ELECTROMAGNETIC EFFECTS ON SOYBEANS

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In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

NIKHIL PARSI

Dr. Naz E. Islam, Thesis Supervisor

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The undersigned, appointed by the dean of the Graduate School,

have examined the thesis entitled.

ELECTROMAGNETIC EFFECTS ON SOYBEANS

Presented by Nikhil Parsi

A candidate for the degree of Master of Science

and hereby certify that in their opinion it is worthy of acceptance.

Naz E. Islam, Associate Professor, Dept. of Electrical and Computer Engineering

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John Gahl, Professor, Dept. of Electrical and Computer Engineering

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David A. Sleper, Professor, Dept. of Plant Sciences

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figure Page

LIST OF TABLES

Table Page

CHAPTER 1: **INTRODUCTION**

Natural or visible light belongs to a family of electromagnetic waves known as the electromagnetic (EM) spectrum. Each member of the EM family is defined by its unique frequency or wavelength. Natural light plays an important role in the growth and survival of species in our eco-system. For example, trees and plants have a number of light absorbing molecules that enable organisms to respond to changes in the natural light environment. Light signals thus regulate changes in structure and form, such as seed germination, leaf expansion, stem elongation, flower initiation and pigment synthesis. These photomorphogenic thus responses give an enormous survival advantage on organisms. It is therefore of interest to determine whether other members of the EM family, besides visible light, have any effects on plants and seeds. With the ever-shrinking natural resources, we specifically need to determine whether EM waves can be utilized in the growth of some energy producing resources that are necessary for the future survival of mankind. This research was conducted in order to answer the questions posed earlier.

All plants on the earth's surface experience electric and magnetic fields. An electric field exists between clouds and the earth due to the Schumann resonance [1] which occurs in the space between the surface of the earth and the conductive ionosphere which acts as a waveguide. The limited dimensions of the earth cause this waveguide to act as a resonant cavity for electromagnetic waves in the Extremely Low Frequency (ELF) band. The cavity is naturally excited by energy from lightning strikes. Schumann resonance modes are observed in the power spectra of the natural electromagnetic background noise, as separate peaks at extremely low frequencies around 7.8, 14.3, 20.8, 27.3 and 33.8 Hz.

Earth acts as a permanent magnet. The earth's natural magnetic field consists of one major component on the order of 50 milli Tesla (magnetic flux density) and several minor components, which depend on characteristics such as solar activity on the order of 0.03 milli Tesla and atmospheric events on the order of 0.5 milli Tesla [2]

Strength and direction of the earth's magnetic (geomagnetic) field have significant local differences. At the surface of the earth, the vertical component is maximal at the magnetic pole, amounting to about 67 milli Tesla and is zero at the magnetic equator. The horizontal component is maximal at the magnetic equator, about 33 milli Tesla, and is zero at the magnetic poles.

Schumann resonance and the geomagnetic field are among the environmental elements whose effects cannot be disregarded in life on the earth. It has been stated that external electric and magnetic fields influence both the activation of ions and polarization of dipoles in living cells [3-4].

Using an optimal external electromagnetic field the activation of plant growth, especially seed germination, can be accelerated. However, the mechanism of these actions is still poorly understood [5-6], and the feasibility of the effects of electromagnetic field being beneficial for plants and animals has been discussed for more than a century.

Electric or magnetic treatments are assumed to enhance seed vigor by influencing the biochemical processes that involve free radicals and by stimulating the activity of proteins and enzymes [7-9].

We have many positive reports regarding the exposure of different intensities of electric fields with seeds. Destruction of microorganisms in liquids by using high intensity electric fields has been thoroughly investigated by many scientists [8-9] and is already a patented method to preserve fluid foods. A review of the efforts on the inactivation of microorganisms by pulsed electric fields can be found in [10].

