DESIGN AND CONSTRUCTION OF HELMHOLTZ COIL FOR BIOMAGNETIC STUDIES ON SOYBEAN

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by

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The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

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ABSTRACT

A Helmholtz Coil with a large usable area of uniform field was designed, constructed and characterized, specifically for Bioelectrics studies. The Helmholtz coil was designed for use with both AC and DC power sources. The design and analysis of the coil were carried out through experiments and the use of industry standard electromagnetic software suite. MATLAB was also used in the simulation studies. The location and the area that would have uniform field intensity were determined through simulation and compared with measurements. Analyses show a large area uniform field can be created along the axis of the two coils which makes the usable area about approximately one third the coil internal volume.

The effects of magnetic fields on soybean germination rate were studied using the lab designed Helmholtz coil. A specific soybean variety, code named Magellan, was used because of its potential application as a renewable energy resource, specifically for use in producing biofuels. Magellan was chosen because in previous studies it was shown that this variety, amongst four others, showed promise in germination rate improvement as compared to other varieties. Experimental results indicate that presoaked soybean seeds when treated under static low intensity and extremely low frequency magnetic fields show improved growth and germination rates when compared to those grown under earth's geomagnetic fields. The extreme-low-frequency (ELF) AC magnetic field is more conducive to Soybean germination compared to the static magnetic field. Maximum germination rate, which was 18 % higher than control rate, was obtained at around 14 Gauss, 60 Hz. An alternating magnetic field of 60 Hz was shown to have a statistically significant effect on soybean seed germination. Results have also shown that magnetic fields influence soybean germination more than electromagnetic fields from an anechoic chamber and a TEM cell.

The magnetic field may provide a feasible non-chemical solution in agriculture, and thus offers advantages over chemical methods in terms of environment protection and safety for the applicator. The increased germination rate of soybean means that the soybean can be projected as alternative fuel source as well as for the growing global need for this 'miracle crop'. For improving the crops yield using clean technology of magnetic field exposure it is necessary to determine, at the seed and cellular level how the seeds are altered when treated in the magnetic field. Further study is needed to determine at the molecular level the main reason for this phenomenon.

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INTRODUCTION

Sources for electromagnetic energy can be both natural and manmade and the latter has many known commercial and defense applications. Examples include mobile telephones, television, radio transmission, microwave ovens, computers, transmission lines and sensors of every kind. Electric and magnetic fields that carry electromagnetic energy can be of different forms. They can be in the steady-state form, like the North-South of a magnet, or they can oscillate at any given frequency. Frequencies have a wide range starting from the extreme low frequencies (ELFs) such as the power line at 50 or 60 Hz, radio and communication frequencies, cellular telephones, microwave ovens, satellite links, and on to visible light and UV rays. At high frequencies, beyond visible light, the radiation is ionizing since the energy carried by the wave can be sufficient to break bonds or ionize ($E= h\nu$, where E is the energy, h is a constant and ν the frequency, assuming 1 ev for ionization or breaking a bond, and $h=6.6 \times 10^{-34}$ J/s, being a constant, the frequency for ionizing is ~ 10^{14} Hz). High frequency electromagnetic waves thus cause heating effect in cells and tissues and hence, human being avoids exposure of EM field at high frequencies. The International Commission of Non-Ionizing Radiation Protection, ICNIRP [1998] has formed a guideline to protect human health from possible thermal effects form EM radiation. Below visible light electromagnetic fields is non-ionizing

It was previously thought that the heating effect from the exposure of EM field brings the altercation in plant and cells and tissues. The specific absorption rate (SAR), measured in watts per kilogram, is the suitable parameter for charactering the absorption of EM fields in the body while discussing the thermal effects at high intensities and frequencies. This may not be appropriate one to use when discussing possible altercation of plant and animal cells at non-ionizing and non-ionizing level.

EM waves may not always have enhancing effect on plant and animal cells. They might initiate negative development in terms of physical growth and health issue. EM radiation might lead to symptoms such as headaches, fatigue, dizziness, warmth sensation etc when exposed to human being. There has been concern about possible cause of cancer when living cells are exposed at EM radiation for longer period but connection between cancer and EM field has not been established yet. Similarly, plant cell are altered and growth retarded when exposed to high intensity of EM radiation. Based on previous studies we are trying to find out the frequency level and intensity of magnetic field which enhance its germination rate and physical growth. The main interest today is the exposure of EM wave at non-ionizing and non-thermal level for better germination and growth of plants.

The influence of the geomagnetic field on the growth of plants was scientifically established for the first time in 1862 by the French chemist Louis Pasteur (1822-1985), during his experiments on fermentation, when he discovered that the Earth's magnetic field had a stimulating effect on that process. Experimentation with weak and extremely low frequency magnetic fields has existed for nearly 50 years. Electromagnetic and magnetic fields have effect on plant and seeds based on the field intensity, exposure time, signal form, flux density and source frequencies. A magnetic field is an inescapable environmental factor for plants and seed in the earth. However, there is no distinct behavior that plants and seeds follow while they are exposed to the electromagnetic field.

Some species of plant are affected by exposure of electromagnetic field of certain intensity while others are not. Similarly, strong electric field affects the physiological and chemical behavior of plants and seeds cells.

Growth of seeds and the germination process may be improved through bio-stimulation using any one of the following agent (s): i) electromagnetic stimulation, ii) magnetic stimulation, iii) radiation with laser light, iv) radiation of live organisms with ultraviolet (UV-rays), gamma rays, ultrasound, ionized radiation, v) dialectical separation and stimulation of seed, vi) resonance impulse electromagnetic stimulation of seed and plants, vii) application of effect of "gold crossing" of electromagnetic fields and the principle of "Keops Pyramid", and viii) weed control with high electro frequency. An advantage of these stimulators over traditional chemical processes is that they do not leave any toxic residue. The main concern today is the possible cause of physical and chemical altercation in plant and living cells with EM field at non-thermal level i.e. at static and low frequency range of EM field. Previous studies have shown that the low intensity magnetic field gives rise to bio-stimulation and enhance the seed germination rate and plant growth. Some of the discussed effects are based on physical and molecular altercation of in seedling and plant germination.

The Earth's magnetic field is a natural component of the environment for living organisms and plants. The intensity of geomagnetic field is about 50 μT. Plant and seedling growth generally takes place in the 50 μT magnetic field environment. If the magnetic environment is change the development of plant may be altered. The magnetic environment is one of the factors that might influence the growth of plant. The role of magnetic fields and their influence on functioning of biological organisms are still insufficiently understood, and is actively studied. Some of the studies with seedlings of different plant species placed in the magnetic field show that their growth enhanced while other shows that development is inhibited. Hence, it may be predicted that seeds and plant react differently at different frequencies and different intensity of magnetic fields. The magnetic may provide a feasible non-chemical solution in agriculture. At the same time it offers advantages to protect environment and also safety for the applicator. The biological effect of high frequency portion of the electromagnetic spectrum has been reported in recent years but there is lack of data to explain the biological effects of low frequency fields. It is assumed that high frequency exposure brings about the heating effect in the plant cells. In the present work emphasis is given to static and ELF magnetic field which has nothing to do with the heating effect. Both AC and static magnetic field have been used to investigate magnetic exposure effects on soybean germination, in particular on Magellan variety. Magellan seeds were exposed to different intensities of magnetic field at static and 60 Hz magnetic field. Magnetic exposure was done with both regular seeds and presoaked seeds. Germination was done at controlled laboratory condition.

Some research shows that plants, when placed in weak magnetic field, give positive results in terms of plant growth. This thesis is an attempt to demonstrate the enhancing soybean germination rate at static, low frequency (60 Hz) and low intensity of magnetic fields. The germination results projects that seeds treated in low intensity, static and alternating magnetic field enhance the germination rate and physical growth.

As stated earlier, electromagnetic waves come from both passive (natural) and active (man-made) sources. Visible light rays are example of passive EM and microwave imaging, laser profiler & radar are active sources of EM. TEM (Transverse Electromagnetic Cell), Anechoic Chamber and Helmholtz coil can be considered as sources of EM waves. In this thesis Helmholtz coil, source of uniform magnetic field, has been designed, simulated and constructed to study the effects of magnetic fields on germination of seeds, specifically a known variety available at the Soybean Center at the University of Missouri (MU). CST microwave studio and simulation software and MatLab coding were used to simulate the designed structure and verify the generated field's intensity and uniformity. The theoretical magnetic field measurement was compared with the practical design. The uniformity of the generated field is verified. Soybean seeds are exposed to magnetic field for different time duration and their germination rate is determined in collaboration with researchers at the Soybean Center. It is important that the treated seeds are equally exposed to the exposed magnetic field, which emphasizes the need for a new design of a Helmholtz coil as was done in this project.

The organization of this thesis is as follows. The first introduction chapter is followed by a background chapter, where a typical of electromagnetic wave and its characteristic is presented. It also discusses the ionizing and non-ionizing effects of electromagnetic fields. It highlights the importance of soybean as vegetable oil and potential source of biofuel. It also discusses the sources of electromagnetic fields (TEM Cell, Anechoic Chamber & Helmholtz coil) which were used in this research. The third chapter provides the literature survey for this research. It has electromagnetic, magnetic and electric effects on different plants, seeds and animal tissues. Effect of EM field at physical and molecular level is also discussed in this chapter. The various research works discussed in this chapter forms the base for the current research. The fourth chapter describes the theory, design and construction of the Helmholtz coil used for the research. Monoaxial and a meter diameter Helmholtz has been constructed. The different power sources used for driving the coil and the magnetic field measuring equipments have been discussed. The fifth chapter discusses the simulation of the designed coil and the germination process & result. The simulation was done using Matlab code and CST Microwave Studio. The germination studies were done at Soybean Center Lab at MU in a controlled environment. The sixth chapter discusses and concludes the findings for this current study. It compares the measured and simulated results of Helmholtz coil. It discusses the various parameters that were changed to improve the germination. The chapter concludes that soybean seeds exposed to static and ELF magnetic field have enhancing germination rate compared to the non exposed seeds. It also presents an analysis at the molecular level. This chapter also presents the new ideas which would be pursued for further research work in this area.

CHAPTER 2

BACKGROUND

2.1 Introduction

Studies related to the biological effects of Electromagnetic (EM) Fields are a new and dynamic area of scientific research, involving both biology and physics. Initially it was presumed that EM field interactions increases the temperature of the cells through heating effect and consequently affect living organisms, but now it is known that the interactions are different. It is now postulated that electromagnetic fields alters the internal signals within a cell to cause the effect it does. This is evident if one considers the germination of seeds due to the earth's own magnetic fields and electric fields. The germination of seeds and the growth of plants are affected factors that need a close scrutiny. Even though the interactions are not fully understood, electromagnetic fields have been known to act as bio-stimulators for the growth of many types of plant and seeds.

In this chapter basic information on the technical terms, instruments and interaction mechanisms discussed later is provided for easy comprehension of the process to be discussed. It includes:

2.2 Electromagnetic field

Electric field between two points is created when there is difference in voltage between the two points. Higher the potential difference the stronger is the resultant electric field. Magnetic field, on the other hand, is created due to current flow in a conductor. Higher the current the stronger is the magnetic field. Both electric and magnetic fields are components of electromagnetic waves and in vacuum they both move at the same frequency.

Electromagnetic waves are present everywhere in space but they are invisible to our eyes. Light rays, local build up of electric charges and earth magnetic field are natural sources of EM field. Besides natural sources, the electromagnetic spectrum also includes fields generated by human-made sources like X-rays, transmission lines and various sources of higher frequency radio waves used in communication. [1]

2.3 The EM Spectrum

The EM spectrum (Figure 2-1) is spectral band of various waves in terms of frequency or wavelength. They are categorized from audio waves, radio waves, microwaves, infrared (IR), visible light, ultra violet, X-rays to gamma rays based on increasing frequency of the wave. There is no single source to emit the spectral bands. Microwaves are emitted by magnetron, IR is emitted by incandescent object, visible light is emitted by tube lights, X-rays are produce when electron knocks a metal plate and Gamma rays are emitted by radioactive sources. Gamma rays and X-rays have higher frequency, more energy (E=hf) and involves expensive devices for generation. Each spectral band of wave may have different effects on seed and plant germination. EM wave interact with plant or matter in terms of frequency of the wave and penetration depth of the wave in medium.

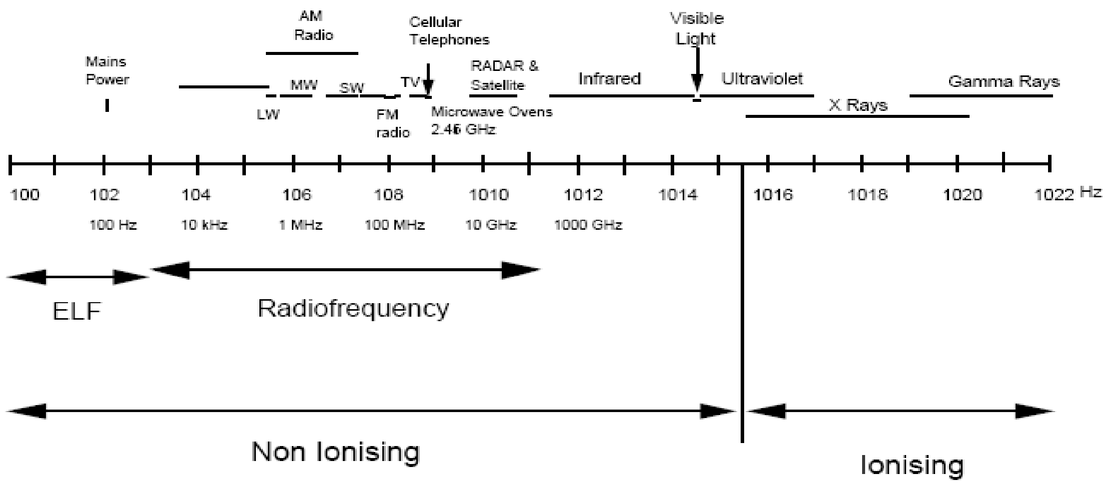


Figure 2-1: The electromagnetic spectrum

2.4 Characteristic of EM wave

The characteristic of EM field is mainly described by its energy content, which is related to its frequency by E=hf, where E= Electric field, h= plank constant and f= frequency. All EM wave consists of electrical **E** and magnetic **H** field components vibrating in phase and perpendicular to direction of propagation. EM waves differ depending upon frequency or wavelength. Frequency or corresponding wavelength defines the characteristics of EM wave. Frequency (f) and wavelength (λ) are connected by the following equation:

$\lambda = c / f$,

where $c = 3 * 10^8 \text{m/s}$ is the speed of EM wave in vaccum.

All the waves can be described mathematically by the following equation [2]:

$y(x,t) = A\cos(\frac{2\pi t}{T} - \frac{2\pi x}{\lambda} + \emptyset_0)$

where A is the amplitude of the wave, T its time period, λ is its spatial wavelength and $\emptyset_0$ is a reference phase.

The existence of electromagnetic wave, presumes time varying electric and magnetic fields connected in a way such that one creates other in a degree proportional to the rate of variation. The Maxwell's equation relates the electric and magnetic fields in different conditions. Table 2-1 summarizes the Maxwell's equations in various forms.

Table 2-1: Maxwell's equations

	Integral form in the absence of magnetic or polarizable media	Differential form in the absence of magnetic or polarizable media	Differential form with magnetic and/or polarizable media
Gauss's Law for electricity	$\oint \vec{E}\,.d\vec{A} = \frac{q}{\varepsilon_o}$	$\nabla.E = \frac{\rho}{\varepsilon_o}$	$\nabla.D = \rho$
Gauss's Law for magnetism	$\oint \vec{B}.d\vec{A} = 0$	$\nabla.B = 0$	$\nabla.B = 0$
Faraday's Law of induction	$\oint \vec{E}.d\vec{s} = -\frac{d\emptyset_B}{dt}$	$\nabla \times E = -\frac{\partial B}{\partial t}$	$\nabla \times E = -\frac{\partial B}{\partial t}$
Ampere's Law	$\oint \vec{B}.d\vec{s} = \mu_0 i + \frac{1}{c^2}\frac{\partial}{\partial t}\int \vec{E}.d\vec{A}$	$\nabla \times B = \frac{J}{\epsilon_0\, c^2} + \frac{1}{c^2}\frac{\partial E}{\partial t}$	$\nabla \times H = J + \frac{\partial D}{\partial t}$

2.5 Magnetic field

All the magnetic field has two components namely Magnetic Force (F or mmf), and the magnetic flux (Φ). Amperes law states that the total magnetic force, F integrated along any closed path is equal to the total current enclosed by that path. Wherever there is current flow there is a corresponding magnetic force. SI unit of magnetic force is N. The unit of magnetic field is Gauss or Tesla (1T= 10,000G). Table 2-2 illustrates the typical B value in various applications [15].

2.5.1 Magnetic Force (potential) can be described vectorially, or as a series of equipotential surfaces. Magnetic force equipotential surfaces are not closed surfaces.

These surfaces terminate, and are bounded, by the current flow that produces the field. The spacing between the equipotential surfaces gives the magnetic field Intensity (H, in Amps/meter).

2.5.2 Magnetic Flux (Φ, in Webers) can be described vectorially, or in more physical terms, as lines. Flux lines always form closed loops. No flux line ever begins or terminates. In any homogeneous region, flux lines are normal to the magnetic force equipotential surfaces. The spacing between flux lines indicates Flux Density (B, in Tesla). For any homogeneous region, Flux Density, B, is proportional to Field Intensity, H and related by the following equation:

$B=\mu H$

$\mu = \mu_0 \mu_r$

where μ_0 is the permeability of free space or any nonmagnetic material and μ_r the permeability of a magnetic material relative to free space.

$\mu_0 = 4\pi \text{ x } 10^7$

Table 2-2 Typical B field values in selected applications

Application	B field (Teslas)
Sensitivity of a scanning SQUID microscope	10^{-16}
Human Brain	10^{-13}
Intergalactic and interstellar magnetic fields	10^{-11}
Human heart	10^{-9}-10^{-8}
Earth's magnetic field	0.5×10^{-5}
Refrigerator magnets	10^{-4}- 8×10^{-3}
Electron beam of CRT	5×10^{-4}-10^{-3}
Magnetic read switch	10^{-3}- 2×10^{-3}
1-horsepower electric motor	0.1-0.2
Rare-earth permanent magnets	2
Magnetic Resonance Imaging	0.5-5
High-energy particle accelerators	10
World Record Continuous Field	45 T
Long-Pulse Magnet (800 ms)	60
Strongest Destructive Pulsed Magnet at NHMFL-Los Alamos (4-8 μs)	850
Neutron Stars	10^{8}

2.6 Power Density

The RF field is usually expressed in power density. Power density is the product of Electric field density and the Magnetic field density.

Power Density (W/m^2) = E x H

Power Density in Watts per square metre (W/m2)

E - Field in Volts per metre (V/m)

H- Field in Amps per metre (A/m)

The power density from the transmitter is also given by,

Power Density = $PG/4\pi d^2$ (W/m2)

where, P = the maximum output power

G = the antenna gain, d = the distance from the antenna

The power density depends on the square of distance between the transmitter and the antenna and the field strength close to the small transmitter is larger than the field strength at a greater distance from a large transmitter.

2.7 Artificial Electromagnetic Waves and Natural Light

Artificial Electromagnetic waves are emitted my manmade electronic equipments and electrical circuits. They are lower than the infrared frequency, $\nu < 3 * 10^{11}$ Hz, may be continuous wave and linearly polarized. On the other hand, EM waves emitted by natural sources and some artificial lights are not polarized. They are emitted discontinuously in the form of quanta photons and are above infrared frequency, $\nu > 3 * 10^{11}$ Hz. Polarized wave have a tendency to bring interference effect and become bioactive compared to non polarized wave [3]. Table 2-3 shows the artificial electromagnetic waves from different application.

Table: 2-3 Artificial Electromagnetic Waves

Frequency Zone	Frequency	Wavelength (air)	Transmission Sources
E.L.F	0-300 Hz	> 1000 km	Electricity lines, Radio frequencies, Underwater communication
V.F	0.3-3 kHz	1000-100 km	Human voice, Acoustic frequencies
V.L.F	3-30 kHz	100-10 km	Acoustic frequencies
L.F.	30-300 kHz	10-1 km	Navigational radio frequency, Long-distance communication
M.F.	0.3-3 MHz	1-0.1 km	Navigational radio frequency, amateur radio stations
H.F.	3-30 MHz	100-10 m	Amateur international radio stations, Airport control
V.H.F	30-300 MHz	10-1 m	Police, stations FM-VHF-TV, Airport and Navigation control
U.H.F.	0.3-3 GHz	1-0.1 m	Taxi communication, Police, UHF-TV, Microwave oven, Medical diathermy
S.H.F.	3- 30 GHz	10-1 cm	RADAR, Satellite communication
E.H.F.	30-300 GHz	1-0.1 cm	RADAR, Satellite communication, Radio spectra measurement
I.R.	300 GHz-300 THz	1m-100 um	Surveillance, Electronic war, Industrial heating

2.8 Ionizing and Non-ionizing EM radiation

Electromagnetic waves are carried by particles called quanta. Quanta of higher frequencies carry more energy than the quanta of lower frequencies. The EM wave has more energy per quanta means they can break the chemical bond of material they are exposed to. In electromagnetic spectrum, radiation from EM fields with high order of frequencies is classified as ionizing radiation. Low frequency EM fields whose quanta are insufficient to break molecular bonds are called non-ionizing radiation. Gamma rays, X-rays are examples of ionizing radiation where as radiation form electricity, microwaves and radiofrequency fields are found at the relatively long wavelength and low frequency and are classified as non-ionizing radiation. Non-ionizing radiation ranges from 0 to approximately $3x10^{11}$ Hz which is the lower limit of infrared radiation. Similarly radiation above $3x10^{11}$ Hz is considered as ionizing radiation [4]. Table 2-4 differentiates ionizing and non-ionizing in terms of energy level.

Table 2-4: Energy levels for different types of ionizing and non-ionizing radiation

	Energy (eV)	
Gamma radiation	10^{3}-10^{6}	Ionizing radiation
Ultraviolet radiation	~6	
Optical radiation	~3	Non-ionizing radiation
RF	10^{-6}	
ELF	10^{-13}	

2.9 Specific Absorption Rate

A common way to describe the absorption of EM field in matter is to calculate the specific absorption rate or SAR. SAR is the measure of the absorption of non-ionizing

EM radiation by living tissue. Mathematically it is defined as the quantity of energy per unit time (P) to the unit mass (m) of the living tissue. Its unit is W/Kg.

$$SAR = \frac{P}{m}$$

When Electric field intensity, E, within the body the relation becomes:

$$SAR = \frac{\sigma E^2}{\rho}$$

where σ is the specific conductivity (S/m) of the body and ρ is the density of the living tissue (kg/m^3).

SAR can be measured by inserting micro-antennas within the measured body to determine E field or by measuring the induced current in the matter.

2.10 Use of Electromagnetic Waves

The interaction between living cells and EM wave is a complex subject due to diversity of living cells and the physical phenomena that comes into play. Each living cells react differently with different wavelength of radiation. The EM wave interaction depends upon the intensity of exposure, frequency of wave and duration of exposure. Depending upon frequency and intensity, EM exposure may lead to altercation or breakdown of chemical or genetic link, heat generation and may be favorable for cell growth. The advantage of EM experimental technique on plant and animal cells is that it doesn't leave any toxic residue.

2.11 Forms of Electromagnetic Field

Electromagnetic fields can have static, time varying, sinusoidal, pulsed or damped pulses wave forms. Following figures show the intensity of electromagnetic field having various waveforms as a function of time.

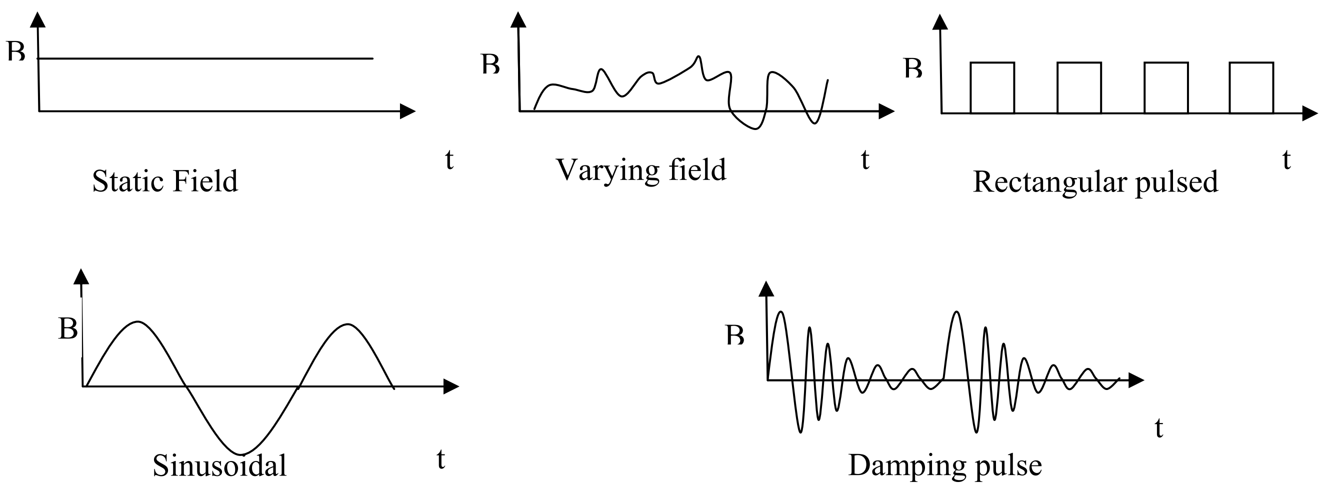


Figure 2-2: Different Forms of Electromagnetic Fields

2.12 Electromagnetic radiation – Threat to human health

Many people fear that EM radiation has memory loss and carcinogenic effect. However there is no concrete evidence established between cancer and the EM radiation. Nevertheless, it is impossible to prove that no study will ever find a significant correlation between EMFs and cancer or any other disease or disorder. A study shows that children living close to high voltage power lines at birth have slight tendency of having leukemia [5]. A review of available literature and research regarding possible human health risks associated with exposure to DC (Static) magnetic fields reveals limited concern except in very high DC field environments. In the last several years various research groups have written about the impact of Electromagnetic radiation on human, plant, animal and living system. Static magnetic fields are known to cause increased blood pressure on some individuals [6]. It has been reported that damage to corneal epithelium in Cynomolgus monkeys after 2.45 GHz irradiation for 6 hours at only 20-30 mW/cm^2 (CW) or even 10-15 mW/cm^2 with pulsed fields [7]. The relationship between the electromagnetic fields and health of people is increasingly being investigated. International organizations have proposed bylaws that put limits on the value of the generated magnetic field. Following are the evidence that extremely low frequency magnetic field do affect living cells and tissues [8].

- In 1977, Robert Becker, physician and biophysicist Andrew Marino testified before the New York State Public Service Commission about the results of their experiment that
- In 1979, Nancy Wertheimer an epidemiologist and physicist Ed Leeper published a study that showed a statistical link between childhood cancers and the proximity of certain types of high-current power lines to the home.
- In 1988, the Maryland Department of Health and Hygiene found an unusually high rate of fatal brain cancer among men employed in electrical occupations.
- In 1989, John Hopkins University found an elevated risk of all cancers among New York Telephone Company cable splicers.
- In 1990, David Savitz, an epidemiologist at the University of North Carolina, determined through a study that pregnant woman who used electric blankets have children who have a 30% increased risk of cancer as compared to children whose mothers didn't use electric blankets.

2.13 Bioelectric effects

The well documented effect of EM fields is heating effect. The heating effect is defined by SAR. The greater the absorption rate, the more likely that significant heat occurs [9]. Higher frequency and high intensity of EM field give rise to SAR effect. In this thesis, however, low intensity and low frequency magnetic field is used for seeds treatment. The magnetic field exposure at non-thermal level probably has little effect due to heat. The mechanism by which ELF field affect a biological tissue is still not exactly known. But it has been shown that cells and tissues are affected by ELF magnetic field. In molecular level changes have been noted in the kinetics of some cellular biochemical reaction, changes in DNA synthesis and RNA transcription upon the application of magnetic field. Not all ELF radiation proves that there is an altercation at cellular level. Some effects are only noted at discrete frequencies and amplitude of the magnetic field. Others depend on the strength, orientation and duration of the exposed field.

2.14 Helmholtz Coil

Helmholtz coils are used to generate uniform magnetic field for different research application. They have application in calibrating sensors and different low frequency magnetic field testing. Helmholtz coils can be easily constructed and the fields are easily calculated. Chapter 4 of this thesis discusses the design, simulation, construction, calculation and measurement of Helmholtz coil fields to be used for soybean treatment.

2.15 TEM Cell

A TEM (Transverse Electric and Magnetic) cell is rectangular or square coaxial transmission line. TEM cell is tapered at both ends of an enclosed unit. The cell is fed at one end with a signal generator and terminated at the other end by resistor equal to the characteristic impedance of the line. The electromagnetic field generated by the source propagates between the septum, the inner conductor and the grounded metal exterior in the free space. The exterior of the transmission line forms the enclosure of the internal field which would otherwise radiated in the external environment. Hence, prevents field to interfere with peripheral equipment and shields the internal volume from external electromagnetic environment. The filed in the TEM cell is well characterized and uniform within the test volume. The shortcoming with the TEM cell is the frequency limit is determined by the size of the cell and the limited test volume. [10]

TEM cells generate a uniform or a homogenous field and 1/3rd the area of the TEM cell structure has the uniform field for experimentation. Wide band of frequencies can be coupled to TEM cell ranging from DC to 400MHz. This makes TEM cell versatile for bio related experimentation. For a matched TEM cell electric field strength along the septum axis of TEM cell is given by,

$$E = \frac{\sqrt{P Z_0}}{d}$$

where P is Power, Z_o characteristic impedance and d distance between septum and the outer conductor of the cell.

The magnetic field strength H and the power density S have the following expressions:

$$H = \frac{\sqrt{P Z_0}}{d \; Z_{00}}$$

$$S = E \cdot H = \frac{E^2}{Z_{00}} = Z_{00} \, H^2 = \frac{P Z_0}{d^2 \; Z_{00}}$$

Z_{oo} is the impedance of free space and mathematically,

$Z_{oo}=E/H=377\Omega$

The usable volume of the exposure of the TEM cell system has to be big enough to allow uniform exposure of many samples. The exposure system should have good shielding of EMF, generated within the cell. This is important for protection of operator and to eliminate parasitical radiation.

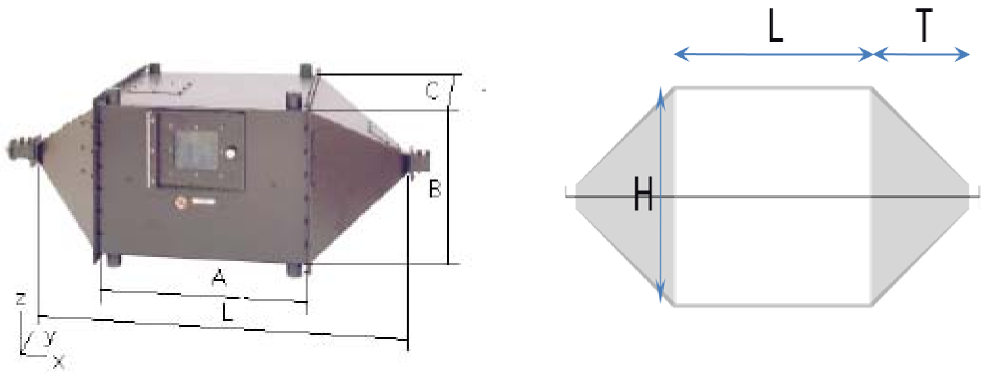


Figure 2-3 General View and Front view of TEM Cell [11]

2.16 Anechoic Chamber

An Electromagnetic anechoic chamber is a shielded room whose walls have been covered with a material that scatters or absorbs so much of the incident energy that it can simulate free space. Recent innovations such as the use of ferrite tiles have greatly enhanced performance of these chambers. The EM field treatment of soybean is done using TC4000B test cell. TC4000B is semi anechoic chamber that falls in between the TEM cell and expensive anechoic chamber. The interior of the chamber enclosure, lined with a radio frequency absorbing material, creates a self-contained, semi-anechoic enclosure that includes field launching/receiving devices. An internal log-periodic antenna acts as a launching/receiving device at higher frequencies. Vertical or horizontal polarization is user selected. The high-efficiency launching device allows 80-4.2GHz, 10V/m field strengths with 80% AM modulation to be generated at the preferred 3 meter distance with a 150 watt RF source for immunity compliance testing [12]. For the seeds treatment 80 MHz of frequency and 50 watt power setting was used. Seeds are placed at far field approximately 3 m away from periodic log antenna. Figure 1-4 shows the schematic diagram of TC4000B Anechoic Chamber and Figure 1-5 is the Semi Anechoic chamber at the lab.

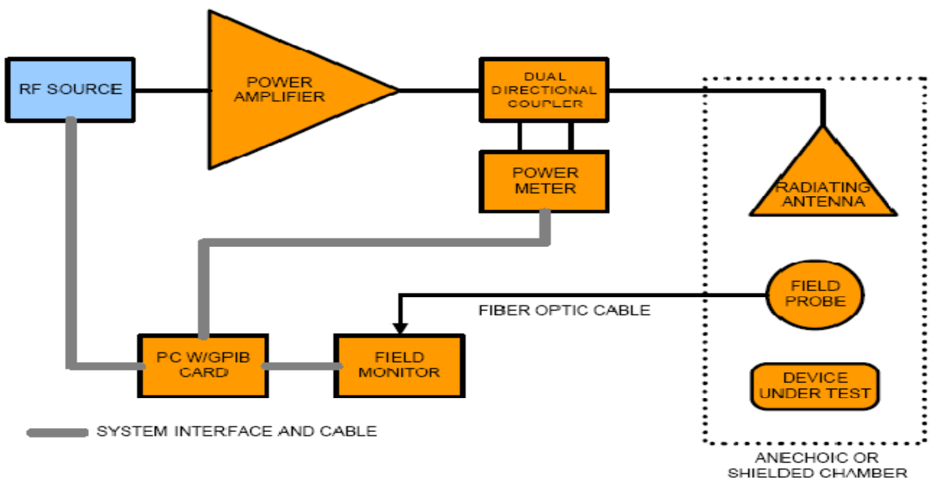


Figure 2-4 Schematic diagram of TC 4000B Anechoic Chamber

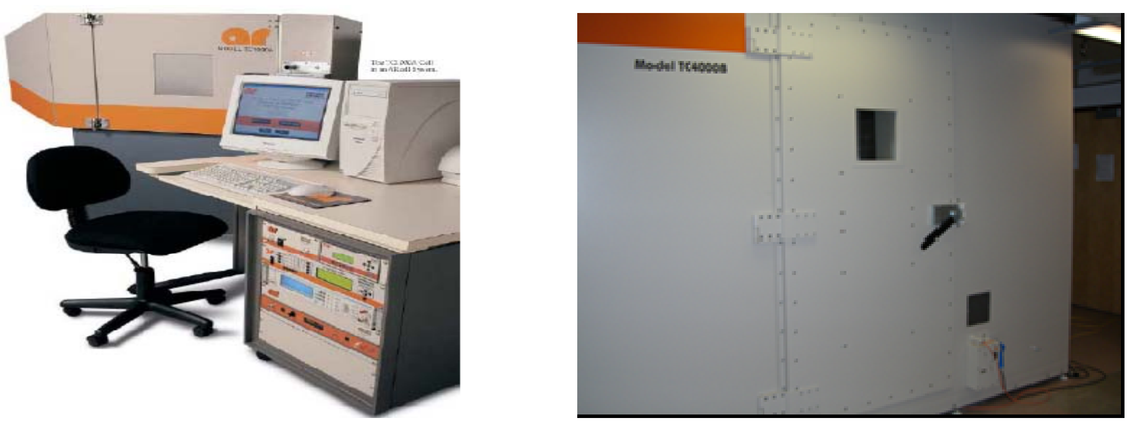


Figure 2-5 Anechoic Chamber at EM Lab

2.17 Soybean

Soybean is a plant of Asian origin that produces beans used in many food products. Soybean seeds are small round greenish-yellow in color. Magellan, Maverick, SS97-6946 and Williams 82 are some of the varieties of soybean. Magellan is chosen for seed treatment as previous studies shows that it is most responsive to electromagnetic field. Soybeans contains high amount of protein and contain beneficial photochemical, such as isoflavones, which may help fight chronic diseases. A mature soybean is 38% protein, 30% carbohydrate, 18% oil and 14% moisture, ash and hull (www.asasoya.org). More soybeans are grown in the United States than anywhere else in the world. Figure 2-6 and 2-7 shows the distribution of world and US soybean production in 2006. Presently the U. S. is at 38%. Although it varies from year to year, in general, Iowa and Illinois are the two largest producing states followed by Minnesota, Indiana, Ohio, Missouri and Arkansas.

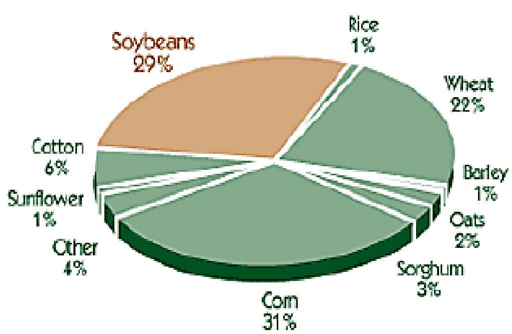


Figure 2-6: World soybean production in 2006 [USDA]

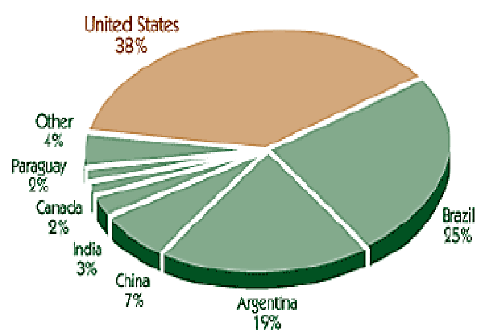


Figure 2-7: US soybean production in 2006 [USDA]

Soybean butter and soymilk are two widely consumed products in the market. The first notable use of soymilk in the U. S. was infant formula. 1909, an American pediatrician created the first soy-based infant formula and soymilk from soy powder. In 1913 was the first patent for soymilk in the U. S. and the first commercial production of soymilk started in 1917. Soy products contain isoflavones (estrogen-like substances) that are being studied for the prevention of cancer, hot flashes that occur with menopause, and osteoporosis (loss of bone density). Soy products in the diet may lower cholesterol levels and reduce the risk of heart disease. It is also called soy, soya and Glycine max. Of the many varieties of seeds used as a potential biofuel resource (such as corn, canola, olive and soybean), soybean is the most efficient with the highest energy emitted per gram per second [13]. If the yield of soybean can be improved it can also be cost competitive with fossil fuels.

2.18 CST Microwave Studio 2008

CST MICROWAVE STUDIO® (CST MWS) is the software application tool for most efficient and accurate computational solutions to 3D electromagnetic designs. CST MWS specializes in providing fast and accurate 3D electromagnetic simulation of generally high frequency problems. CST MWS is one component of the CST STUDIO SUITE™ package, which includes CST DESIGN ENVIRONMENT™, CST DESIGN STUDIO™, CST EM STUDIO™ and CST PARTICLE STUDIO™. We have used CST MWS for the simulation of the Magnetic Field Intensity H [14].

CHAPTER 3

LITERATURE REVIEW

3.1 Introduction

Environmental conditions that effecting plant growth such as light, moisture, temperature etc are well documented and research papers based on these studies are extensively available. However, not much information is available on the response, behavior and growth of plants and seeds when exposed to electromagnetic fields. Research in this topic area is few and far between. Early research on the effects of static or extremely low alternating magnetic field of low intensity suggested negative effects (retarding growth, death etc) on various living organism, including plants. Besides experiments on plants, animals etc, research were also conducted on plants and animals at the cellular and molecular levels. Some of the frequency ranges covered in the early electromagnetic field effects studies include:

i) Microwave region of 300 MHz to -300 GHz: The possible effect of cancer in living organism was studied by induction of brain tumors in rat and exposure of radiofrequency. [16]

ii) Static or DC magnetic field region: The orientation of migratory birds on geomagnetic field was studied. Similarly, effect of plant growth and biochemical activities of living cell under the influence of static magnetic field was studied [18].

iii) Extremely Low Magnetic field generated by currents of 10-100 Hz: The effect of EM field from high voltage transmission line and electric engine on human and animal were studied [17].

In this chapter some of the results from research papers describing the effect EM field on seeds and plants in terms of physiology and chemical composition have been discussed. This includes research papers on plants and seedling germination following exposure at low frequency magnetic fields. Studies of electromagnetic field on seeds and plant germination are also discussed.

3.2 Zea may plant under static magnetic field

Zea may seeds were germinated and then cultivated under the static magnetic field of 50 mT. The results analyzed after 14 days of cultivation shows that there was increase in average plant length, enhancement of fresh tissue mass and chlorophyll ratio was increased. When magnetic field was increased to 100 and 150 mT inhibitory effect was seen in all the measured parameters. [18]

3.3 Mitochondria activities under static magnetic field

The NG108-15 cell-line (Neuro-blastoma) was exposed to the static magnetic field between 15 to 100 mT. The cell motion and configuration were studied when exposed to the magnetic field and compared with the control. The mitochondria activities of the exposed cell were promoted, affecting the normal behavior of cell [19]. Figure 3-1shows that the mitochondria activities of the cells exposed to static magnetic field of 100 mT is 1.5 high compared to that of control.

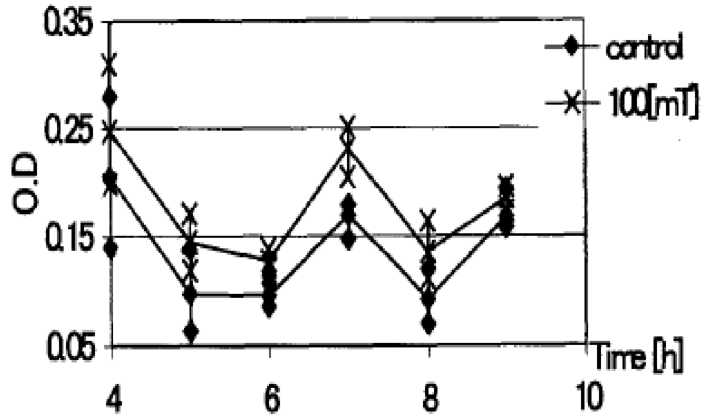
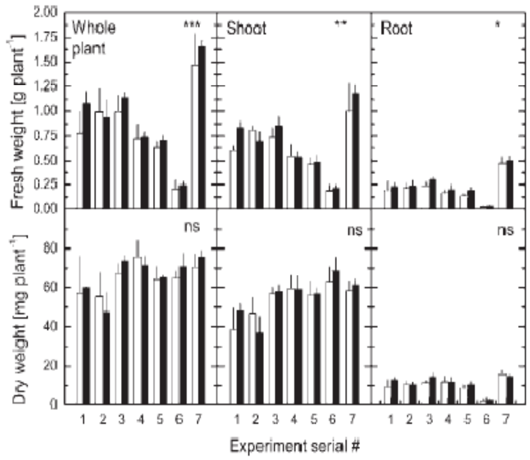


Figure 3-1: Mitochondria activities based on microculture tetrazolium (MMT) assay [19]

3.4 Effect of AC magnetic field on Sunflower and Wheat Plant

The effect of weak 16.66 Hz magnetic fields on growth parameters of Sunflower and Wheat seedlings was studied to show that even weak, low frequency magnetic field has influence on plant germination and seedling growth [20]. Wheat seeds and sunflower seeds were germinated and treated with AC magnetic field of 16.66 Hz, 12 uT for 12 days. The result was analyzed statically based on length of root and shoot, total fresh weight and dry weight. Sunflower seedling exposed to magnetic field showed, small, but significant increases in total fresh weights, shoot fresh weight, and root fresh weight, where as dry weights and germination rate was statistically constant when compared to control. The magnetically exposed wheat shows marginally higher root fresh and dry weights, total fresh weight and higher germination rate. The experiment demonstrate that even low frequency and low intensity magnetic field influence plant physiology.



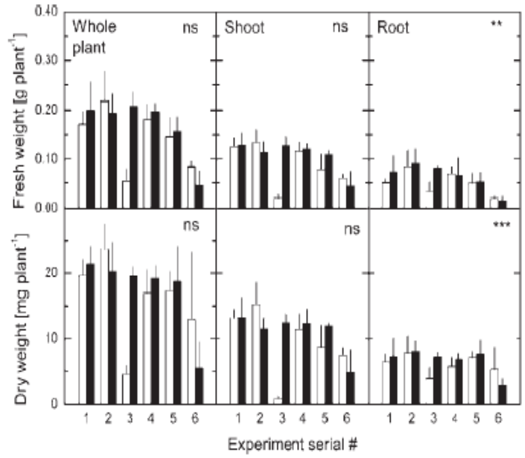


Figure 3-2-1 **Figure 3-2-2**

Effect of 20 uT, 16.66 Hz magnetic field on fresh and dry weight of (1) sunflower seedling and (2) young wheat seedlings. Black columns: treatment; White columns: controls. Twelve seeds in each experimental group

3.5 AC electric and magnetic fields on tomato seeds

In this paper [21] the germination rate of tomato seeds (Lycopersicum esculentum L.) were studied while they were exposed to both electric field and magnetic field. The seeds were exposed with various 60 Hz AC electric fields ranging from 4 to 12 kV/cm using parallel plate electrodes. The magnetic field was created using rectangular type transformer core (3 kVA capacity, 6000 turns) with 60 mm air gap spacing where magnetic cell was placed. The magnetic field in the cell was varied from 3G to 1000 G by changing the applied current and exposure time was between 15 to 60 s. It was found that percentage of germination increased by 1.1 to 2.8 times compared to the seeds in control. However, there was an inhibitory effect when seeds were exposed in the electric field higher than 12 kV/cm and the exposure time more than 60 s.

3.6 AC Magnetic Field on the Growth of the Primary Root of Corn

In this paper [22] Corn seeds were germinated and seeds with relatively straight roots were chosen and placed in hermetically sealed experimental box between the magnetic poles of electromagnet. The germinated seeds were exposed to magnetic field of 0.005 T at frequencies 40, 80, 120, 160, 200, 280, and 320 Hz. When compared to control in the fields of 40, 80, 120, and 160 Hz the growth were enhanced, but, in the fields of 240, 280, and 320 Hz the growth was reduced. The relatively low frequencies were constructive for primary growth of root while compared to high frequencies.

3.7 Low Frequency Magnetic Field Exposure on Maize seeds

Maize seeds from the single genitor plant were taken for this experimental study [23]. Seeds were germinated and exposed to magnetic field of various doses (1-2-4-8-10 mT) at 50 Hz for the exposure time of two hours. The magnetic field was generated using Helmholtz coil having diameter 26 cm and 1000 turns. Pigment and average nucleic acid level were analyzed using spectrophotometric methods. The level of chlorophyll and total carotenoid was calculated with quantitative formula. The plant individual length was measured and compared with control. Fig 3-3-a shows that for highest value of magnetic field (4-8-10 mT) the average length of plant is relatively diminished compared to control. Figure 3-3-b shows that average nucleic acid level is diminished up to 12% compared to control. It can be inferred that magnetic simulation affects the photosynthesis process while nucleic acid biosynthesis is inhibited. It also shows that high intensity of magnetic field may not be generous for plant growth.

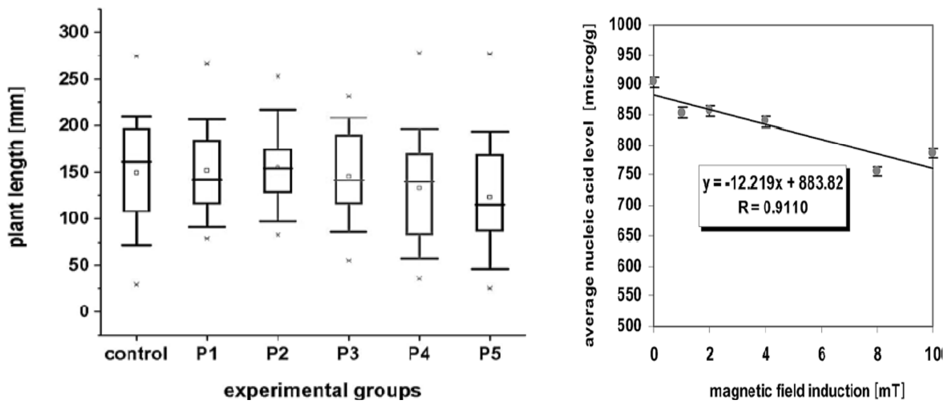


Figure 3-3: Plant growth at different magnetic field (0-1-2-4-8-10 mT) and the average nucleic acid level at different magnetic field

3.8 Effects of Electric Field on Bean Sprout Growing

This paper [24] presents the effect of electric field on Bean sprouts growing. Healthy bean sprout seeds were segregated and soaked in water for 6 hours. Seeds were planted in two different plastic containers. First group was exposed in the 25 kV/cm of electric field and other was kept as control. 5kV of DC voltage was applied to generate 25 kV/cm of field as shown as in figure 3-4. Length of root and stem was recorded from day 1 to 5. It was observed that the bean growing in electric field has longer root and stem compared to the control. The table one shows the statistical comparison between E-field and without E-field.

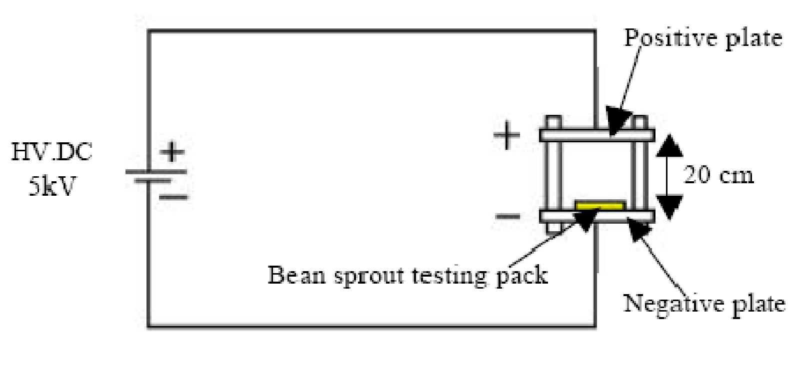


Figure 3-4: Experimental set up with 25 kV E-field

Table 3-1: Mean, standard deviation and Z-value of the height of the stem and the length of root

	Mean		S.D		Z-value
	With E field	Without E field	With E field	Without E field	
Height of stem	36 mm	29 mm	25	25	1.98
Length of root.	41 mm	31 mm	23	16	3.57

3.9 Effect of Pulsed Variable Magnetic Fields over Wheat Seeds

This paper [25] shows that when pulse variable magnetic field is correctly administered it has significant effect on plant cell multiplication, growing and division. Two sets of experiments were performed. In the first set, wheat seeds soaked in water was exposed to constant magnetic field intensity of 400 uT while the exposure time was varied. In the second set the exposure time was maintained constant for 8 minutes but the intensity was varied (100, 200, 400 uT). The source of pulsed magnetic field was Vita-life eMRS with frequency variation of 0.01 to 20000 Hz. The triangular wave was generated. After 5 days the average mass and length of the plants were measured and compared with control.

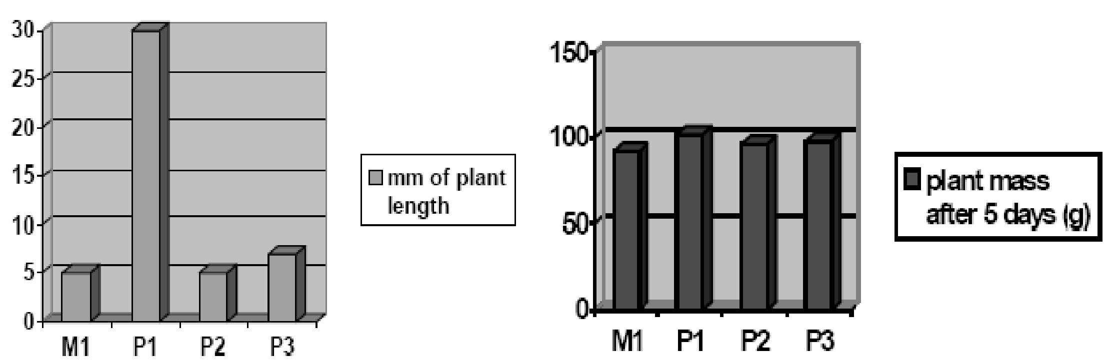


Figure 3-5 Plant length and weight for B=400 uT and exposure time 8, 16, 24 minutes

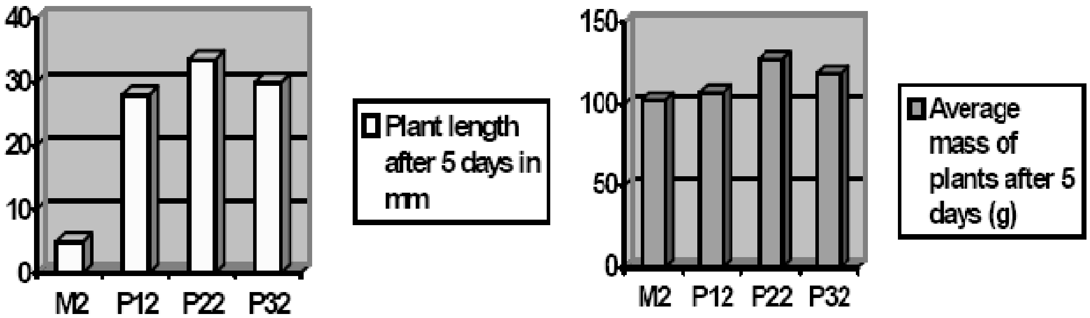


Figure 3-6 Plant length and weight for exposure time=8minutes and B= 100, 200, 400 uT

3.10 Influence of ferrofluid and a static magnetic field on Zea mays

This paper [26] describes the effect of static magnetic field on Zea mays plants interms of photosynthesis pigments. Seeds from singe Zea mays plant were germinated on water porous paper in petri dishes each with 50 seeds. After germination each petri dish is supplied with 10 mL ferrofluid solution for 15 days. The experiments were conducted in same environment in terms of temperature, illumination and humidity. Experimental variant was the magnetic field. The first set was the sample with aqueous ferrofluid supplied (LMW) and the second was supplied with aqueous ferrofluid in presence of static magnetic field of 50 mT (LMW-NMF) such that North pole was in contact with dishes. The experiment was carried out with different concentration of aqueous ferrofluids solution (10, 50,100, 150, 200 and 250 uL/L. After 15 days of germination contents of photosynthesis pigments (a and b chlorophylls and total carotenoids) in the tissue of plants were analyzed.

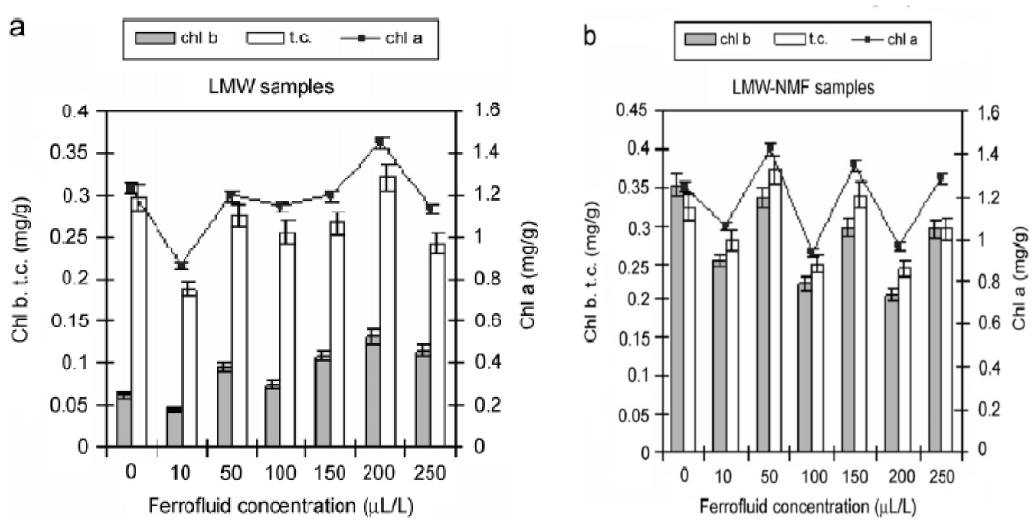


Figure 3-7: Assimilatory pigments content in Zea mays plants after supplying with aqueous ferrofluid in a) LMW sample array, b) LMW-NMF sample array

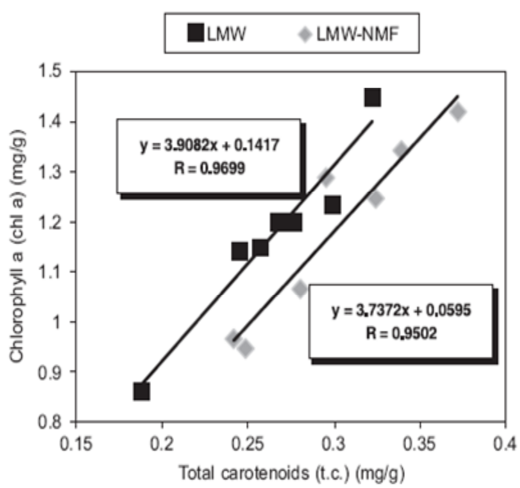


Figure 3-8: Linear correlation between chlorophyll a total carotenoids pigments level for the two sample arrays

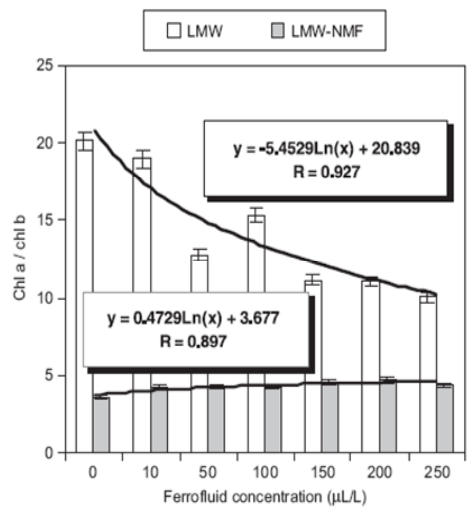


Figure 3-9: Chlorophylls ratio level in LWM and LMW-NMF sample.

There were no significant change in chlorophyll a levels but chlorophyll b level was significantly increased for LMW-NMF while compared to LMW samples in Figure 3-7. Figure 3-8 shows that good linear correlation between chlorophyll a and total carotenoid pigment levels. Figure 3-9 shows the chlorophyll ratio against the ferrofluid concentration. There is a logarithmic decrease of chlorophyll ratio for LMW samples and slight increase in the ratio for LMW-NNF samples while aqueous ferrofluid concentration is increased. The chlorophyll ratio was smaller in LMW-NNF samples than in LMW.

3.11 Effect of 60 Hz Magnetic Field on Raddish Seedlings

Radish Raphanus sativus L. seedlings were exposed to an extremely low frequency magnetic field (ELF MF) and various parameters such as CO2 intake was investigated. Radish seedlings were exposed to a 60 Hz, 50 mT root mean square sinusoidal magnetic field (MF) and a parallel 48 mT static MF for 6 days immediately after germination. Control seedlings were maintained in geomagnetic field. TheCO2 uptake rate of ELFMF exposed seedlings on day 5 and later was lower than that of the control seedlings. This shows that photosynthesis process is affected. The dry weight and the cotyledon area of ELFMF exposed seedlings on day 6 and the fresh weight, the dry weight and the leaf area of ELF MF exposed seedlings on day 15 were significantly lower than those of the control seedlings, respectively [27].

Table 3-2: CO2 Uptake Rate per Seedling of Radish Seedlings Exposed to the ELF MF or Ambient MF (Control) for 6 d

	Replication				
	1	2	3	4	5
Control (nmol CO_2/s)	3.24	2.77	2.70	3.33	4.24
ELF MF (nmol CO_2/s)	2.28	2.73	2.45	2.06	4.00

3.12 Bean seeds exposed to static magnetic field

The faba bean plants were grown out of the seeds treated with the static magnetic field prior to sowing. The aim of this [28] study was the estimation of changes in the growth, development and dynamics of dry matter accumulation course of faba bean plants. A determinate form of faba bean seeds (Tim) were exposed to different doses of magnetic field intensity: D1 – 10750 J m-3 s (B = 30 mT, s = 15 s), D2 – 85987 J m-3 s (B = 85 mT, s = 15 s) and D0 – without stimulation (control). Seed treatment with magnetic field positively affected plant emergence, modified the course of individual faba bean developmental phases, and had a significant effect on dry matter accumulation rate in particular plant organs and on their size. The highest effect of this treatment on the increase of vegetative organs dry matter yield had place at flowering and pod setting period, and in the case of the generative organs – during seeds filling and maturation of pods.

3.13 Stimulation of germination in rice by a static magnetic field

In this study [29] rice (*Oryza sativa* L.) was exposed to static magnetic field in the laboratory conditions and the percenatage and rate of germination of the same was studied. The seeds were exposed to 150 mT and 250 mT of static magnetic fields both chronically and for 20 min after seeding. Nonexposed seeds were used as control. Chronic exposure to a 150-mT magnetic field increased ($p < 0.05$) both the rate and percentage of germination relative to nonexposed seeds (18% at 48 h). Significant differences were also obtained for seeds exposed to a 250-mT magnetic field for 20 min (12% at 48 h). Additionally, seeds were moistened with water magnetically treated by static and dynamic methods. Dynamic and static treatment of water improved the germination of seeds related to the control, but significant differences ($p < 0.05$) were only obtained for the dynamic method (16% at 48 h).

3.14 Effect of Weak Sinusoidal Magnetic Field on Germination and Yield of Cotton

It is studied [30] that the outcome of a preliminary study on the effects of sinusoidal magnetic fields on percentage germination, growth, and yield of cotton (*Gossypium* species). The essential variable parameters employed were the intensity of magnetic field, frequencies and the cotton seeds having different germination capacities. Three different class of Var.spch-1 cotton seeds having the germinating capacities of Type 1—31%, Type 2—49% and Type 3—64% were used for the experiment. The seeds were subjected to magnetic fields with nine different frequencies and intensities as follows: A. 1 Hz, 100 nT; B. 1 Hz, 1500 nT; C. 1 Hz, 4000 nT; D. 10 Hz, 100 nT; E. 10 Hz, 1500 nT; F. 10 Hz, 4000 nT; G. 100 Hz, 100 nT; H. 100 Hz, 1500 nT; I. 100 Hz, 4000 nT. In Type 3 cotton seeds exposed to 10 Hz, 100 nT fields, the yield was 75.3% higher than that of control, and in Type 2 cotton seeds exposed to 100 Hz, 1500 nT fields, the yield was 85.2% higher than that of control. The result shows that the presowing cotton seeds when exposed to extremely low frequency catalyze the type 2 cotton to yield more compared to the non exposed controls. The yield is also frequency dependent. Only the seeds exposed to particular frequency yields better.

3.15 Influence of magnetic field on biological characteristics of Maize seeds

The study [31] on magnetic field effect on the growth parameters and germination rate of maize seeds was done. The germination energy, germination, fresh weight and sooth length was compared with the control. The magnetic field strength of 0.15 T (static) was applied for 10, 15, 20 and 30 minutes. It was established that the enhancing effect would occur at 10- min exposure and the most strongly expressed simulation was for the fresh weight of shoots. Similarly, it was established that the water extract extinction for the treated samples increased by 80% compared to the non-exposed ones. Data in Table 1 show the germination energy GE, germination G and germination uniformity D of the seeds that were detected after 10, 15 and 20 min of exposure. The fresh weight m and the shoot length l on the 7^{th} day were measured for the three variants. The treatment of maize seeds with a magnetic field of an induction of 0.15 T had an optimal effect at 10-min exposure. Then a maximal increase was observed compared to the control: by 72 % for the fresh weight and by 25 % for the shoot length. A change of the specific electroconductivity of the water extract has been detected after submitting it to the magnetic field effect, the change disappearing after stopping the magnetic field treatment. Maybe it is due to the diffusion of the ions, which change their trajectories in the magnetic field.

Table 3-3 Indices of seed vitality of *Zea mais*, treated by a magnetic field

Variety	GE, %	G, %	D, %	l		m		σ, $\Omega^{-1}m^{-1}$
				mm	%	*g*	%	
Control	56	85	12	15,2	100	0,59	100	0,0122
10 *min*	80	100	14	20,2	125	1,01	172	0,0131
15 *min*	64	100	14	18, 4	110	0,72	122	0,018
20 *min*	48	100	14	19,9	108	0,68	115	0,017
30 *min*	44	100	14	18,2	110	0,76	129	0,0117
5,0%	39,64	18,581	2,477	5,499		0,43		0,008
GD 1,0%	65,82	30,857	4,114	9,133		0,72		0,013
0,1%	98,17	46,018	6,135	13,62		1,08		0,0198

In this chapter various research and papers showing the effect of electromagnetic exposure on seeds and plant are cited, specifically stimulation of seeds and plants following electromagnetic field, electric and magnetic field exposure were discussed. The magnetic field treatment involved both static and alternating fields. Most of the studies quoted in this chapter reflect the enhancing effects of EM field on seeds and plant growth. EM field can also have detrimental effect on molecular level or physiological growth of seeds and plant. Hence, it is important to determine the wave length (frequency), exposure duration and intensity of the EM wave at which plant growth has enhancing effect upon exposure.

CHAPTER 4

HELMHOLTZ COIL DESIGN AND CHARECTERIZATION

4.1 Background

Helmholtz coil is a parallel pair of two similar circular coils wounded in series such that current passes in same direction in each coil. The coils are spaced one radius apart. The basic principle is that the coils produces uniform magnetic field at the center [32]. This arrangement of coil was invented by German physicist, Hermann von Helmholtz, over a century ago. The intensity of magnetic field is directly proportional to the number of turns and the current through the coil. The primary component of field is parallel to the axis of the coil. The uniform field within the coil accounts from the summation of fields parallel to the axis and the difference of vertical component fields.

Helmholtz coil design is simple and well understood and there are many commercially available designs for all kinds of applications. In order to study the germination of seeds, soybeans, a large area with uniform magnetic field is required. The advantage of having a large area is that it will accommodate a large number of seeds per experimental set. Consequently the results analyzed statistically will have a greater confidence level. Besides, statistically significant data is best defined when the total number in the data set is very large. However, Helmholtz coil with larger areas that are available in the market are very expensive. A laboratory design and characterization is a better choice. Therefore it was decides to design the coil and characterize the setup as a part of the research project. This exercise has resulted not only a much cheaper system but the setup can be used later for other experiments in the future, perhaps with other seed types.

In this research work, the primary objective of the test coil design is to provide uniform magnetic field in the test area for Bioelectric or electromagnetic susceptibility experiments. The coil can be driven by both AC and DC source, as the requirement may be. Magnetic field from DC to 200 Hz can be generated by the coil. If frequency is higher, the increase in impedance will require high voltage to drive the desired current. Besides experiments in Bioelectrics, magnetic susceptibility esperiments, Helmholtz coils are also typically used in the following application types:

1. Measurement, such as permanent magnet moment measurement
2. Compatibility and Susceptibility test of electronic devices [33].
3. Nullifying earth's magnetic field.
4. Biomagnetic application.

4.2 Equations for Helmholtz Coil

The electromagnetic fields generated by circular wire carrying current I, satisfies Maxwell equations. The EM field generated by a loop can be determined using the circuit theory and using uniform current as the source for the vector potential [34]. Fields can be derived from the resulting vector potential. The potential vector is given by,

$$\vec{A}(r) = \frac{\mu}{4\pi}\int\frac{I\vec{dl}}{\vec{r}-\vec{r}'} \qquad \text{------1}$$

where A is the potential vector and I is the current through the loop.

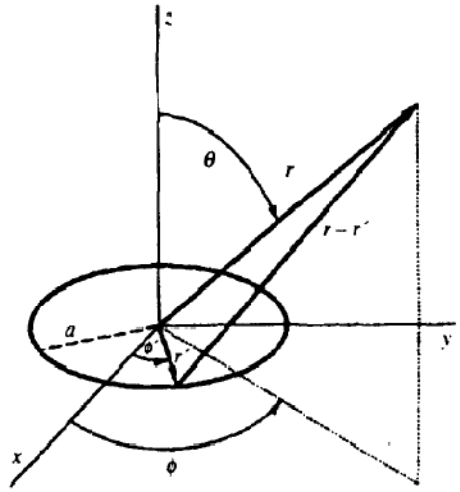


Figure 4-1: Variables describing EM in a loop

Following can derived based on the geometry in Figure 4-1:

$\overrightarrow{dl}$= $(\sin\emptyset', r\cos\emptyset', 0)d\emptyset'$

$\vec{r}$=(rsinθ, 0, rcosθ),

$\overrightarrow{r'}$= $(a\cos\emptyset'$, $asin\emptyset'$, 0)

$|\vec{r}-\overrightarrow{r'}|$= $\sqrt{r^2+a^2-2rasin\theta cos\emptyset'}$ ------2

$A_\emptyset(\mathrm{r}, \theta) = \frac{\mu_0 \mathrm{Ia}}{2\pi}\int_0^\pi \frac{cos\emptyset' d\emptyset'}{\sqrt{r^2+a^2-2rasin\theta cos\emptyset'}}$ ------3

Expressing above equation in the cylindrical form with the following equations:

$r^2 = \rho^2 + a^2$ and $\sin\theta = \rho/\sqrt{\rho^2+z^2}$

$A_\emptyset(\rho, z) = \frac{\mu_0 \mathrm{Ia}}{2\pi}\int_0^\pi \frac{cos\emptyset' d\emptyset'}{\sqrt{\rho^2+a^2+z^2-2a\rho cos\emptyset'}}$ ------4

Making the upper limit of the integral $\pi/2$,

$A_\emptyset(\rho, z) = \frac{\mu_0 \mathrm{Ia}}{2\pi}\int_0^{\pi/2} \frac{(2\sin^2\emptyset'-1)d\emptyset'}{\sqrt{(a+\rho)^2+z^2-4a\rho\sin^2\emptyset'}}$ ------5

considering $k^2 = \frac{4a\rho}{(a+\rho)^2+z^2}$

$A_\emptyset(\rho, z) = \frac{\mu_0 \mathrm{I}}{\pi k}\sqrt{\frac{a}{\rho}}\left[\left(1-\frac{1}{2}k^2\right)K(k) - E(k)\right]$ ------6

Where, $K(k) = \int_0^{\pi/2}\frac{d\emptyset}{\sqrt{1-k^2\sin^2\emptyset}}$ and $E(k) = \int_0^{\pi/2}\sqrt{1-k^2\sin^2\emptyset}\,d\emptyset$ and K and E are elliptical integral of first and second kind.

The magnetic field is given by the curl of the vector potential

$\vec{B}=\nabla \times \vec{A}$ ------7

$B_\rho\,(\rho, z) = -\frac{dA_\emptyset}{dz}$ and $B_z\,(\rho, z) = \frac{1}{\rho}\frac{d(\rho A_\emptyset)}{dz}$

$B_\rho\,(\rho, z)=\frac{\mu_0 \mathrm{I}}{2\pi}\frac{z}{\rho\sqrt{(\rho+a)^2+z^2}}\left[\frac{a^2+\rho^2+z^2}{(a-\rho)^2+z^2}E(k) - K(k)\right]$ ------8

$B_z\,(\rho, z)=\frac{\mu_0 \mathrm{I}}{2\pi}\frac{1}{\rho\sqrt{(\rho+a)^2+z^2}}\left[\frac{a^2-\rho^2-z^2}{(a-\rho)^2+z^2}E(k) - K(k)\right]$ ------9

Equations 8 and 9 gives the ρ and z components of magnetic field of a loop. For the Helmholtz coil the expression of magnetic field is summation of fields from individual loop. Two loops are separated by 2d. The following equations give the total magnetic fields in terms of ρ and z components.

$Toal\ B_\rho\,(\rho, z)= B_\rho\,(\rho, z+d) + B_\rho\,(\rho, z-d),$ ------10

$Total\ B_z\,(\rho, z)= B_z\,(\rho, z+d) + B_z\,(\rho, z-d)$ ------11

Equations 10 and 11 are derived from the summation of magnetic field from the individual loop.

On the axis, $\rho = 0$ and this implies k=0, $K(0) = E(0) = \pi/2$, and application of l'Hopital's rule gives $B_\rho = 0$. The expression for total magnetic field the loop becomes,

$$B_z = \frac{\mu_0 a^2 I}{2(a^2+z^2)^{3/2}} \qquad \text{------12}$$

The magnetic field along the axis due to both the coils

$$B_z = \frac{\mu_0 a^2 I}{2}\left[\frac{1}{(a^2+(d-z)^2)^{3/2}} + \frac{1}{(a^2+(d+z)^2)^{3/2}}\right] \qquad \text{------13}$$

For the coil having N number turns the expression for magnetic field density is,

$$B_z = \frac{\mu_0 a^2 IN}{2}\left[\frac{1}{(a^2+(d-z)^2)^{3/2}} + \frac{1}{(a^2+(d+z)^2)^{3/2}}\right] \qquad \text{------14}$$

When the equation is solved for z = 0 at the center of axis between two coils,

$$B_z = \frac{8}{5^{3/2}}\frac{\mu_0 IN}{a} \qquad \text{------15}$$

4.3 Helmholtz Coil Design

Magnetic field has significant impact on plants and seeds both at the physical and molecular level. The Helmholtz coil that can generate a uniform magnetic field in a large area can be ideal for Biomagnetic experiments, and this was the main motive of the Helmholtz coil design, it had bioelectric perspective. Bioelectric experiments with plants and seeds require large volume of uniform magnetic field for exposure. The ordinary Helmholtz coil, 30 cm diameter, has insignificant volume of uniform magnetic field for biomagnetic experiments which requires large number of samples. The Helmholtz coil was designed for treating 200 seeds at a time. The uniform magnetic field is generated at center of the structure and covers approximately 1/3 the total volume. It was designed such that it is driven by both AC and DC current source. The Helmholtz coil was also designed such that it would withstand temperature rise even when driven for long period of time. This is necessary because bioelectric experiments involve long period of exposure in the magnetic field, sometimes requiring several days of exposure.

The equation for the field strength at the center of the coils is:

B(R)=0.00899178 NI/R,

B=magnetic field, in gauss

R=radius of coils, in meters

N=number of turns of wire on each coil

I=current through each turn of wire, in amperes

Using the above equation, with 100 turns of wire and 10 A of current will meet the desired intensity of approximately 20 G of magnetic field.

4.4 Wire Temperature Concerns

The resistance and the impedance of the coil give rise to heat buildup. The temperature could conceivably be great enough to melt the insulation of the wire. In order to analyze how coils would heat, the power that would be absorbed by the wires in 10 inch segment of the coil was determined. The equations for analysis are as follows

$P = I^2$R

Resistance per length=0.001 Ω/ft, Resistance per 10 inch wire (R) = 8.33 x 10^{-4} Ω

P=0.083 J/s

Thermal energy absorbed each minute =0.083 x 60s x 100 turns = 498 J

From the specific heat equation [35]:

Q = m x c x ΔT

Thermal energy, Q = 498 J

Specific heat of copper, c = 0.386 J/Cg

Density of copper = 8.9 g/cm^3

Volume of copper segment = 1004 cm^3

ΔT = 0.144 Celsius

According to calculations, a 10 inch coil will gain approximately 0.144 degree Celsius each minute when driven by 10 A of current. This is insignificant value since the wire is rated by the manufacturer to go up to 250 degree Celsius. The structure is placed in the open air environment where it is air cooled. The natural air cooled Helmholtz coil is designed for driving with 25 A current to generate 48 G of magnetic field intensity.

4.5 Helmholtz Coil Construction

Helmholtz coil was designed and simulated using CST Microwave Studio Software. The coil was designed to bear up to 20 A current and resist 250'C temperature. The structure was constructed using ¼" plywood. The plywood was cut and glued into desired circular shape. Wooden dowels and glue were used for fixing the structure. Copper wire, 10 AGW, was wounded in both the coils and connected in series. Copper winding was done manually as shown as in figure 4-2b. Connectors were used to terminate and join the contacts. Connectors were terminated such that the winding could be used either in series mode or in parallel. The series mode was opted for the experiment. Figure 4-2c shows the connectors and fuse embedded in the structure. Each coil has a diameter of 95.5 cm with 100 turns each of copper wire. Wooden base was fixed at the center of the structure such that targets can be exposed to the uniform magnetic field. Figure 4-2d shows the final

Helmholtz coil structure with DUT base at center of the structure. While the coil was constructed metal parts and nails were avoided while constructing the coil to insure a minimum of distortion and the best possible homogeneity of magnetic fields within the test volume. Similarly 10 AWG copper wire was used to handle high input current up to 20 Amp DC or AC.

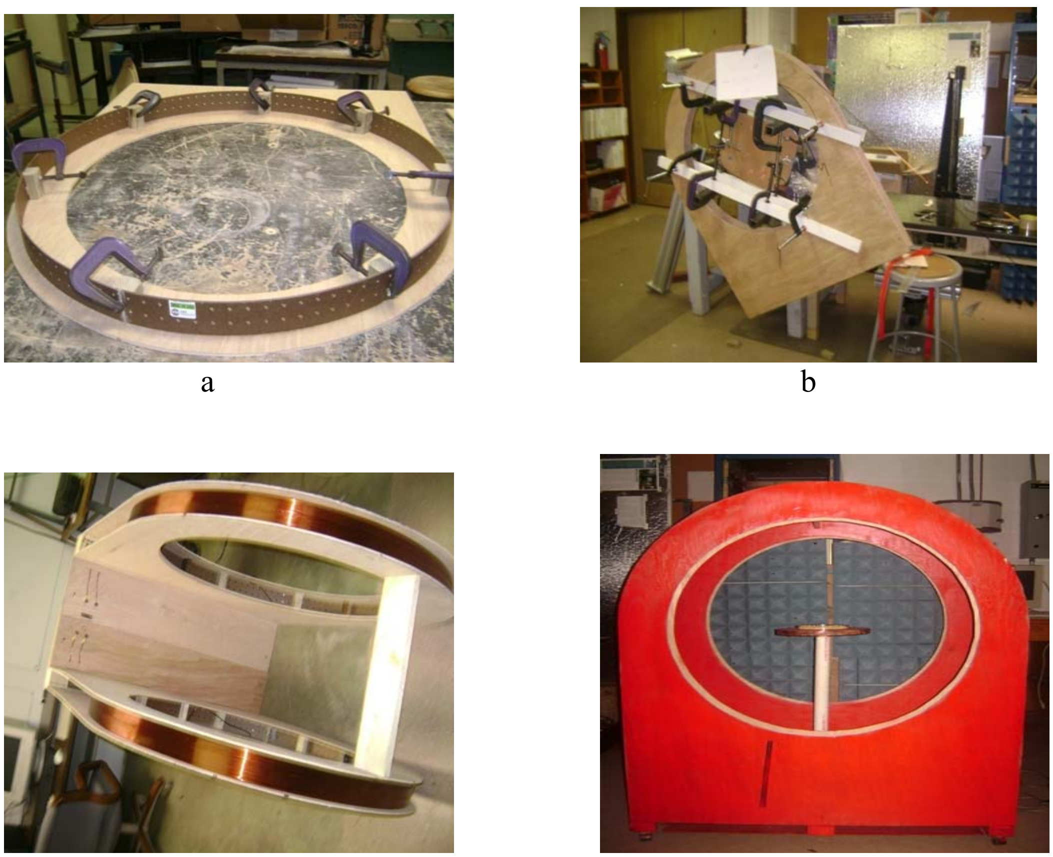
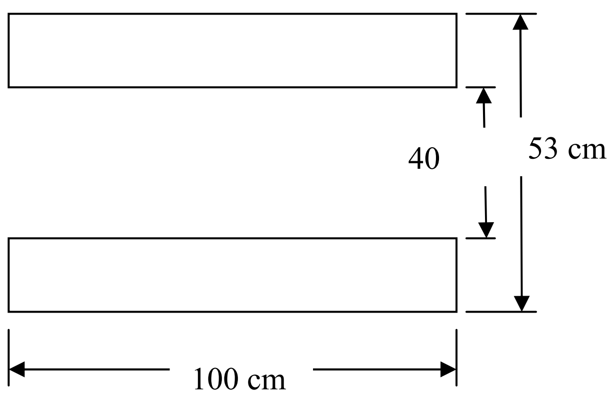


Figure 4-2 (a) The coil frames are glued and clamped (b) Winding of Copper wire around the frame (c) Winded Helmholtz coil with connectors (d) Helmholtz Coil with DUT base

4.6 Coil Specification

Type: Monoaxial	Coil Diameter: 47.5 cm
Number of turns per coil: 100	Coil Width: 100 cm
Gauge: 10 AGW Copper	Coil Depth: 53 cm
Total Resistance: 2 ohm DC	Coil Height: 130 cm

Construction Material: Nonmagnetic (Plywood and Plastic)



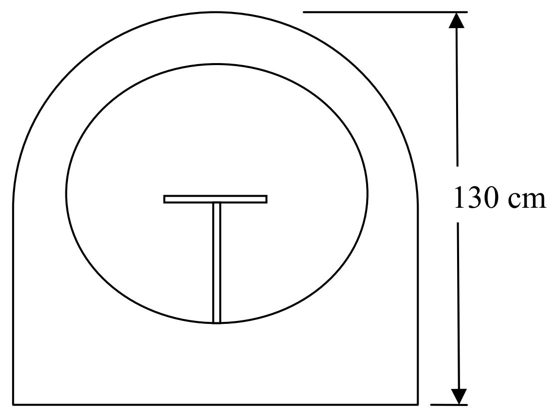


Figure 4-3-1 Top view of Helmholtz coil **Figure 4-3-2 Front view of Helmholtz coil**

4.7 Test Configuration and Measurement

Magnetic field sensor PASCO, CI 6520A was used to measure the DC magnetic field in the coil. Scienceworkshop 750 Interface was used as data acquisition computer interface. Selecting "radial" mode at magnetic field sensor records the strength of the field pointing into the dot on the side of the device, while "axial" records the strength of the field pointing into the dot on the end. There is also a tare button which sets the current field strength to zero. The magnetic field in the range +/- 100 G can be measured with 0.05 G resolution

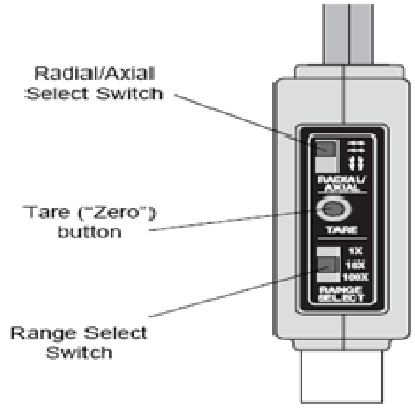


Figure 4-4: ScienceWorkshop 750 Interface

Figure 4-5: Pasco CI 6520A Magnetic

Similarly, 5170 Series Hall Effect Gauss/Tesla Meter was used to measure the AC magnetic field. The hand held meter was designed for measuring magnetic field at 0-20 kHz with 0.001 G resolution at 1.1 % accuracy. 4" Transverse probe was used for the field measurement inside the coil. The probe is fragile and is made up of polypropylene. Figure 4-6 shows the hand-held meter and Figure 4-7 is the transverse probe used for the field measurement.

Figure 4-6: Model 5170 Hall Effect Gauss Meter

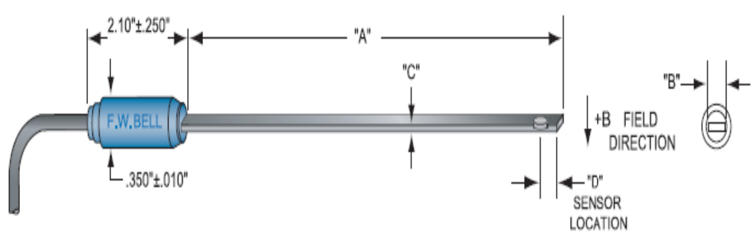


Figure 4-7: Model STD 18-0404 Transverse probe

4.8 Power Supply

The Helmholtz coil can be driven by both AC and DC power supplies. For the experimental purpose DC power source GPS-1850D was used to drive the coil with DC current [Figure 4-8]. The power supply was rated for 0-18 V, 0-5 A. Similarly, transformer rated 480/240 V, 0.5 kVA was used to drive the AC current [Figure 4-9]. Direct power supply of 110 V, 60 Hz was also used during the experiment.

Figure 4-8: GPS-1850D DC Supply

Figure 4-9: 480/240 V, 0.5kVA Transformer

4.9 Characterizing the Coil Design

The construction of the Helmholtz coil based on the design specifications was followed by measurements and simulations to characterize the field inside the coil. This was achieved through both measurements and simulations. Simulations were carried out using the CST Microwave Studio ® industry standard software and also by a code written through MATLAB. CST is a direct and iterative matrix solver with convergence acceleration techniques. It is a fully featured software package for electromagnetic analysis and design in the high frequency range. It simplifies the process of inputting the structure by providing a powerful solid modeling front-end, which is based on the ACIS modeling kernel. Strong graphic feedback simplifies the definition of your device even further. After a component has been modeled, a fully automatic meshing procedure is applied before the simulation engine is started.

The simulators feature the Perfect Boundary Approximation method and its Thin Sheet Technique extension, which increase the accuracy of the simulation by an order of magnitude in comparison to conventional simulators. Since no method works equally well in all application domains, the software contains four different simulation techniques which best fits for their particular application.

The Helmholtz coil was designed with a radius of 47.5 cm with 100 turns of 10 AWG copper wires. The equivalent cross section area of the coil with 100 turns was calculated to be 4.9 cm^2 and later modeled into a single loop with 2.5 cm diameter for simulation purpose. The current injected through port 1 and port 2 (Figure 4-10) are in same amplitude and in phase. The Hexahedral and auto mesh generation options were selected to generate fine mesh, while copper was selected as the material.

The CST software automatically defines the characteristics of material selected. Vacuum was chosen as the background material and simulations were made with the assumption that there is no external interference and coils are wounded in a vacuum environment. Simulated results of the magnetic field (H-field) in 3D were obtained at various horizontal planes. Figures 4-10, 4-11 and 4-12 represents x, y and z component of the magnetic field (H-field) respectively. The direction of H-field is shown in the Figure 4-13. The magnetic field components at different planes visualize the nature and uniformity of the generated field. It also reflects the direction of the generated field.

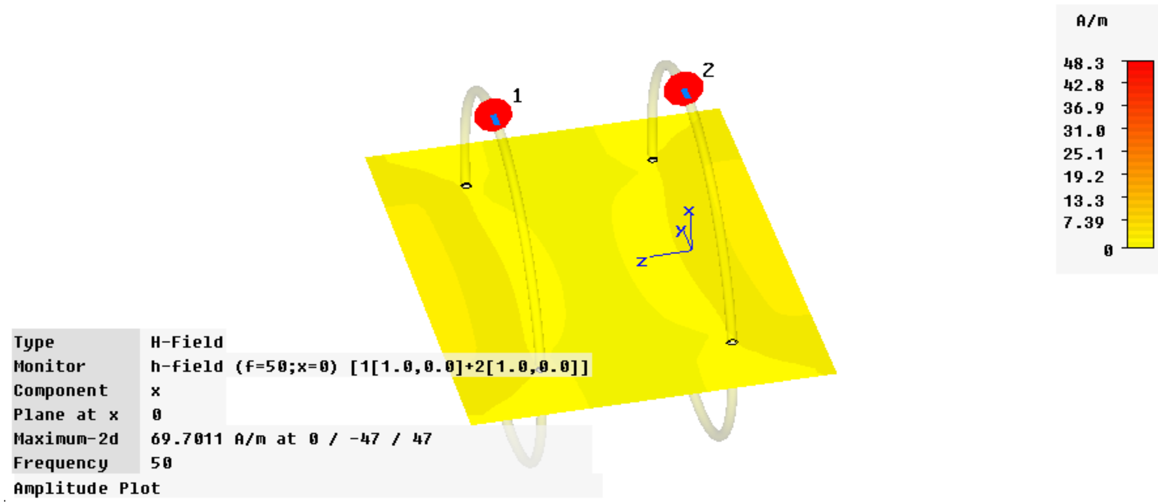


Figure 4-10: Hx field at x=0 plane

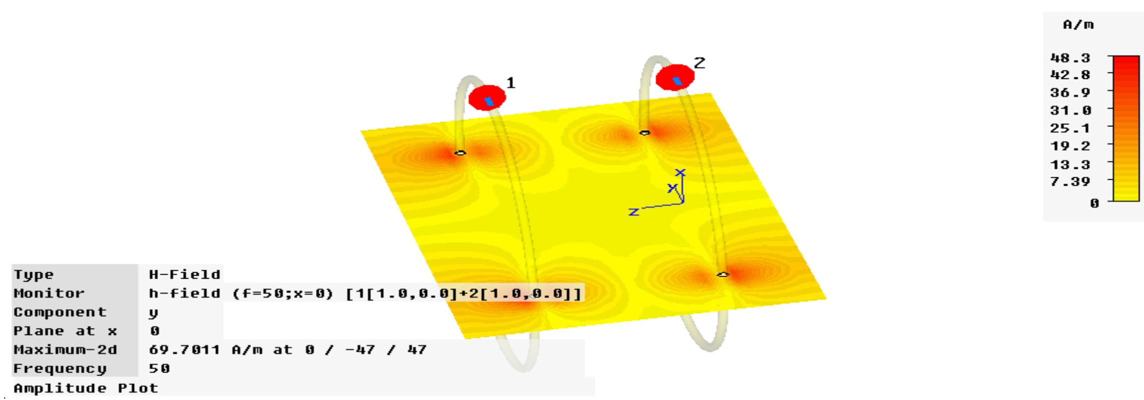


Figure 4-11: Hy field at x=0 plane

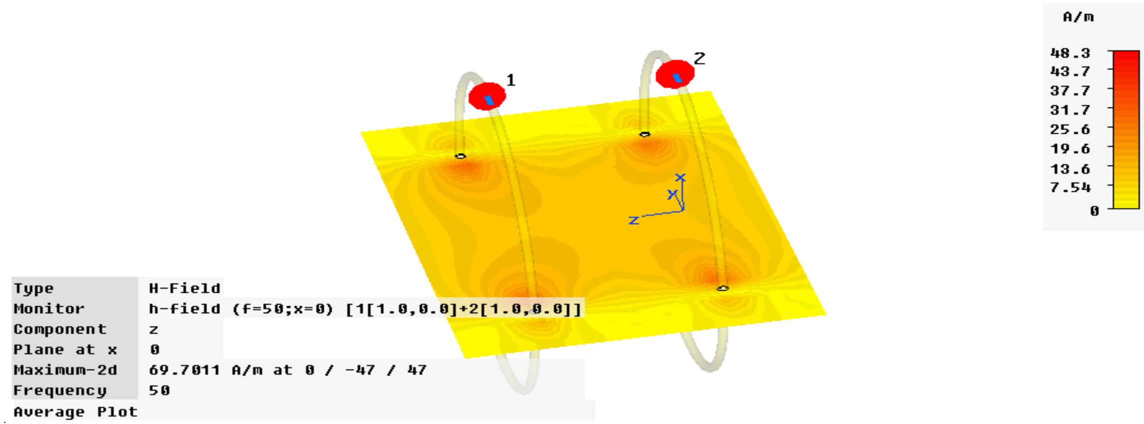


Figure 4-12: Hz field at x=0 plane

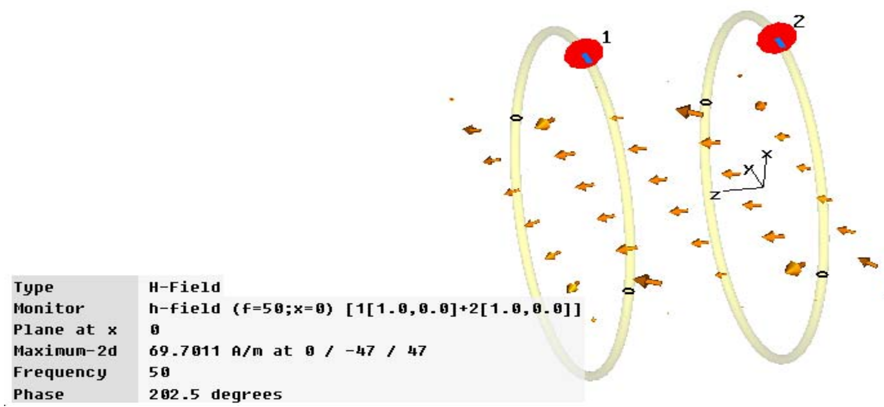


Figure 4-13: Direction of H field at x=0 plane

Similarly, Matlab code was used to simulate the Helmholtz Coil. Figure 4-14 is the 3D simulation plot simulated using Matlab. The coil consists of 100 turns and the radius of coil is 47.5cm. The magnetic field density (B) is graphically represented at different region inside the coil.

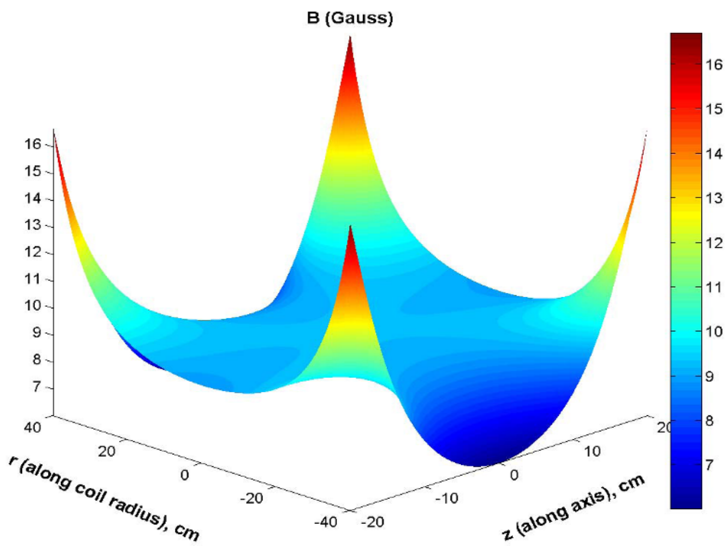


Figure 4-14: Simulated 3D plot using Matlab

4.10 Magnetic Field: Simulation and Measurement

The experimental and simulated coils were driven with DC current of 4.8 A. GPS-1850D DC Supply was used as power source. A CI-6520A Magnetic Field Sensor and Scienceworkshop 750 interface were used to measure the magnetic field intensity at various locations along the x-plane. The simulated and experimental results were compared. The experimental measurements were performed with a resolution of 5 cm along the axis, and 10 cm along the diameter of the coil; the MATLAB simulation was limited to a resolution of 1.25 cm and 2.5 cm for the axis and the radial distance, respectively. Even though the experimental measurements could not be made with high resolution, both graphs (Figure 4-15 and 4-16) show a highly similar pattern. The color bar shows that the uniform field region with magnetic field density of ~9 G spread in the center region of the coil.

The uniform magnetic field at center of the coil is distinct if high resolution is considered (Figure 4-14). Simulation result can be used to determine the exact area of uniform magnetic field at the center of the coil.

The total contribution to the total field is given by the component along the axis of the coil (in the +*z* direction) and the radial component cancels out due to symmetry of coil structure. The z-component of the magnetic field was measured and compared with Matlab simulation. Figure 4-15 shows the simulated axial component of the magnetic flux density and Figure 4-16 shows the experimental axial component of the magnetic flux density at x=0 plane. The measurement shows that the x and y components of B-fields were absent.

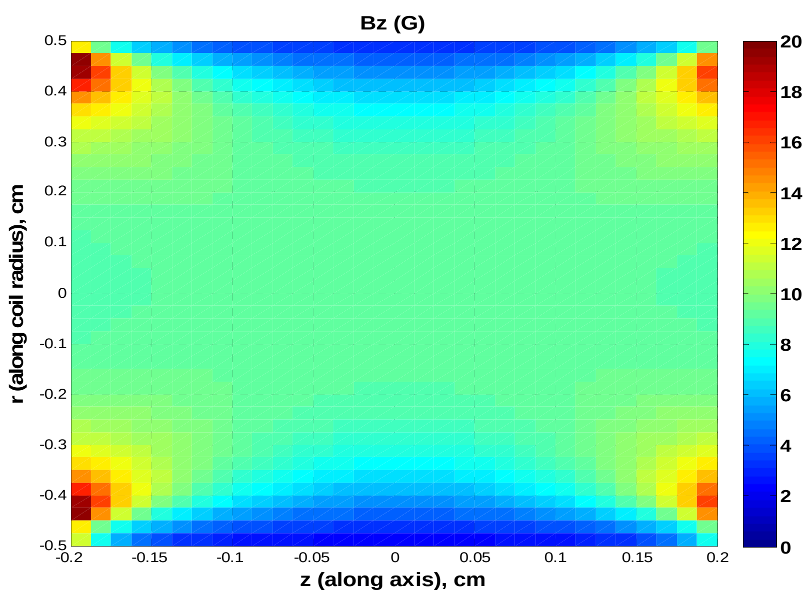


Figure 4-15: Calculated axial component of the magnetic flux density

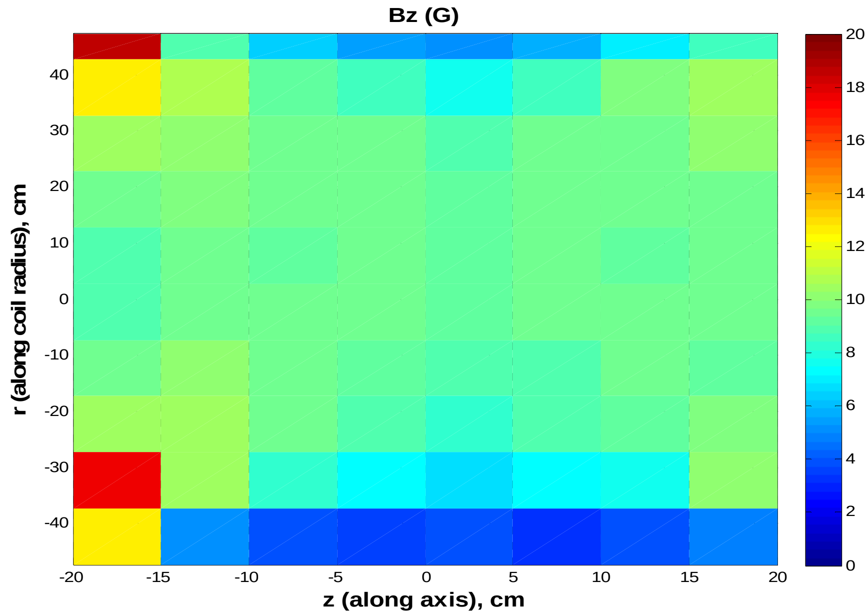


Figure 4-16: Measured axial component of the magnetic flux density

The flux density Bz, was measured along the z-axis of the coil and compared with calculations. Figure 4-18 shows the comparison between the calculated and measured coil for 4.8 A of DC current through the coil. Figure 4-19 is the comparison between theoretical and measured value when driven by 7.3 A AC current. The AC current was generated by a step down transformer of 0.5 kVA, 240/220 V w. The DC magnetic field was measured using CI-6520A magnetic field sensor and the AC magnetic field was measured using 5170 Hall Effect Gauss Meter. Figure 4-17 shows the measurement of static magnetic flux density using Scienceworkshop 750 interface. The reading shows the magnetic field strength of ~9 G.

