

Das and Bhattacharya (2006) found the maximum root growth during exposure to a magnetic field strength of 0.88 T for 80 min. From that investigation it was clearly understood that the exposure to magnetic field strength of 0.66-1.1 T for time periods between 0 and 120 min (0 as a control) changed the seedlings growth of gram seeds (*Cicar arietium*). The exposure effect of the ambient magnetic field strength of 0.88 T for 80 min exerts the best stimulating effect for germination of gram seeds.

Two most important germination problems of the seeds of forage legume crops are low germination and competition with other plants like weeds. One reason of low germination

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is hard seededness. *Medicago* species may have 100 % hard seeds according to eco-types (Uzun and Aydin, 2004; Walsh *et al*., 2001). The most effective and practical method for breaking hard seededness is 96% sulphuric acid application for 10 min (Balouchi and Modarres Sanavy, 2006). The main advantages of this method are speed, ease of use, unaltered physical condition of the seeds following treatment, and its low cost. But also magnetic field strength might increase seed germination by providing a feasible non-chemical solution for breaking hard seededness. This non-chemical alternative may have many advantages, such as protecting the environment and, in turn, offering safety. Understanding alfalfa germination and growth is important for matching management decisions to alfalfa development. Thus this research is essential for increasing forage production.

Among the weed species, *Cuscuta monogyna* (Dodder) is predominant grass weed in wet and dry regions. Dodder is the most trouble some weed in medic fields in the world (Cudney *et al*., 1992). Dodder is a parasite for various kinds of wild and cultivated plants, and is especially destructive to medics, alfalfa, lespedeza, flax, clover and potatoes. Its wide host range and long life of its dormant seeds make *Cuscuta* hard to control and nearly impossible to eradicate. Dodders are annuals that spread by seed (Cudney *et al*., 1992).

The effects of electromagnetic field and exposure times on annual medics and dodder seed germination have been evaluated to investigate the potential of the treatment for accelerating medics seed germination and decelerating dodder growth.

MATERIALS AND METHODS

The seeds of three of annual medics (*Medicago radiata, Medicago polymorpha* and *Medicago scutellata*) and dodder (*Cuscuta monogyna*) were used. Within each species a completely randomised design with three replications was applied.

For establishing the electro magnetic field (EMF), a locally designed MF generator (Sahebjamei *et al*., 2007) and a 220 V AC power supply equipped with a variable transformer as well as a single-phase full-wave rectifier was used. The maximum power was 1 kW, the passing current 50 A DC. This system was designed to generate EMFs in the range of 0.5 μT to 30 mT. It consisted of two coils (each with 3000 turns of 3 mm copper wire) on a U-shaped laminated iron core (to prevent eddy current losses). Using two vertical connectors, the arms of the U-shaped iron core were terminated in four circular iron plates covered with thin layer of nickel (each 23 mm thickness, 260 mm in diameter).

A water circulation system around the coils was employed to avoid significant temperature increases. Without this system, after 10 minutes of operating the temperature of the coils would increase from 25 to 40°C. The temperature between the circular iron plates, where the samples were located, was measured and was within ±1°C around room temperature.

Control cells were kept far enough from the EMF producing apparatus to avoid any potential exposure to the EMF. Moreover, other electric appliances and laboratory facilities were not working; the control samples were therefore exposed only to the extremely low MF of the Earth (60±5 μT), as were the treatment groups, too.

The presence of any pulsation in the current from the rectifier was tested by an oscilloscope (40 MHz, model 8040, Leader, and Yokohama, Japan) and a pulsation frequency of 50 Hz with a voltage variation of about ±1 V was found. This pulsation frequency may be related to the shortcoming of the single-phase full-wave rectifier, which provided a ripple voltage around 5%. This small ripple voltage allows considering the generated EMF as highly homogeneous.

An electronic board was used to stabilise the system. Calibration of the system as well as tests for the accuracy and uniformity of the EMFs were performed by a teslameter (13610.93, PHYWE, Goettingen, Germany) with a probe type of Hall Sound. The accuracy of the system was ± 1% for EMF and the range of measurements was 3 μT to 30 mT.

Annual medics seeds were treated with electro magnetic field (EMF) of 88 μT for 10 and 30 min and 128 μT for 10 min. Wet and dry seeds of *Cuscuta monogyna* were treated with 88 and 128 μT for 12 and 24 h. Wet seeds were obtained by imbibition in water for 12 h at 16°C resulting in final moisture content of about 40%. Crop and weed seeds with no electromagnetic field exposure were considered as control. After the treatments, treated and control seeds were sterilised by sodium hypochlorite and distilled water. Germination assays were carried out on three replicates of 50 seeds. Seeds were placed on germitest papers imbibed in distilled water (H_2O) in a proportion of 2.5 times the mass of the paper and incubated in a germinator at 25±1°C for 14 days. A seed was regarded as germinated when the radicle protruded through the seed coat. The number of germinated seeds was recorded every 24 h, and in case of moisture deficiency distilled water was added.

In addition to the percentage of normal seedlings, the germination index (GI) and the germination rate coefficient (GRC) were calculated as follows:

$$\mathrm{GI} = \frac{\sum n_i T_i}{N},$$

$$\mathrm{GRC} = \frac{\sum n_i}{\sum n_i T_i} 100,$$

where: n_i – number of seeds germinated at day T_i, N – total number of seeds germinated, T_i – number of days after starting the test.

Shoot length (SL) and root length (RL) were measured for all seedlings on the 14th day of the germination test. At the end of the germination test, fresh mass of ten weed seedlings as well as dry mass after oven drying at 65°C for 72 h were determined. The seedling vigour index was calculated as seedling dry mass x seed germination percentage.

Germination percentages were subjected to analysis of variance using the SAS statistical software package (SAS, 1997). When analysis of variance showed significant F-test for treatment effects, Duncan's multiple range tests was applied to compare the means at P≤0.05 (Steel and Torrie, 1998).

RESULTS

In *Cuscuta,* germination percentages could not be improved by EMF treatments but were lower than the control after treatments of wet seeds at EMF strength of 128 μT for 12 and 24 h (Table 1). Electromagnetic field treatments did not affect the growth index, seedling fresh mass and shoot dry mass of Cuscuta. Shoot length was improved only after treating wet seeds at EMF strength of 88 μT for 24 h. Magnetic field treatments at 88 μT did not affect seedling vigour index and seedling dry mass, but treatments at EMF strength of 128 μT decreased seedling dry mass. Seedling vigour index decreased in treated wet seeds with EMF strength of 128 μT for 12 h (Table 1).

In annual medics, germination percentages were improved by all treatments except 88 μT for 30 min in *M. scutellata* (Fig. 1). Germination rate was improved in all three species by EMF strength of 128 μT for 10 min (Fig. 2). In *M. radiata* also EMF strength of 88 μT for 10 min and in *M. polymorpha* EMF strength of 88 μT for 10 and 30 min

Table 1. Mean values (Duncan's test, P≤0.05) of traits of *Cuscuta* seedlings under different electromagnetic fields and exposure time and condition of treatments

Weed	Electromagnetic field (μT)	Time (h)	Seed conditon	SG (%)	GI	GRC	SL (cm)	SFM (g)	SDM (g)	ShDM (g)	SVI
F-test				**	*	ns	**	ns	**	ns	**
Dodder	88	12	Dry	36.00ab	12.01abc	20.53b	4.75bc	2.10ab	0.18ab	0.12a	6.67ab
			Wet	42.67a	14.22a	20.07b	4.49bc	1.75ab	0.18ab	0.11a	7.87ab
		24	Dry	37.33a	12.74ab	20.27b	4.38bc	1.48b	0.18ab	0.11a	6.79ab
			Wet	44.00a	14.92a	20.17b	6.07a	1.92ab	0.18ab	0.10a	8.08ab
	128	12	Dry	34.67ab	11.16abc	19.77b	5.18b	2.17a	0.17bc	0.10a	5.83cd
			Wet	26.67cb	9.11bc	20.40b	4.05c	1.70ab	0.13d	0.09a	3.62c
		24	Dry	41.33a	13.15ab	18.96b	4.02c	1.98ab	0.17bc	0.10a	6.92ab
			Wet	24.00c	8.15c	20.27b	3.97c	1.61ab	0.16cd	0.10a	3.75c
Control	0	0	Dry	40.00a	13.31ab	19.53b	4.83bc	2.02ab	0.20a	0.20a	8.32a
			Wet	40.00a	10.82abc	24.03ab	4.83bc	2.02ab	0.20a	0.20a	8.32a

Different letters indicate significant difference between the values in the column (Duncan's multiple comparison test, P≤0.05). F-testes are indicated by significant at: 5%*, 1%**, and ns – not significant. SG – seed germination, GI – germination index, GRC – germination rate coefficient, SL – shoot length, SFM – seedling fresh mass, SDM – seedling dry mass, ShDM – shoot dry mass, SVI – seedling vigour index.

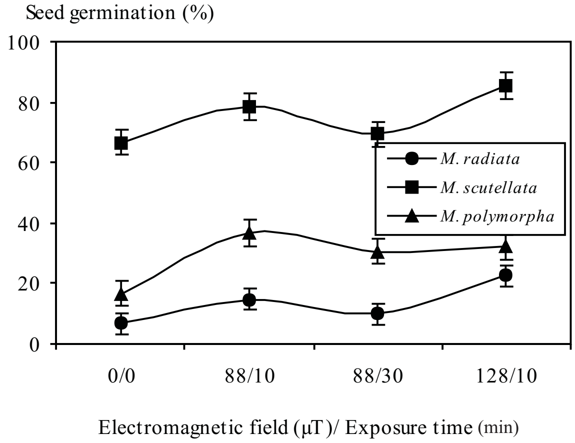

Fig. 1. Seed germination percentages under different electromagnetic fields and exposure time treatments.

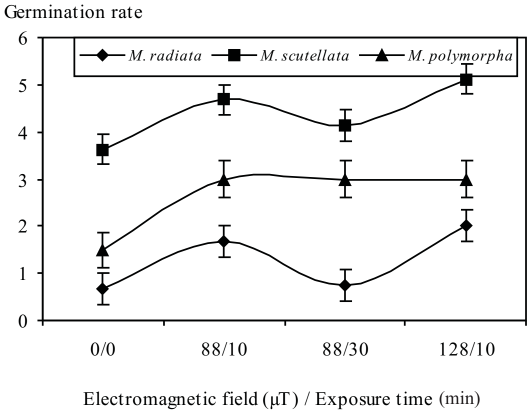

Fig. 2. Seed germination rate under different electromagnetic fields and exposure time treatments.

Table 2. Mean values (Duncan's test, $P<0.05$) of traits and annual medics seedlings under different electromagnetic fields and exposure time treatments

Crop	Electro-magnetic field (μT)	Time (min)	SL (cm)	RL (cm)
	128	10	3a	1.09a
M. radiata	88	30	0.54b	0.1b
	88	10	3a	1.07a
Control	0	0	0.5b	0.1b
F-test			**	**
	128	10	4.03b	3a
M. scutellata	88	30	6.16a	3a
	88	10	4.03b	3a
Control	0	0	6.33a	2.06b
F-test			**	*
	128	10	1.47a	0.06b
M. polymorpha	88	30	1.1b	2.02a
	88	10	1.47a	0.06b
Control	0	0	1.02b	2.01a
F-test			**	**

Different letters indicate significant difference between the values in the column (Duncan's multiple comparison test, $P < 0.05$). RL – root length. Other explanations as in Table 1.

were successful in improving the germination rate (Fig. 2). Shoot length could only be improved by EMF treatments for 10 min in *M. radiata* and *M. polymorpha* but not in *M. scutellata*. Here, no improvement was found in the shoot, but all treatments showed higher root length than the control. In *M. radiata* root length was improved by the 10 min treatments, in *M. polymorpha* no improvement was found (Table 2).

DISCUSSION

In many treatments applied in this study, seedlings grown from seeds treated with electromagnetic fields developed longer hypocotyls and roots. This was also found by Podleśny *et al*. (2003) in reference to the growth and development of some cereals and legumes species. After treatments with magnetic field seed germination was faster. Favourable effects of magnetic field on germination and emergence of seeds were shown for cereals (Pietruszewski, 1999b) and legumes (Podleśny, 2003). The study by Prokop *et al*. (2002) proves also a positive effect of magnetic field on seed germination of some vegetables, as Podleśny *et al*. (2004) found in white lupine seeds. Studies conducted by Rochalska (2002) on the germination and growth of wheat, triticale, maize and soybean also indicate that magnetic field can be used as a method of seed vigour improvement. It is particularly important when the weather conditions are unfavourable for germination, or in the case of seeds with inferior quality parameters. The value of obtained effects was dependent on the dose of magnetic field and on the time of exposure used. It is known from literature that the best effects of seeds stimulation with physical factors are possible to obtain when optimal exposure doses are applied. Lower doses of a factor usually stimulate seed germination and later development of plants grown from them, while higher doses can have disadvantageous effects. The experiment with pea varieties indicated that both doses of magnetic field used in the experiment had a favourable effect on the studied features (Podleśny *et al*., 2005). Moon and Chung (2000) reported that the germination rates of treated tomato seeds were 1.1-2.8 times higher compared to the untreated seed. However, an inhibitory effect on germination was shown for electric fields of more than 12 V cm^{-1} and exposure times of more than 60 s. Das and Bhattacharya (2006) found that EMF strength of 0.88 T for 80 min has maximum stimulating effect on germination of gram seeds (*Cicar arietium*) and it may be assumed that under this condition the three-cell water potential forces act in the same direction on germinated seeds. Kiatgamjorn *et al*. (2002) showed maximum improvement of length of bean seedlings during the exposure to electrical field strength of 25 KV m^{-1}. The length of bean roots in with electric field was longer than of those without electric field (Kiatgamjorn, *et al*., 2002). Seed stimulation with magnetic field had a modifying effect on initial growth and development of pea seedlings, mostly on the length of roots and hypocotyls. The greater exposure dose had a more pronounced effect on the length increase of the studied plant organs than the lower one. Both magnetic field doses significantly affected the length increase of shoots and roots of the pea varieties, but better effects were achieved after seed treatment with the higher dose (Podleśny *et al*., 2005). The mass of roots and stem of the pea seedlings was changed in dependence on the dose of EMF used. After 144 h from sowing, both doses of magnetic field (10750 and 85987 J m^3 s) caused an increase of pea roots and shoots mass in comparison to control object by 15.2 and 15.6%, respectively (Podleśny, *et al*., 2005).

CONCLUSIONS

1. Some magnetic field treatments decreased germination percentage and seedling vigour of *Cuscuta*. Thus, magnetic field treatments could control dodder weed population in the field.

2. In annual medics, magnetic field treatments could increase germination percentage and seed vigour.

3. If seed lots of annual medics which are contaminated with *Cuscuta* seeds are treated with electromagnetic fields, in total germination and emergence of medics could be improved and germination of *Cuscuta* decreased. This might become an efficient pre-sowing treatment.

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