Frequency range	**Frequencies**	**Field source**	**Examples of maximal intensities**
Static	0 Hz	Natural VDU (video displays) MRI and other diagnostic / scientific instrumentation Industrial electrolysis	70 µT 1 T in the tunnel; 200 mT at the gate; < 0.5 mT outside the device room 10-30 mT at the level of the feet
Extremely Low Frequency (ELF)	0-300 Hz 50 Hz	Power lines Domestic distribution Electric engines in cars, train and tramway	10-20 µT under the line, or 10 kV/m < 0.1-0.2 µT in the room 50 µT and 300 V/m
Intermediate frequencies (IF)	300 Hz – 100 kHz	Typical examples are: VDU, anti theft devices in shops, hands free access control systems, card readers and metal detectors	30 to max 700 nT 10 V/m
Radio Frequency (RF)	100 kHz – 300 GHz	Broadcasting and TV; mobile telephony microwave oven Radar, portable and stationary radio transceivers, personal mobile radio.	0.1 W/m² 0.5 W/m² 0.2 W/m²

Table 1-1 Typical Sources of Electromagnetic Fields

The electric field might have similar effects on the microorganisms located on seeds. Field tests report greater than 10% increases in the yield of maize and wheat, after submitting the seeds to carefully controlled electric fields [11]. These effects were mainly attributed to the field-induced intensification of the biological processes in seeds. The crop increases could also be related to the sterilizing effect of high-voltage application.

We also have positive reports with magnetic fields. The first studies were conducted by Savostin in 1930 [12], who observed increases in the rate of elongation of wheat seedlings under magnetic conditions. Later, Murphy in 1942 [13] reported changes in seed germination due to a magnetic field, Akoyunoglou in 1964 [14] reported that the activities of some enzymes were increased by exposure to magnetic field.

In general, the enhancement of growth under magnetic conditions appears to have been confirmed by many scientists: Pittman (1963, 1965, 1977) [15-17], Pittman and Ormrod in 1970 [16], Bathnagar and Deb in 1977 [17], Gubbels in 1982 [18] and Kavi in 1983 [19]. Dayal and Singh in 1986 [20] exposed tomato seeds to different magnetic fields varying from 15 to 155mT for different exposure times, and they noted an increase in height and number of primary branches in treated plants compared to controls. Pietruszewski in 1993 [21] reported an increase on seedling growth, seed vigour and crop yield when seeds were exposed to a magnetic field. Aladjadjiyan in 2002 [22] detected that exposure to a 150 mT magnetic field stimulated shoot development and led to increase of the germination, fresh weight and shoot length of maize plants.

In this research, the effects of electromagnetic fields on the seeds of beans will be presented. The objective was to maximize the germination percentage which in turn would increase the yield of the plant. Soybean seeds were exposed to an electromagnetic field for a power level (P), frequency (F) and time duration (T).

In this thesis the effect of electromagnetic fields has been looked at further with a detailed analysis on the fatty acids, protein and oil concentrations on the soybean seed. We started off by taking power level and frequency constant while the time duration was varied. In particular, there was an attempt to increase the germination percentage by changing the values of power, frequency and time duration. We used four different exposure times 10 min, 20 min, 30 min and 40 min before finding 10 min as the best exposure time. We increased the number of soybean seeds with each experiment to determine the effect of electromagnetic fields. Finally, this thesis also analyzes the effects of magnetic fields on germination percentage of soybean.

The organization of this thesis is as follows. This introduction is followed by a background, where a brief history of electromagnetic radiation is presented. It also discusses the effects of electromagnetic fields on humans and plants. It also discusses the properties, physical characteristics, chemical composition and uses of soybean and optimizing soybean as source of biofuel. It also discusses the sources of electromagnetic fields which were used in this research.

The third chapter provides the brief history of the research in this area which had a significant impact on the current research work. It has electromagnetic, magnetic and electric effects on different plants, seeds, fruits and leaves. It provides the literature survey for this research only.

The fourth chapter provides the procedure and results used for this current study. It discusses the various parameters that can be changed to improve the germination. It also concludes the thesis with a summary of the project and presents new ideas which would be pursued for further research work in this area.

CHAPTER 2: **BACKGROUND**

2.1 Electromagnetic Radiation

Transverse Electromagnetic (TEM) radiation is a self-propagating wave in space with electric and magnetic components. These components oscillate at right angles to each other and to the direction of propagation, and are in phase with each other. Figure 2-1 illustrates the representation of electromagnetic field. Electromagnetic waves were first predicted by James Clerk Maxwell and subsequently confirmed by Heinrich Hertz. Maxwell derived a wave form of the electric and magnetic equations. According to Maxwell's equations, (as shown below) a time-varying electric field generates a magnetic field and vice versa.

As the equations suggest, an oscillating electric field generates an oscillating magnetic field, the magnetic field in turn generates an oscillating electric field, and so on. These oscillating fields together form an electromagnetic wave. One of the main characteristics which define an electromagnetic field (EMF) is its frequency or its corresponding wavelength. EM waves can be differentiated by their frequency (f) or their wavelength (λ) which are related by the expression: $\lambda = c / f$, where $c = 3 \times 10^8$ m/s is the speed of EM waves in vacuum.

	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	$\oint \vec{E}.d\vec{s} = -\frac{d\phi_B}{dt}$	$\nabla \times E = -\frac{\partial B}{\partial t}$	$\nabla \times E = -\frac{\partial B}{\partial t}$
Ampere's Law	$\oint \vec{B}.d\vec{s} = \mu_0 i + \frac{1}{c^2}\frac{\partial}{\partial t}\int \vec{E}.d\vec{A}$	$\nabla \times B = \frac{J}{\epsilon_0\, c^2} + \frac{1}{c^2}\frac{\partial E}{\partial t}$	$\nabla \times H = J + \frac{\partial D}{\partial t}$

Table 2-1 Maxwell's equations

Fields of different frequencies interact with the body in different ways. One can imagine electromagnetic waves as series of very regular waves that travel at an enormous speed, the speed of light. The frequency simply describes the number of oscillations or cycles per second, while the term wavelength describes the distance between one wave and the next. Hence wavelength and frequency are inseparably intertwined: the higher the frequency the shorter the wavelength. In electrical systems, the electric fields are created by differences in voltage: the higher the voltage, the stronger will be the resultant field. Magnetic fields are created when electric current flows: the greater the current, the stronger the magnetic field.

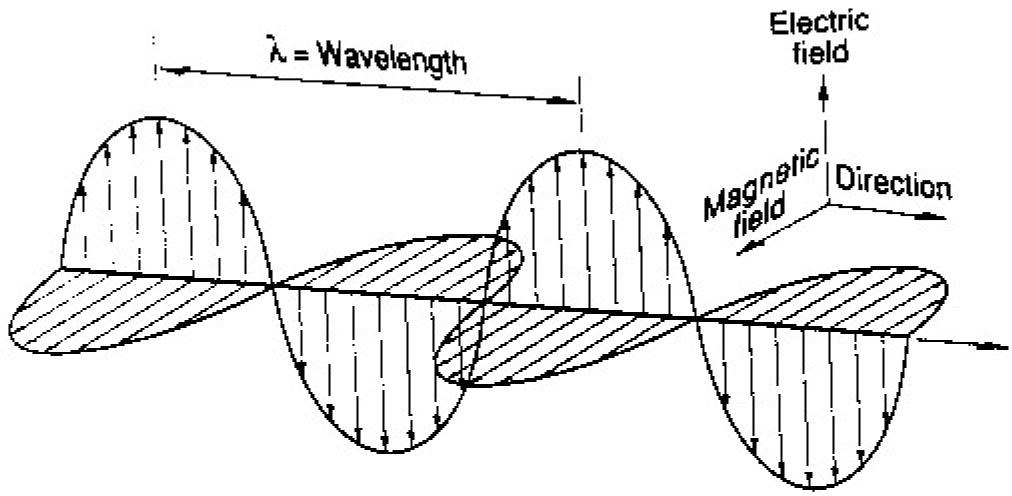

Figure 2-1 Representation of Electromagnetic wave

An electric field will exist even when there is no current flowing. If current does flow, the strength of the magnetic field will vary with power consumption but the electric field strength will be constant [37]. Electromagnetic radiation is classified into types according to the frequency of the wave: these types include, in order of increasing frequency, radio waves, microwaves, terahertz radiation, infrared radiation, visible light, ultraviolet radiation, X-rays and gamma rays. EM radiation carries energy and momentum, which may be imparted when it interacts with matter. Figure 2-2 represents the electromagnetic spectrum which shows all the different frequencies.

Besides natural sources the electromagnetic spectrum also includes fields generated by human-made sources and has various applications: X-rays, which are electromagnetic field of a specific frequency, are employed to diagnose a broken limb after a sport accident. The electricity that comes out of every power socket has associated low frequency electromagnetic fields.

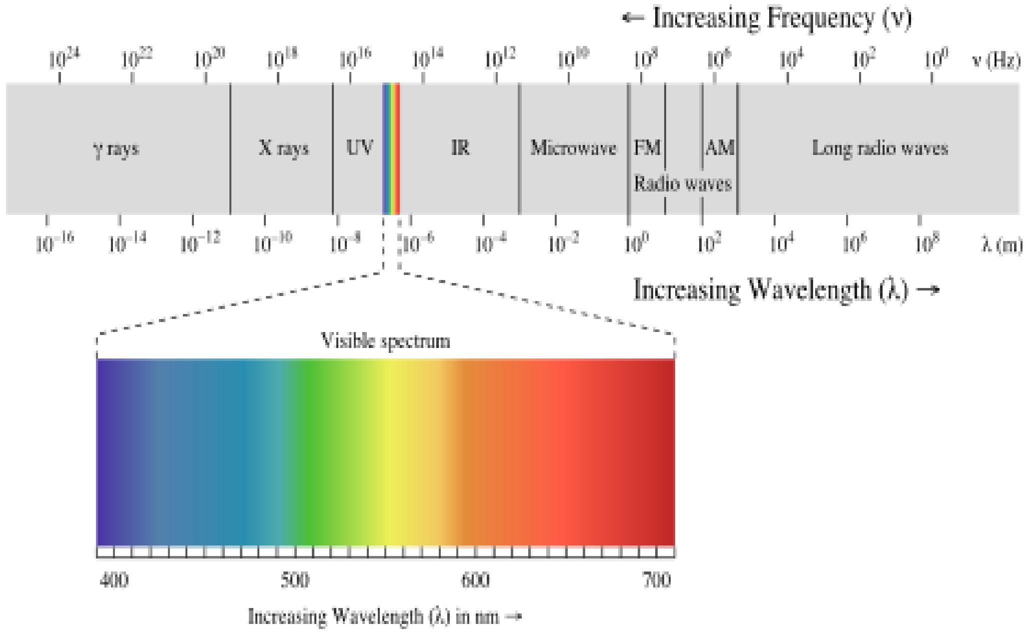

Figure 2-2 Electromagnetic Spectrum

Band	Applications
Extremely high frequency EHF (30-300 GHz)	Radar, advanced communication systems, remote sensing, radio astronomy
Super high frequency SHF (3-30GHz)	Radar, Satellite communication systems, aircraft navigation, radio astronomy, remote sensing
Ultra high frequency UHF (300 MHz – 3 GHz)	TV broadcasting, radar, radio astronomy, microwave ovens, cellular telephone
Very high frequency VHF (30 – 300 MHz)	TV and FM Broadcasting, mobile radio communication, aircraft control
High frequency HF (3 – 30 MHz)	Short wave broadcasting
Medium frequency MF (300 kHz – 3 MHz)	AM broadcasting
Low frequency LF (30 – 300 kHz)	Radio beacons, weather broadcasting stations for air navigation
Very low frequency VLF (3 – 30 kHz)	Navigation and position location
Ultra low frequency ULF (300 Hz – 3 kHz)	Audio signals on telephone
Super low frequency SLF (30 – 300 Hz)	Ionosphere sensing, electric power distribution, submarine communication
Extremely low frequency ELF (3 – 30 Hz)	Detection of buried metal objects
f < 3 Hz	Magneto-telluric sensing of the earth's structure

Table 2-2 Individual bands of the radio spectrum and their primary applications

And various kinds of higher frequency radio waves are used to transmit information – whether via TV antennas, radio stations or mobile phone base stations. Table 2-1 has different frequency bands and their applications.

2.2 Effects of Electromagnetic Fields

The behavior of EM radiation depends on its wavelength, and electromagnetic fields of different wavelengths are present everywhere in our environment but are invisible to the human eye. Such fields may be produced by the local build-up of electric charges in the atmosphere associated with thunderstorms. Also, since electrical charges are present in clouds, an electric field is created between the surface of the earth and the clouds because the space between the surface of the earth and the conductive ionosphere acts as a waveguide [1]. On the other hand, the earth acts as a permanent magnet and the earth's magnetic field causes a compass needle to orient in a North-South direction and is used by birds and fish for navigation. Electric and magnetic fields are present on the earth’s surface at all times. The earth’s natural magnetic field consists of one major component on the order of 50 milli Tesla (a measure of magnetic flux density) [2].

Exposure to electromagnetic fields is not a new phenomenon. However, during the 20th century, environmental exposure to man-made electromagnetic fields has been steadily increasing as growing electricity demand, ever-advancing technologies and changes in social behavior have created more and more artificial sources. Everything is exposed to a complex mix of weak electric and magnetic fields, both, from the generation and transmission of electricity, domestic appliances and industrial equipment, to telecommunications and broadcasting.

2.2.1 Effects on Humans

Tiny electrical currents exist in the human body due to the chemical reactions that occur as part of the normal bodily functions, even in the absence of external electric fields. For example, nerves relay signals by transmitting electric impulses. Most biochemical reactions from digestion to brain activities go along with the rearrangement of charged particles. Even the heart is electrically active - an activity that a trained doctor can trace with the help of an electrocardiogram.

Low-frequency electric fields influence the human body just as they influence any other material made up of charged particles. When electric fields act on conductive materials, they influence the distribution of electric charges at their surface. They cause current to flow through the body to the ground. Low-frequency magnetic fields induce circulating currents within the human body. The strength of these currents depends on the intensity of the outside magnetic field. If sufficiently large, these currents could cause stimulation of nerves and muscles or affect other biological processes. Both electric and magnetic fields induce voltages and currents in the body but even directly beneath a high voltage transmission line, the induced currents are very small compared to thresholds for producing shock and other electrical effects.

2.2.1.1 Effects on General Health

Some members of the public have attributed a diffuse collection of symptoms to low levels of exposure to electromagnetic fields at home [46]. Reported symptoms include headaches, anxiety, suicide and depression, nausea, fatigue and loss of libido. To date, scientific evidence does not support a link between these symptoms and exposure to electromagnetic fields.

At least some of these health problems may be caused by noise or other factors in the environment or by anxiety related to the presence of new technologies.

2.2.1.2 Effects on Pregnancy Outcome

Many different sources and exposures to electromagnetic fields in the living and working environment, including computer screens, water beds and electric blankets, radiofrequency welding machines, diathermy equipment and radar, have been evaluated by the WHO and other organizations [46]. The overall weight of evidence shows that exposure to fields at typical environmental levels does not increase the risk of any adverse outcome such as spontaneous abortions, malformations, low birth weight, and congenital diseases. There have been occasional reports of associations between health problems and presumed exposure to electromagnetic fields, such as reports of prematurity and low birth weight in children of workers in the electronics industry, but these have not been regarded by the scientific community as being necessarily caused by the field exposures (as opposed to factors such as exposure to solvents).

2.2.1.3 Cataracts

General eye irritation and cataracts have sometimes been reported in workers exposed to high levels of radiofrequency and microwave radiation, but animal studies do not support that eye damage can be produced at levels that are not thermally hazardous [46]. There is no evidence that these effects occur at levels experienced by the general public.

2.2.1.4 Electromagnetic Fields and Cancer

Despite many studies, the evidence for any effect remains highly controversial. However, it is clear that if electromagnetic fields do have an effect on cancer, then any increase in risk will be extremely small [46]. The results to date contain many inconsistencies, but no large increases in risk have been found for any cancer in children or adults.

A number of epidemiological studies suggest small increases in risk of childhood leukemia with exposure to low frequency magnetic fields in the home. However, scientists have not generally concluded that these results indicate a cause-effect relation between exposure to the fields and disease (as opposed to artifacts in the study or effects unrelated to field exposure). In part, this conclusion has been reached because animal and laboratory studies fail to demonstrate any reproducible effects that are consistent with the hypothesis that fields cause or promote cancer. Large-scale studies are currently underway in several countries and may help resolve these issues.

2.2.1.5 Electromagnetic Hypersensitivity and Depression

Some individuals report "hypersensitivity" to electric or magnetic fields. They ask whether aches and pains, headaches, depression, lethargy, sleeping disorders, and even convulsions and epileptic seizures could be associated with electromagnetic field exposure [46].

There is little scientific evidence to support the idea of electromagnetic hypersensitivity. Recent Scandinavian studies found that individuals do not show consistent reactions under properly controlled conditions of electromagnetic field exposure. Nor is there any accepted biological mechanism to explain hypersensitivity. Research on this subject is difficult because many other subjective responses may be involved, apart from direct effects of fields themselves. More studies are continuing on the subject.

2.3 Effects on Plants

Besides warm blooded creatures, electromagnetic fields also have effects on plants, seeds and fruits. Since there is a permanent magnetic field of the earth itself, it would be reasonable to believe that the germination of certain plants will be effected by the fields itself. The rate of germination of each species may be dependent on the field strength. It is also possible that an increase in the field strength may in fact enhance or inhibit growth of some species. More on this will be detailed in chapter 3, while this section will strive to introduce the subject which is the main theme for this thesis.

Static, Alternating Current (AC), Direct Current (DC), alternating and stationary fields were used for different experiments conducted worldwide. Experiments were carried out on different things like rate of germination, germination percentage, seed weight, plant height, protein content, productivity, leaf size, fruit weight, fruit number etc. Different power levels, frequencies and time duration were used for different experiments. Results were determined by the selection of different seeds, plants, frequency, power level and time duration. Exposure of electric, magnetic and electromagnetic fields had both positive and negative effects for different combinations. It is essential to find out the right combination for different seeds, plants and also depends on the requirement.

2.4 Focus of Research

This research is to study the effects of electromagnetic fields on soybean, specifically its germination rate. The choice is based on the fact that soybean could be used as a potential source for biofuel and thus minimize our dependency on foreign sources of energy. As a result mechanisms need to be put in place to make biofuels economical, competitive and therefore a viable alternate energy source.

2.4.1 Properties of Soybean

The soybean (Glycine max), a legume native to East Asia that has become a major source of vegetable protein, oil for human and animal consumption and for industrial usage. First written records of soybeans are dated back to 2838 BC., and the Chinese have been cultivating them for thousands of years. It is an annual plant that may vary in growth, habit and height. The valued portion of the plant is the seed, which contains about 40% protein and 21% oil. Illinois, Iowa, Arkansas, Missouri, Indiana, Mississippi, Minnesota, Ohio, Louisiana, and Tennessee are the major soybean producers in the United States.

Soybeans can be broadly classified as "vegetable" (garden) or field (oil) types. Vegetable type's cook more easily, have a mild nutty flavor, better texture, are larger in size, higher in protein, and lower in oil than field types. Among the legumes, the soybean, also classed as an oilseed, is pre-eminent for its high (38-45%) protein content as well as its high (20%) oil content [47]. Besides as a source for biofuels, soybeans can be processed in number of ways, which is briefly described below:

Soy flour

Soy flour refers to defatted soybeans where special care was taken during de-solventizing (not toasted) in order to minimize de-naturation of the protein to retain a high Nitrogen Solubility Index [48]. It is used for the production of soy concentrate and soy protein isolate.

Infant formula

Infant formulas based on soy are used by lactose-intolerant babies and for babies that are allergic to human milk proteins and cow milk proteins. The formulas are sold in powdered, ready to feed or concentrated liquid forms [47].

Substitute for existing products

Many traditional dairy products have been imitated using processed soybeans, and imitation products such as "soy milk," "soy yogurt" and "soy cream cheese" are readily available in most supermarkets. These imitation products are derived from extensive processing to produce a texture and appearance similar to the real dairy-based ones. Soy milk does not contain significant amounts of calcium, since the high calcium content of soybeans is bound to the insoluble constituents and remains in the pulp [47].

2.5 Optimizing Soybean as Source for Biofuel

There is a lot of interest in the optimization of soybean as bio-fuel resource. This research is concerned with increasing the germination percentage of the seeds. Soybean seeds have oil which can be converted into bio-fuels by the addition of chemical called sodium meth-oxide. According to a recent study, soybean bio-fuel was considered to be the most efficient and had the highest energy emitted per gram per second when compared to bio-fuels made out of oil of canola and olive. Diesel in comparison had a very low emission rate per gram. If bio-fuels are manufactured correctly, they have the potential output energy that can compete with fossil fuels [38].

Soybean as a biofuel resource can be produced by the maximization of yield, promotion of plant growth and its protection against diseases and other optimization methods. Bio stimulation is one such optimization method and could be accomplished through various mechanisms and one has to choose the best possible one, depending on the resources available for research. Possible bio stimulation mechanisms include:

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"

Optimization studies include the following:

2.5.1 Study of Physical Characteristics

Germination of plants and seeds can be studied in terms of their changes in physical characteristics as they grow in time. They may grow prostrate, not growing higher than 20 cm (7.8 inches), or even stiffly erect up to 2 meters (6.5 feet) in height. The pods, stems and leaves are covered with fine brown or gray pubescence. The leaves are trifoliolate (sometimes with 5 leaflets), and the leaflets are 6-15 cm (2-6 inches) long and 2-7 cm (1-3 inches) broad. Soybeans occur in various sizes and in several hull or seed coat colors, including black, brown, blue, yellow and mottled [47]. The hull of the mature bean is hard, water resistant and protects the cotyledon and hypocotyl (or "germ") from damage. Seed would not germinate if seed coat is cracked. There is a scar, visible on the seed coat called hilum (colors include black, brown, buff, gray and yellow) and at one end of the hilum is the micropyle, or small opening in the seed coat which can allow the absorption of water.

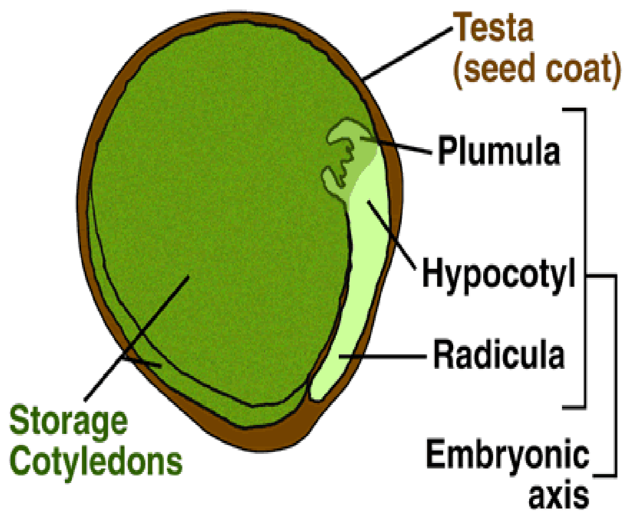

Figure 2-3 Structure of soybean seed

2.5.2 Study of Chemical Composition

The oil and protein content together account for about 60% of dry soybeans by weight, protein at 40% and oil at 20%. The remainder consists of 35% carbohydrate and about 5% ash. Ash is the name given to all compounds that are not considered organic or water. These are the compounds that remain (as "ashes") after a sample is burned, and consist mostly of metal oxides. Soybean cultivars comprise approximately 8% seed coat or hull, 90% cotyledons and 2% hypocotyl axis or germ [47].

The majority of soy protein is a relatively heat-stable storage protein. It is this heat-stability of the soy protein that enables soy food products requiring high temperature cooking, such as tofu, soymilk and textured vegetable protein (soy flour) to be made.

Because of the great diversity of living organisms and the physical phenomena at play, the interactions of EM energy with biological organisms are very complex. Each living organism reacts differently to radiation and interactions depend on the photon energy. Interactions include atomic changes, chemical or genetic links breakdown and possible heat generation. Surface interactions or deep penetrations of the energy are also a possibility. The advantage of using EM wave as a bio stimulator has the advantage over traditional chemical processes is that, in theory, they do not leave any toxic residue

It has been established that bio-stimulators affect the growth and development and protections of plants and seeds. For example, through a series of experiments at the University of Novi Sad, Tampograf, it was shown that magnetic stimulation on cereal seed increased the yield by 20%, and the application of the variable electromagnetic field show a 94% increase in the root mass of sugar beet, the leaf surface by 52%, yield to 12.88 t/ha and the percentage of sugar increased by 70%. Similar experiments with corn show a higher root mass (55%), vegetative mass (57%) and yield (18.70%). Variable electromagnetic fields with different frequency in a macro trial with potato showed a yield increase up to 144.8% [39]. