

The Effects of 60Hz Magnetic Fields on Plant Growth

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ABSTRACT: The biological effects of extremely low frequency magnetic fields (ELF MFs) on living organisms have been explored in many studies, but few of them investigate how different waveform MFs act upon their growth. In this study, the biological effects of both a 60Hz sinusoidal MF and a 60Hz pulsed MF on the early growth of plants are presented using mung beans as an example. The sinusoidal MF is produced using a specially-made circuit with a circular iron coil and a triac lamp in series which is driven by 110Vrms 60Hz AC power, and the pulsed MF is produced using the same equipment with the knob of the triac lamp adjusted manually. The results indicate that the 60Hz sinusoidal magnetic field has an enhancing effect on the early growth of mung beans, however some morbid state phenomena were observed on the sprout roots. Also, the effect and morbidity rate increases with MF intensity. In contrast, the 60Hz pulsed magnetic field has a slightly inhibitory effect on mung bean growth. [Nature and Science. 2007;5(1):60-68].

Keywords: biological effect; coil; ELF MF; triac

1 Introduction

As electric appliances such as TV, lights, fans, radiators, etc. are increasingly commonplace nowadays, the effects of the extremely low frequency magnetic field (ELF MF) produced by such equipment on the living organism are much more of concern. Most of the magnetic fields induced are of 60Hz sinusoidal waveform because 60Hz AC power is the most commonly used power rating all over the world. But there are many other occasions where the magnetic fields produced are in the form of a pulsed train. Therefore it is vitally important to find out whether there is any effect on living organisms resulting from exposure to either kind of MF.

Several studies have suggested that ELF MFs may modify plant growth and development (Celestino, 1998; Davies, 1996; Picazo, 1999; Rapley, 1998; Smith, 1993, 1995; Stange, 2002), but exposure to magnetic fields induces quite a variety of biological effects and moreover, knowledge of the effects on living organisms is still not very clear. Nevertheless, the points of view described in (Lednev, 1991; Liboff, 1992) imply that an ELF MF may affect ions in cells, and can be described by the following equation:

$$f = \frac{q}{2\pi m} B_{DC} \quad (1)$$

where f is the frequency of the ELF MF (Hz), q/m is the charge-to-mass ratio of the ion(C/kg), B_{DC} is the magnetic flux density of the static MF (T) that is superimposed on the ELF MF. From Eq. 1, it can be seen that the motion of ions is severely affected by f and B_{DC} . In other words, different waveform magnetic field sources will result in varied biological effects on living organisms because their frequency spectrums are different.

The present study aims to assess the effects of two different waveforms of magnetic field source (a 60Hz sinusoidal MF and a 60Hz pulsed MF) on plant growth using mung beans as test material, and attempts to relate the effects to the waveform spectrum of the magnetic fields. The sinusoidal MF is induced by a specially-designed electrical circuit which is driven by 110Vrms 60Hz AC power, and the 60Hz pulsed MF is produced from the same circuit, using the knob on the triac (two thyristors in inverse-parallel) for adjustment. Using the exposure system proposed in this paper, the MFs can be produced and mostly concentrated in the coil. Since the MF is concentrated, the affects of the MF on the personnel executing this experiment can be reduced. In the experiment, the exposed mung beans were grown in two places with different magnetic intensity, and additionally the control mung beans were grown in an ambient environment to observe any differences in biological effects on the growth of our test material.

2 Materials and Methods

2.1 Plant material

Mung beans are used as the test material subject in this study, and two tests (one under a 60Hz sinusoidal MF, and the other under a 60Hz pulsed MF) are implemented. In each test, beans of the same weight (0.08g) and similar appearance are selected, and separated into three groups of 10, 30 & 30 beans. Three groups are fertilized with distilled water with initial temperature of $31.5 \pm 0.5^\circ\text{C}$. Two groups of them are grown in a magnetic field (exposed group 1 under higher magnetic intensity and exposed group 2 under lower magnetic field intensity), and the other group is placed in an ambient weak magnetic field (control). The reason only 10 beans are used in exposed group 1 is due to the limited space where they are placed. The environmental conditions such as temperature, humidity and illumination of the three groups of mung beans of two tests are maintained, as shown in Table 1.