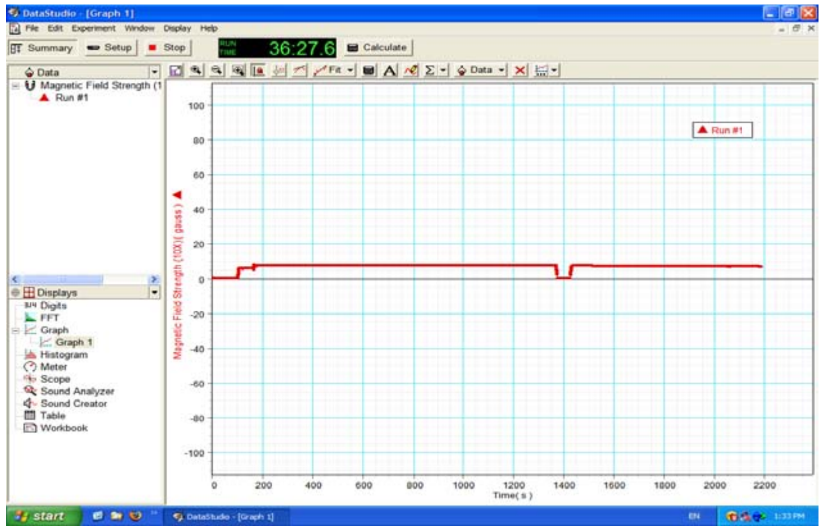


Figure 4-17 Graphical Display-Measurement of Magnetic Flux Density

The measured magnetic flux density is very close to the calculated value. The percentage difference between the measured and the calculated data is 1.1%. The measured magnetic flux density, along the axis of the coil, is symmetric about the center (Figure 4-18 and 4-19). This shows that the coils are aligned perfectly and magnetic flux density from the individual coils is symmetric.

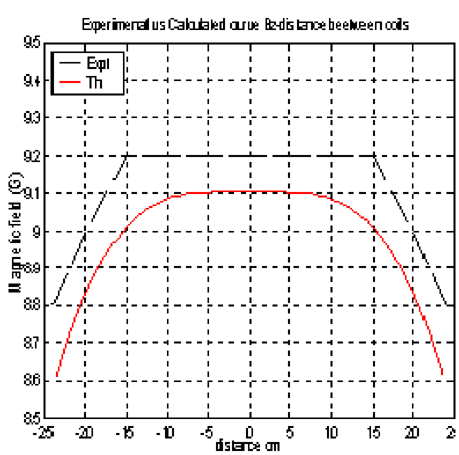


Figure 4-18: Experimental vs. Calculated Bz with DC current I=4.8 A

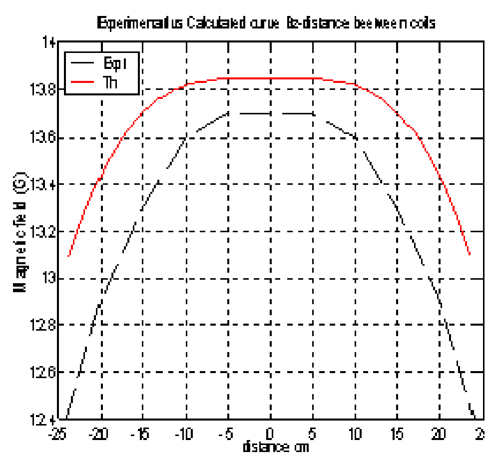


Figure 4-19: Experimental vs. Calculated Bz with AC current I=7.3 A

CHAPTER 5

MAGNETIC AND ELECTROMAGNETIC SOURCES FOR BIOELECTRICS APPLICATIONS

5.1 Introduction

There are a number of agents that stimulate seed growth that include EM field, magnetic field, electric field, radiation with radar, x-ray etc. Such agents are called bio-stimulators. Most widely known bio-stimulators are chemicals in the form of fertilizers. In this chapter magnetic fields from the Helmholtz's coil designed and characterized in the earlier chapter is used as a bio-stimulator for soybean seeds. Specifically, the germination rate of the seeds due to such a stimulator is described. The results are also compared with experiments with soybean seeds using electromagnetic fields from an anechoic chamber and a TEM cell. The study is important since soybean is a potential candidate for renewable energy resource for biofuels. Preliminary studies with soybeans with electromagnetic fields from an anechoic chamber have shown promising results for one variety of soybean seed known as Magellan [36]. As a result, from the numerous varieties available at the Soybean Center, MU, we have chosen Magellan. The frequency of applied electromagnetic spectrum is non-ionizing radiation, low power and produce non-thermal effects. The project utilizes a mature radio-frequency (RF) field effects technology that was initially applied to electronics and other gadgets designed for non-civilian use, for applications in biology, specifically plants and seeds. The approach suggested is relatively new and expected to significantly advance seed germination modalities; define mechanisms that promote our understanding of both the germination process and the effects of fields. It is also expected that a positive outcome of this research will have an impact not only in the agriculture sector but contribute significantly to the ever increasing demand for new and alternate forms of energy.

5.2 Magnetic and Electromagnetic Field Effects on Soybeans

Germination of seeds in nature is affected one way or the other by both electric and magnetic fields. This is because the earth has its own magnetic fields and electric fields develop due to the accumulation of charges in clouds and a field is established between the charges and the ground. Thus all seed growths are somewhat affected by natural magnetic, electric and electromagnetic fields. Chapter 3 has demonstrated the effects of applying both electromagnetic and magnetic fields in maximizing seed germination. Examples include the germination of maize [18], wheat [20], tomato [21], and beans [24] seeds. In this chapter, we extend the study to soybean of the Magellan variety, an important source for biofuels. Soybean seeds, Magellan, were treated with various intensities of electromagnetic field using different sources such as a TEM cell, Helmholtz coil and Anechoic chamber. Dry soybean seeds and presoaked soybean seeds were experimented at different frequencies, intensities and time duration.

5.3 Experimental set up: TEM Cell, Helmholtz Coil and Semi-Anechoic Chamber

5.3.1 TEM Cell

The in-house build Tem Cell, described in chapter 2, was driven by Agilent 33220A 20 MHz Function generator with the sinusoidal peak to peak voltage 1 V. The frequency was maintained at 50 Hz. The characteristic impedance of TEM cell was matched with external 50 ohm resistance. This was done to avoid reflection of the field in the TEM Cell. The input power was maintained at 1 watt. The TEM cell generates uniform E-field around the center of the septum. The volume of uniform field is one third the volume of the whole structure. The experimental seeds were placed at the center of the septum as shown as in Figure 5-1.

5.3.2 Helmholtz Coil

Helmholtz coil, discussed in chapter 4, was driven by AC and DC current sources of different magnitudes. The coil was supplied with 4.8 A of DC current. DC driven Helmholtz coil gives static magnetic field. The corresponding measured magnetic field intensity was 9.1G. The total input power used was 72 Watts. Similarly, the coil was driven by 440/220 V, 0.5 kVA Transformer. The AC ammeter reading was 7.3 A and the corresponding measured magnetic field was 13.3 G. The measured impedance of the coil was 17.2 ohms. The experimental seeds were place at the center of DUT (Figure 5-3) base where uniform magnetic field was present.

5.3.3 Semi-Anechoic Chamber

The experiment was tested inside a semi-anechoic chamber.The monitoring and recording of the signals were controlled through a PC based LabVIEW interface. A computer controlled Radio-Frequency (RF) signal amplifier feeds the antenna, which is at a distance of 3 meters from the conducting sheet to meet the far field condition at low frequency. The frequency was fixed at 80 MHz and power setting was done for 50 W. Soybean seeds were subjected to a variation of such parameters as power level, frequency, and exposure duration. Soybean are taken in PVC tube and supported by thick nonconductive material assuming low level of wave reflection. The setup was located 10 cm away from the field probe as shown as in the Figure 5-2.

5.4 Experiment with Dry Soybean seeds

Healthy dry soybean seeds, without stripes and cuts, were picked. 200 soybean seeds of Mallegean variety were exposed to magnetic field using Helmholtz coil and EM field using TEM cell & semi anceochic chamber. Seeds were taken in petri-dish when they were exposed to TEM cell and Helmholtz coil. Soybean were taken in pvc tube, supported by thick nonconductive material and exposed to EM field in semi-anechoic chamber. Separate experiments were conducted for time durations of 10, 20 and 40 minutes. A set of 200 seeds was kept as control. The exposed and the control sets were sent to Laboratory at Soybean Center, MU for germination. Comparison was made between the control and the exposed seeds after germination. Table 5-1 shows the various sets of experiments performed and the results obtained from treated soybean seeds at different environment.

Figure 5-1: Soybean seed in the septum of the TEM Cell

Figure 5-2: Soybean seeds inside PVC pipe next to the field probe

Figure 5-3: Experimental setup: Soybean seeds at the center of coil

Figure 5-4: Helmholz coil with copper winding and the driving source

Table 5-1: Power, Frequency and duration of Exposure

Exposure Type	Power (W)	Frequency Hz	Time (min)	No of Seeds	Germinated Seeds	Germination %
P0F0T0 –CO	0	0	0	200	134	67
P1F1T1-AC	72	DC	10	200	128	64
P1F1T2-AC	72	DC	20	200	92	46
P1F1T3-AC	72	DC	40	200	146	73
P1F1T1-HC	50	80 M	10	200	124	62
P1F1T2-HC	50	80 M	20	200	130	65
P1F1T3-HC	50	80 M	40	200	138	69
P1F3T1-TC	1	50	10	200	136	68
P1F3T2-TC	1	50	20	200	126	63
P1F3T3-TC	1	50	40	200	134	67

HC-Helmholtz coil, TC-Tem cell, AC-Anechoic chamber, CO-Control, P-Power, T-Time and F-Frequency

The experiments with TEM Cell, Anechoic Chamber and Helmholtz coil were performed simultaneously in the same day to enable comparative study. 200 Magllen seeds were used for each batch of experiments to obtain a significant result. EM treatment of seeds was done for 10, 20 and 40 minutes. Seeds were taken to National Center for Soybean Biotechnology, Agricultural Building, Columbia, MO where they were germinated in paper pouch. Germination score was done on day five. The control sample is measured without any external EM fields on the seeds. This control sample is used as a reference to the other samples used for experimentation. The power and the frequency was 0 W and 0

Hz respectively as it did not undergo any kind of exposure to EM radiations. It is labeled as P0F0T0 according to parametric values used. The samples with a certain applied power and frequency are named P1F3T(x) depending on the sample exposure time in the source. Three samples are taken as P1F3Tx-AC, P1F3Tx-HC, and P1F3Tx-TC at exposure time of 10 minutes, 20 minutes, and 40 minutes respectively.

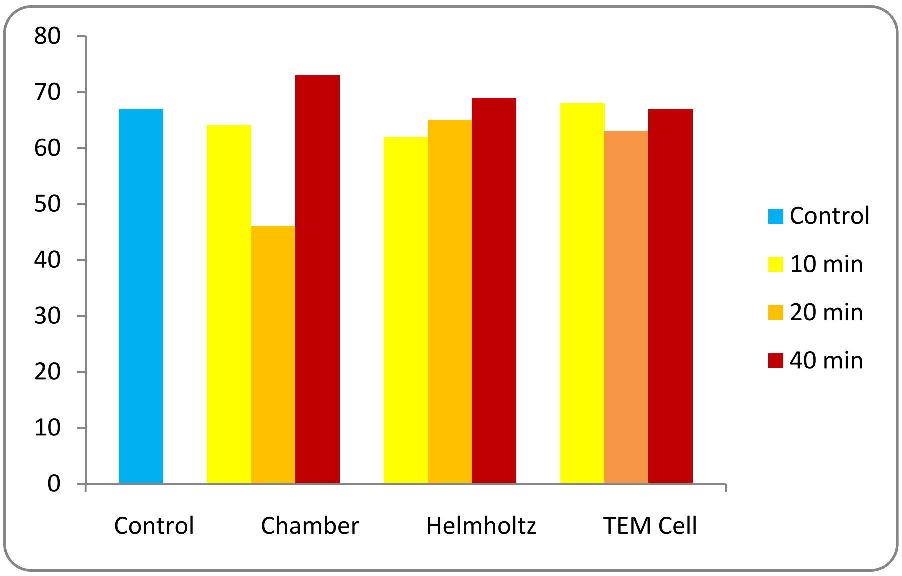


Figure 5-5: The Germination Rate as a Function of Exposure Time

5.5 Results with Dry Seeds in TEM Cell, Chamber and Coil

A total of 200 soybean seeds, per sample, have been used for the experiment. The germination rates of the seeds after treated in the EM environment, expressed as the percentage of seeds germinated in the samples are observed and tabulated accordingly (Table 5-1). The germination percentage is determined for the seeds treated in chamber, Helmholtz coil and TEM cell. Figure 5-5 shows that the anechoic chamber gave some noteworthy outcome for the seeds (P1F2T2-AC) exposed for 20 minutes. The germinated rate was reduced by 22% compared to the germination of control. This shows that EM radiation can have both enhancing and reducing alteration effect on germination of plants at particular time, frequency and intensity. There is no significant variation result with the TEM cell. The seeds exposed to static magnetic field in Helmholtz coil shows that the germination rate is better when the exposure time is increased. The germination rate for 40 min is 69% compared to 10 and 20 minutes which are 62% and 65 % respectively. For further analysis we decided to exclude anechoic chamber treatment though it gave a significant result. The chamber treatment was performed at high frequency (80MHz) and our area of interest is low intensity and low frequency of EM wave. Based on the results obtained from seeds treated with Helmholtz coil we assumed that if seeds are exposed to the magnetic field for longer duration the results are more significant. Hence, the experiments were continued with the seeds treated with magnetic field using Helmholtz coil but with different parameters.

5.6 Presoaked seeds treated in AC and DC magnetic fields using HC

In this experiment Magellan seeds were presoaked before they were treated in the magnetic field. About 450 Magellan soybean seeds were soaked in distilled water for 8 hours after which the water was drained off. A total of 150 seeds were kept as control, 150 seeds were exposed to an alternating (AC) magnetic field whereas 150 seeds were exposed to direct-current (DC) magnetic fields, both for total duration of 6 hours. The static magnetic fields were generated by driving with 10V, 4.8 A of DC current and alternating magnetic field was created by driving with 110 V, 7.4 A AC current. After magnetic field treatment seeds were taken for germination test at National Center for

Soybean Biotechnology, Agricultural Building, MU. Soybean seeds were soaked in 10% bleach for 3 minutes. They were rinsed several times before they are arranged for germination to ensure that they are pathogen free. The seed were placed in the paper pouch, about 30 seeds per pouch for germination studies and analysis. The pouches were placed in a plastic container half filled with paper and were dipped only at one end. Seeds were germinated using paper pouch as shown as in Figure 5-16. The germination was done in the indoor environment and 30 degree Celsius temperature was maintained throughout the germination process. At the end of fourth day, the roots were analyzed in terms of physical length and germinated seeds in each group were analyzed. Germination was statically analyzed based on 5 sets of germinated seeds each holding 30 seeds. Statically significant results were calculated and tabulated.

Figure 5-6: Soybean germinated in paper pouch

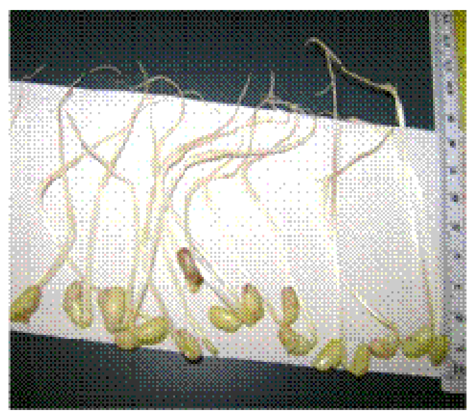


Figure 5-7: Segregating and counting germinated seeds longer than 8 cm.

5.7 Results from Presoaked seeds treated in AC and DC magnetic fields using HC

The germinated seeds were scored and physical root length were measured and compared with the control. Table 5-2 shows the 5 sets of experiment performed and the respective germination rate. Statistical analysis was made with the 5 sets of germination test. Table 5-3 shows result based on statistical analysis. The mean in terms of germination number is tabulated. The results show that germination rate is enhanced for the seeds exposed with magnetic field. The mean of germinated seeds show an increase from a control value of 13.6 to 18.4 and 16.6 respectively for seeds exposed to AC and DC fields. These results are displayed in figure 5-18 in terms of percentage rates.

Table 5-2: Germination Results for different samples

Group	Treated seeds (no)	Germinated no of seeds	Germination %
Control-1	29	11	37.9
HC-AC-1	30	22	73.3
HC-DC-1	28	14	50.0
Control-2	30	14	46.7
HC-AC-2	30	19	63.3
HC-DC-2	29	16	55.2
Control-3	30	17	56.7
HC-AC-3	28	18	64.3
HC-DC-3	30	15	50.0
Control-4	28	12	42.9
HC-AC-4	29	16	55.2
HC-DC-4	29	23	79.3
Control-5	28	13	46.4
HC-AC-5	27	17	63.0
HC-DC-5	30	15	50.0

Table 5-3: Statistical Germination Results

Group	Number of Germinated seeds (mean)	Standard deviation
Control	13.4	2.3
HC-AC	18.4	2.3
HC-DC	16.6	3.64

For the growth measurement, the roots of the germinated seeds were measured and divided into the following length-based categories: 0-1, 1-3, 3-5, 5-8 and 8-11 cm. The count of these length groups are displayed in Table 5-4. It shows that group exposed to magnetic field stimulators has longer roots than the control group. A total of 18 seeds exposed to AC magnetic field fall into the 8-11 cm root length category while there is only 1 for the control group. Only 9 numbers exposed to a DC field fall in this category. From this we can infer that low intensity AC magnetic field is better stimulus compared to 9.18 G static magnetic field.

Table 5-4: Root length results

Group	0-1 cm	1-3cm	3-5cm	5-8cm	8-11cm
Control	19	27	12	8	1
HC-AC	27	14	20	13	18
HC-DC	29	20	12	13	9

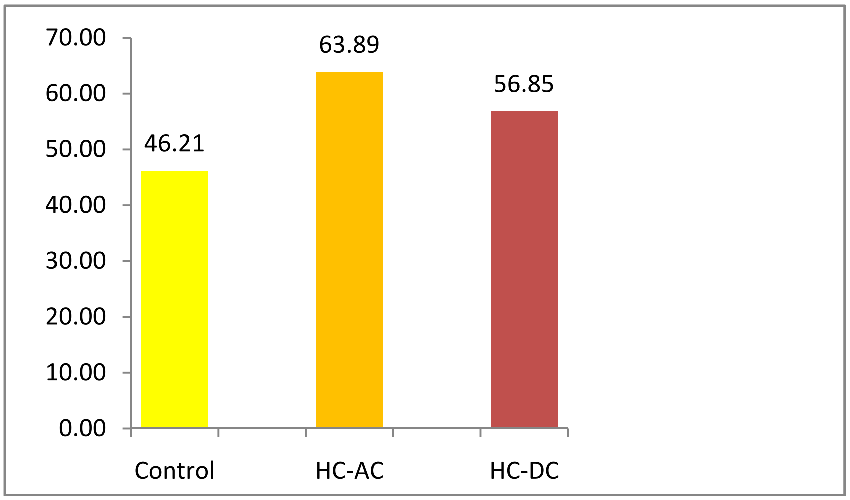


Figure 5-8: Percentage germination for Control, AC and DC (HC=Helmholtz Coil, AC= 60Hz 7.3 A current and DC=4.8 A Static current)

CHAPTER 6

CONCLUSIONS

Helmholtz coil besides their applications in Electromagnetic Compatibility Test and Magnetic Field Susceptibility Testing finds wide application in Biomagnetic Studies. The biomagnetic studies requiring uniform magnetic field is achieved by Helmholtz coil. The small sized Helmholtz coil available in the lab (30cm diameter) does not have large enough uniform magnetic field required for hundreds of Soybean seeds treatment. In this thesis large uniform magnetic field, necessary for treating more than 200 Mallegan seeds, was accomplished by constructing Helmholtz coil with approximately 1 m diameter.

The coil model was created and the magnetic field was simulated using CST Microwave Studio and Matlab softwares. The CST was used to create a model and simulate in order to find the nature of the magnetic field that would be generated in between the coils. The magnetic field components H_x, H_y and H_z were determined in various planes. The dominant magnetic field was H_z, along the axis of the Helmholtz coil. The components H_x and H_y cancel out due to the coil geometry. It was determined that approximately one third the volume in-between the coils has the uniform magnetic field.

The coil was designed, simulated and constructed. Coil parameters were carefully chosen while designing the coil. The coil radius was chosen to be 47.5 cm for achieving approximately 15 cm wide useable uniform magnetic field. Nails are other meal fixtures were avoided to make any magnetic field distortion while constructing the coil. Coil was designed to operate at around 20 A of current using 10 AGW copper wires. The polymide coated copper wire could withstand 250 ^{o} C of temperature. The coils were connected in series. If connected in parallel, unsymmetrical field would have been generated from two coils due to the difference in the impedance of the coils.

The magnetic field strength of the constructed coil was experimentally measured using various probes and instruments as discussed in chapter 4 and compared to the simulated and calculated field strength. The major contribution to the total field is given by the component along the axis of the coil system, so the radial component can be neglected. When the field was measured by the transverse magnetic probe along x and y axis there was negligible amount of field.

The calculated and measured magnetic flux density B, at plane x=0 was compared. The simulated result was limited to a resolution of 1.25 cm and 2.5 cm for axial and radial distances, respectively. Similarly, experimental magnetic field density result was limited to 5cm by 10 cm for the same parameters. The experimental measurement could not be done with high resolution because of difficulty of placing the probe too close. The experimental result is highly matched with the simulated one. The measured and calculated magnetic flux density along the axis of the coil was plotted and compared. When driving 4.8 A of DC current the B field at the center of the coils was 9.12 G when calculated and the experimental value was 9.2 G. Similarly, for AC current of 7.3A the calculated value was 13.8 G and the measured value was 13.7 G. This shows that the constructed coil is almost symmetrical and matches with the calculated one. Slight difference in the measurement might be due to the error in the placement of the probe while taking the measurement. The probe should be perfectly parallel to the plane being measured. Similarly, the geomagnetic field and the magnetic field due to the surrounding circuits and electronic devices might have influenced the magnetic flux density reading.

Plant growth is influenced by many factors. One of them is magnetic field. The geomagnetic field intensity of earth is 50uT, which is the natural component of environment of living beings. When external electromagnetic field is applied there is the altercation of plant growth in physical and molecular level. We have tried to demonstrate the physical altercation on soybean seeds when exposed to the low intensity static and alternating magnetic field. The goal of this experiment is to find out, if any, the germination rate and root growth of soybean plant when exposed to low intensity magnetic field. Germination rate of Mallegan variety has been statically analyzed. Germination test of soybean seeds were carried out after treating in EM sources like TEM Cell, Anechoic Chamber and Helmholtz Coil. Anechoic chamber gave significant result for the exposure type P1F1T2-AC and P1F1T3-AC. Since the seeds were exposed at high frequency of 80MHz in the Anechoic Chamber, lower frequency sources were opted for further experiments. The germination rate, for the seeds treated in Helmholtz coil for 40 minutes (P1F1T3-HC), increased by 2% when compared to control. It was predicted that germination rate will be enhanced if the seeds are treated for longer duration. Seeds were soaked in water before they were treated in magnetic field. Soaking seeds in water may overcome seed coat dormancy and become more stimuli to applied magnetic field. When seeds are presoaked and treated in magnetic field the germination rate was enhanced for both AC (13.3 G) and DC (9.2 G) treatment. This has been statistically determined. The mean germination rate was 63.89 % when exposed to AC magnetic field, 56.85 % when exposed to DC magnetic field when compared to germination rate of 46.21 % for the untreated seeds. When the root length at the end of fifth day of germination were measured and counted the group exposed to AC or DC magnetic field has longer roots than the control group. A total of 18 seeds exposed to AC magnetic field fall into 8-11 cm root length category while there is only 1 for the control. Only 9 seeds exposed to a DC field fall in this category. From these results, we conclude that alternating magnetic fields of a given intensity seems to be better stimulus than 9.2 G static magnetic field.

It is observed that dormant seeds when treated with magnetic field improve the germination rate and crops yield. The main problem of the study of this phenomenon is that we do not have the concrete reason why it happens. For improving the crops yield using clean technology of magnetic field exposure it is necessary to find out how the dormant seeds are altered when treated in the magnetic field.

The cell is thought of composed of various ions channels namely Na^+, K^+, Ca^+. Current flowing through the channels transmits signals in the intracellular level. Similarly opening of channels in the cell membrane enables nutrients and water flow within and outside the cell membrane. When the magnetic field is exposed at the plant cell, the magnetic field interacts with ionic current in the cell. This induces in the osmotic pressure within and outside cell membrane and ultimately alters the flow of nutrients in and out of cell.

It may be postulated that the effects of magnetic fields on plants may be species-specific. Magnetic field may stimulate growth of certain plant species, inhibit growth in some species, and have no effect on others. The study of exposure under static, ELF and weak magnetic fields has been considered in the experiments. The exact intensity and the frequency of the magnetic field is an important variable. Levels of calcium (Ca++) inside of plant cells increases following exposure to magnetic fields, which is one of the proposed mechanisms by which magnetic fields may affect plants. Calcium ions (Ca++) participate in many plant growth processes and responses to stress (heat and salt stress, wounding, etc.). Another potential mechanism is being explored by NASA, which has done some research showing that magnetic fields may also affect the position of starch grains (aka amyloplasts) within plant cells, which will influence the direction of growth of the plant. This phenomenon is called geotaxis. We have not analyzed this effect in our result. Application of ELF magnetic or electric field on living cells influences the calcium efflux in the cell membrane. The calcium efflux is thought to be varied as the frequency of the ELF signal is varied. There is distinct maximum efflux at a resonance frequency. Previous research has shown that the calcium efflux was increased or decreased a function of frequency of the ELF field, and also the efflux was varied as a function of the magnitude of the DC magnetic field to which cell were exposed [37]. It can be predicted that this might be one of the factors that brought the physical and molecular changes in the soybean growth after the seeds are treated in the magnetic field.

These findings could be useful in developing ways to use magnetic field to positively manipulate soybean plant growth, which could help increase the productivity of soybean plants.

BIBLIOGRAPHY

1. http://www.who.int/peh-emf/about/WhatisEMF/en/

2. Fawwaz T. Ulaby, Fundamentals Of Applied Electromagnetics, 2004 Medaia Edition pg 14

3. Dimitris J. Panagopoulos and Lukas H. Margaritis, Theoretical Considerations for the Biological Effects of Electromagnetic Fields, University Of Athenes, Department of Cell Biology and Biophysics

4. Biological Effects of Electromagnetic Fields, Peter Stavroulakis

5. Gerald Draper, Tim Vincent, Mary E Kroll and John Swanson, Childhood cancer in relation to distance from high voltage power lines in England and Whales, BMJ 2005;330;1290-doi:10.1136/bmj.330.7503.1290

6. Easterly, C. E. (1982). Cardiovascular risk from exposure to static magnetic fields. J. Am. Ind. Hyg. Assoc., 43, 533-539

7. McCally, R. L., Farrell, R. A., Burgeron, C. B., et. al. (1986). Neuronizing radiation damage in the eye. Johns Hopkins Apl. Tech. Dig., 7, 73-91.

8. John Iovine, Electromagnetic Fields and Your Health, Popular Electronics, March 1993

9. Durney C.H., Massoudi H. and Iskander M.F. (1986) Radiofrequency radiation dosimetry handbook. Salt Lake City, UT: University of Utah. http://www.brooks.af.mil/AFRL/HED/hedr/reports/handbook/home.html

10. http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=ADA299751&Location=U2&doc=GetTRDoc.pdf

11. C. Goiceanu D.D. Sandu, O.G. Avadanai, TEM Cell as Exposure System for Biological Experiments

12. http://www.ar-worldwide.com/html/18200.asp?id=216

13. David Sleper, M. S. Pathan, Bruno Camps-Raga, Somsak Tantong, Phumin Kirawanich, James E. Thompson, and N. E. Islam, Optimization of Soybeans as a

Biofuel Resource through Germination Studies under Electromagnetic Fields, Proceedings, 18th Int. Zurich Symposium on EMC, Munich 2007.

14. CST MICROWAVE STUDIO® 2008, Manual

15. Umran S. Inan, Aziz S. Inan. Engineering Electromagnetics. p. 448. Addison Wesley Longman, Inc.

16. Zook B. C., Simmens S. J. 2001. The effects of 860 MHz radiofrequency radiation on the induction or promotion of brain tumors and other neoplasms in rats. Radiation Research 155: 572-583.

17. Korpinen L., Partanen J. 1996. Influence of 50 Hz magnetic fields on human blood pressure. Radiation and Environmental Biophysics 35: 199-204.

18. M. Racuciu, D. Creanga, I. Horga, Plant Growth Under Static Magnetic Field Influence,

19. Kazuhiko Yamashita, Toshiki Ono, Daisuke Saito and Masao Saito, Effect of Static Magnetic Field on Cell Growth and Mitochondria, 1999 IEEE TENCON

20. G. Fischer, M. Tausz, M. Kock, and Dieter Grill, Effects of Weak 16 2/3 Hz Magnetic Fields on Growth Parameters of Young Sunflower and Wheat Seedlings, Bioelectromagnetics 25:638-641(2004)

21. Jae-Duk Moon, Hwa-Sook Chung, Acceleration of germination of tomato seed by applying AC electric and magnetic fields, Journal of Electrostatics 48 (2000) 103-114

22. Masafumi Muraji, Masao Mishimura, Wataru Tatebe and Momoo Fuji, Effect of Alternating Magnetic Field on the Growth of the Primary Root of Corn, IEEE Transactions on Magnetics, Vol. 28, No. 4, July 1992

23. Mihaela Racucui, Dorina Creanga, Carmen Amoraritei, Biochemical Changes Induced by Low Frequency Mangetic Field Exposure of Vegetal Organisms, Rom. Journ. Phys., Vol. 52, Nos. 5-7, P. 645-651, Bucharest, 2007

24. P. Kiatgamjorn, W. Khan-ngern and S. Nitta, The Effect of Electric Field on Bean Sprout Growing, IEEMC Bangkok 2002

25. I.I Nagy, R. Georgescu, L. Balaceanu, S. Germene, Effects Of Pulsed Variable Magnetic Fields Over Plant Seeds, Romanian J. Biophys., Vol 15, Bucharest, 2005

26. Mihaela Ra cuciu,, Dorina-Emilia Creanga, Influence of water-based ferrofluid upon chlorophylls in cereals, Journal of Magnetism and Magnetic Materials 311 (2007) 291–294

27. AkiraYano, Yoshiaki Ohashi, Tomoyuki Hirasaki, and Kazuhiro Fujiwara, Effectsof a 60 Hz Magnetic Field on Photosynthetic CO2 Uptake and Early Growth of Radish Seedlings, Bioelectromagnetics 25:572-581 (2004)

28. Janusz Podlesny, Anna Podleśna, The effect of seed treatment with magnetic field on development and dynamics of dry matter accumulation by faba bean, International Agrophysics, vol. 4, nr. 3 (2004), pp. 787-801

29. Maria Victoria Carbonell, Elvira Martinez, Jose Manuel Amaya, Stimulation of germination in rice (Oryza Sativa L.) by a static magnetic field electromagnetic biology and medicine, volume 19, issue 1 march 2000 , pages 121 – 128

30. T. Leelapriya, K. S. Dhilip, P. V. Sanker Narayan, Effect of Weak Sinusoidal Magnetic Field on Germination and Yield of Cotton (Gossypium spp.) Electromagnetic Biology and Medicine, Volume 22, Issue 2 & 3 December 2003 , pages 117 – 125

31. Aladjadjiyan A., Study of the Influence of Magnetic Field on some Biological Characteristics of Zea Mais, Journal of Central European Agriculture, volume 3 (2002) no. 2

32. S. R. Trout, "Use of Helmholtz Coils for Magnetic Measurements", IEEE Trans Magnetics, V.24, No.4, Jul 88 pg.2108

33. Dr. Theodore Anderson, Design of a Helmholtz coil for susceptibility testing usingvariational calculus and experimental verification, Electromagnetic Compability 1999 IEEE Symposium , page(s): 601-604 vol.2

34. Helmholtz Coil Manual EMC Test Systems. EMC Test Systems (2001)

35. Jerome L. Rosenberg, Lawrence M. Epstein, Schaum's Outlines, College Chemistry pg 94

36. Nikhil Parsi, Electromagnetic Effects on Soybeans, Thesis MU (2007)

37. Paul T. Lynch, Michael R. Davey, Electrical Manipulation of Cells, pg 23