TABLE 1 The temperature, humidity and illumination conditions in each group of the two tests

Item	Sinusoidal MF			Pulsed MF		
	Exposed 1	Exposed 2	Control	Exposed 1	Exposed 2	Control
Position	In the airgap	Adjacent airgap	the Ambient environment	In the airgap	Adjacent airgap	the Ambient environment
Temperature ($^\circ\text{C}$)	28.0 ± 0.2	28.1 ± 0.2	28.2 ± 0.2	25.5 ± 0.5	25.5 ± 0.5	25.5 ± 0.5
Humidity (%)	48.2 ± 0.1	48.2 ± 0.1	48.2 ± 0.1	54.1 ± 0.2	54.1 ± 0.2	54.1 ± 0.2
Illumination (LUX)	608 ± 2	609 ± 2	605 ± 2	598 ± 2	599 ± 2	597 ± 2

Comment: 調整 illumination data

^aThe environmental conditions of the two tests are slightly different because they are carried out in the different seasons.

After the three groups of mung beans have been absorbing water for 8 hours, they are taken out, dried and weighed to measure the water absorption rate. The residual water is then poured out and both groups of beans are put back in their original positions to continue growing. After they have been growing for a total of 24 hours, all groups of mung beans are taken out, and each mung bean's sprout diameter and length are measured.

2.2 Exposure system

The purpose of this study is mainly to assess the influence on the early growth of mung beans exposed to a 60Hz sinusoidal MF and a pulsed MF. The equipment needed in this experiment includes a resistor (triac lamp), an inductor (winding coil), oscilloscope, frequency analyzer, etc. The complete set-up is shown in Figure 1.

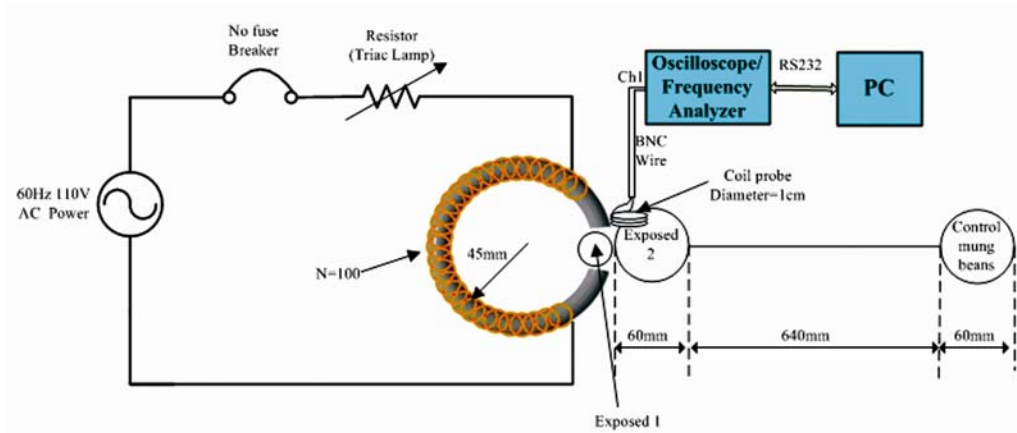


Figure 1. The complete set-up in this experiment

As shown in Figure1, the electrical power used to drive the circuit is 1ψ 110V 60Hz AC power. The circular coil with outer diameter of 130mm and a 24mm air gap (cross section diameter = 28mm) is wound 100 turns with copper wire. The magnetic flux density (B) circulating in the iron core and air gap can be theoretically expressed in the following equations:

$$B = \frac{Ni}{R} \quad (2)$$

$$R = \frac{l_c}{\mu A} + \frac{l_g}{\mu_0 A}$$

where R is total magnetic reluctance of the core and air gap, μ and μ_0 are the magnetic permeability of the core and air respectively, A is the cross sectional area of the circular core, N is the number of turns of wire, i is the current flowing through the wire and l_c & l_g are the core circumference and air gap distance, respectively.

When the knob of the triac lamp is set to the high level position, the MF flowing in the iron coil is in a 60Hz sinusoidal form. However, when the knob is adjusted to the low level position, the MF produced shows as a pulsed train, as shown in Figure 2 and Figure 3. The locations of the three groups of mung beans are shown in Figure 1. In order to confirm the magnetic flux density (B) in each position of two tests, a magnetic meter is used to measure the B value at each position. These data are listed in Table 2.

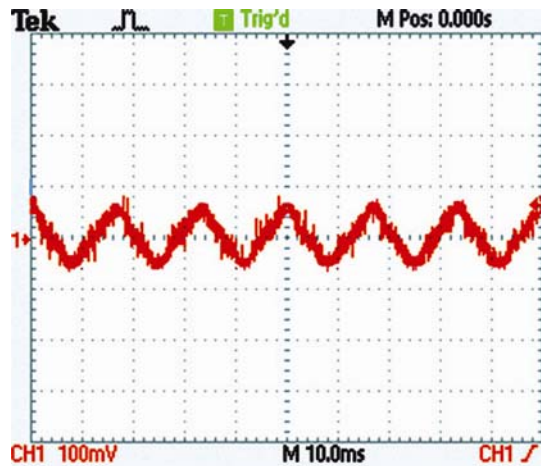


Figure 2 The 60Hz sinusoidal magnetic field produced. Due to the poor quality power used and impedance mismatching between the coil probe and oscilloscope (shown in Figure 1), the waveform of the MF does not look like a perfect sine wave.

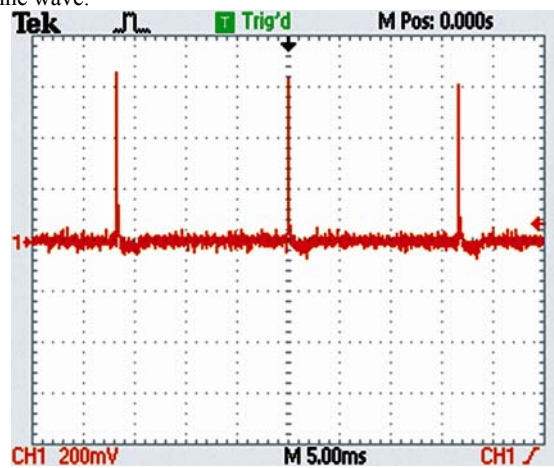


Figure 3. The 60Hz pulsed magnetic field induced

TABLE 2. The magnetic field intensities produced in each group of mung beans of the two tests

Test	Exposed 1	Exposed 2	Control
Sinusoidal MF	235.0 μ T	94.1 μ T	0.17 μ T
Pulsed MF ^a	11.1 μ T	6.2 μ T	0.20 μ T

^aThe pulsed MF intensities are measured using a magnetic meter which has limited bandwidth, so the peak value will be higher.

3 Results

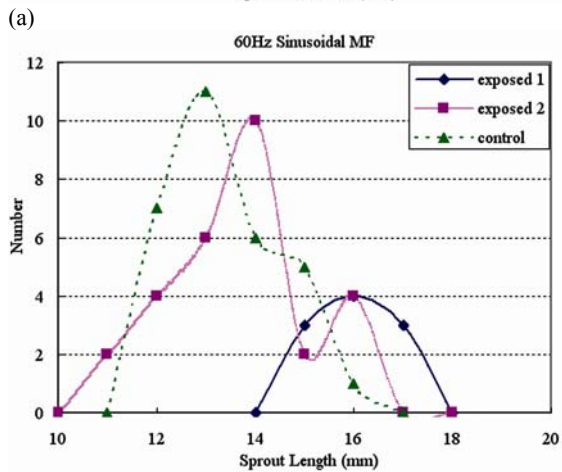
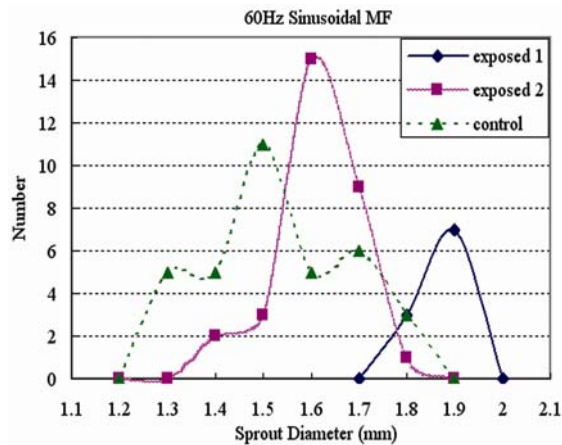
3.1 Water absorption

After 8 hours fertilization with distilled water, the three groups of mung beans were taken out to be observed for germination and weighed. Exposed to the sinusoidal MF, the average weights of the mung beans in both the exposed 1 and exposed 2 groups were 0.180g, and the average weight of the control mung beans was 0.140g. The weight ratio between the exposed and control mung beans was 1.29. This result

indicates that the mung beans that had been exposed to the sinusoidal MF had absorbed much more water compared with the control mung beans. As for the other test exposed to the pulsed MF, the average weights of the mung beans in both the exposed 1 and exposed 2 groups was 0.136g, and the average weight of the control mung beans was 0.145g each. The weight ratio between the exposed and control mung beans was 0.94. This result shows that the mung beans that had been exposed to the pulsed MF had absorbed less water compared with the control mung beans.

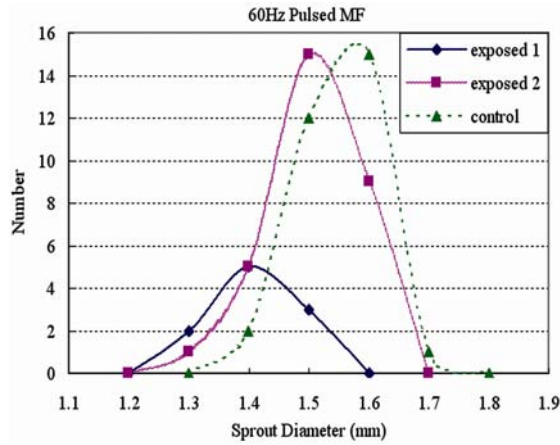
3.2 Early growth

The three groups of mung beans were then put back in their original positions for the remaining 16 hours of the experiment. After they had been growing for 24 hours, the sprout diameter and length of the mung beans in three groups were measured. For the test exposed to the sinusoidal MF, the distribution of the sprout diameters of the three groups with 24 hours growth is sketched in Figure 4(a), and that of their sprout lengths is shown in Figure 4(b). The statistical data are listed in Table 3. As shown, the average sprout diameter and length of the mung beans in exposed group 1 were the greatest of all three groups, and those of the mung beans grown in the ambient environment were the least. Therefore, a sinusoidal MF has an enhancing effect on the early growth of mung beans, and the effect gets stronger as the MF intensity increases.

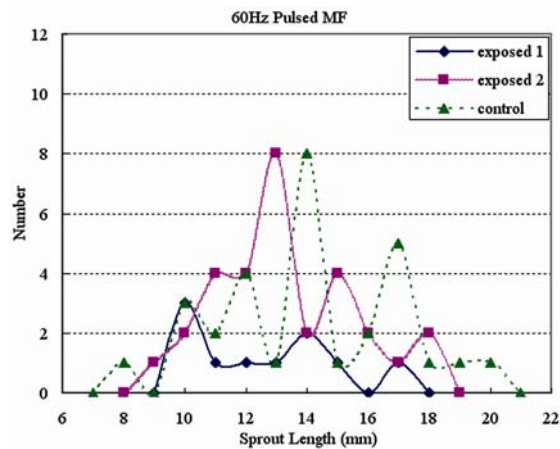


(b) Figure 4 (a) The sprout diameter distribution of the mung beans exposed to the sinusoidal MF. (b) The sprout length distribution of the mung beans exposed to the sinusoidal MF. Both growth distributions shift higher with increasing MF intensity. (There are 10 sample beans in exposed group 1, which is less than the other groups because of limited space in the iron core airgap)

As for the test exposed to the pulsed MF, the distribution of the sprout diameters of the three groups with 24 hours growth is sketched in Figure 5(a), and that of their sprout lengths is shown in Figure 5(b). The statistical data are also listed in Table 3. As shown, the average sprout diameter and length of the mung beans in exposed group 1 were the least of all three groups, and those of the mung beans grown in the ambient environment were the greatest. The difference is not very significant because the magnetic field intensity used in this test is smaller than that in the sinusoidal test. In any case, a pulsed MF does have an inhibitory effect on the early growth of mung beans.



(a)



(b)

Figure 5 (a) The sprout diameter distribution of the mung beans exposed to the pulsed MF. (b) The sprout length of the mung beans exposed to the pulsed MF. Although the sprout length distribution is quite dispersed, the distribution of both sprout diameter and length shift lower as the MF intensity increases. (There are also 10 samples in exposed group 1)

TABLE 3 The statistical data of the growing mung beans

Item	Sinusoidal MF			Pulsed MF		
	Exposed 1	Exposed 2	Control	Exposed 1	Exposed 2	Control
Sprout diameter (mm)	Avg: 1.87 SD: 0.05	Avg: 1.61 SD: 0.09	Avg: 1.53 SD: 0.15	Avg: 1.41 SD: 0.07	Avg: 1.51 SD: 0.08	Avg: 1.55 SD: 0.07
Sprout length (mm)	Avg: 16.0 SD: 0.77	Avg: 14.0 SD: 1.90	Avg: 13.4 SD: 1.11	Avg: 12.6 SD: 2.29	Avg: 13.3 SD: 2.26	Avg: 14.1 SD: 2.89
Morbid Proportion	4/10	9/30	0/30	1/10	3/30	0/30

^aAvg refers to average, and SD stands for standard deviation.

3.3 Morbidity

After 24 hours cultivation, the three groups of mung beans were taken out to be observed for germination. Not only are the sprout length and diameter of the mung beans in each group different, but they also differ in external appearance. The morbidity rates of the mung beans in exposed 1, exposed 2 and control groups of the two tests are sketched in Figure 6. It can be clearly seen that, the morbidity rates of mung beans grown exposed to the MF becomes greater as the magnetic intensity increases regardless of magnetic field type.

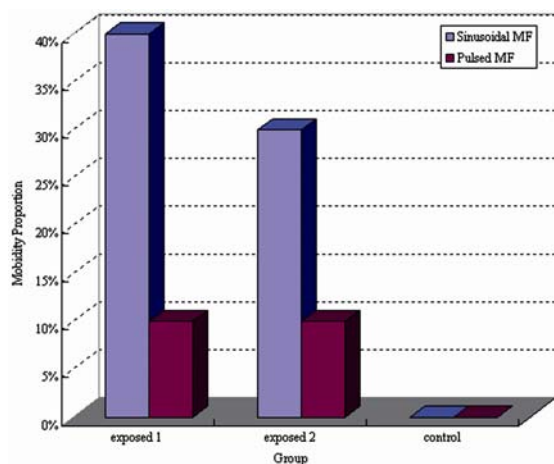


Figure 6 The morbidity rates of the mung beans in exposed 1, exposed 2 and control groups of the two tests

4 Discussion and Conclusion

To investigate how the plant growth was affected by the induced MF, a little probe coil of diameter 1cm (Misakian, 1993) was used to induce an electromagnetic force next to the core where the exposed mung beans were placed. The probe was connected to a frequency analyzer (Tektronix 2012) to obtain the components of the two different kinds of MF in the frequency domain. Figure 7 demonstrates the spectrum of the sinusoidal MF induced next to the iron core. As shown, it can be seen that most of the energy of the MF is concentrated in its fundamental frequency (60Hz), and some distributed among its odd harmonic frequencies. In other words, most energy of the sinusoidal MF is distributed in the lower frequency band. In addition, the spectrum of the pulsed MF produced is shown in Figure 8. Its spectral energy is widely spread in the frequency domain almost reaching 12.5MHz. As mentioned in the introduction, the motion of ions of plants is not only affected by the magnetic intensities but also the frequency. Following this viewpoint, there should exist many natural frequencies of the cells in all kinds of plants, which are dependent on the cell elements, structures, components, alignment, etc. Each cell is capable of “resonating” to an external source of frequencies in the same manner as a guitar string beginning to vibrate when exposed to the

standard pitch of the correct tuning fork (Lakhovsky, 1963; Brown, 1989). Therefore, as the frequency of the applied magnetic field approaches the natural frequency of the plant, some sort of excitation occurs and the original cellular motion is changed. Since there is more than one natural frequency in the plant and there exist different distributions of the natural frequencies with regard to different kinds of plant, the effects of the ELF MF on plant growth is complicated to predict. Nevertheless, this study provides an experimental method to figure out the biological effects.

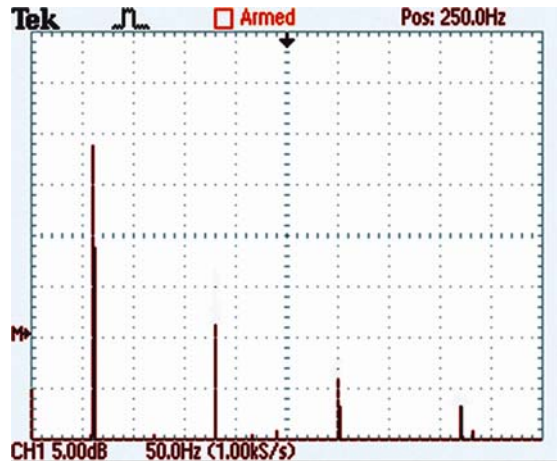


Figure 7 The frequency spectrum of the sinusoidal MF produced. Some harmonic components exist in the spectrum since the MF is not a pure sine.



Figure 8 The frequency spectrum of the pulsed MF induced, with bandwidth reaching 12.5MHz.

The enhanced growth of mung beans exposed to the 60Hz sinusoidal MF might result from the fact that 60Hz is close to the natural frequency of mung beans, thus exciting the motion of the Ca^{++} ions within mung beans. It was also presumed that the broad band frequency spectrum of the pulsed MF causes more than one excitation force that turn out to be disturbances. In fact, the kinetic energy of the cellular response to ELF MF exposure can be theoretically calculated, but more work needs to be done to understand the disturbances caused by other ions.

In conclusion we observed that the sinusoidal and pulsed MFs affect the plant growth in different ways (with respect to different kinds of plant). Generally speaking, the 60Hz sinusoidal ELF MF has an apparent enhancing effect on mung bean growth but with the occurrence of some morbid state phenomena. In contrast, the 60Hz pulsed MF inhibits growth. From the results obtained in this experiment, it can be understood that the pulsed MF harms plant growth rather than enhancing growth as the sinusoidal MF does.

This may imply that this kind of MF is detrimental to health.

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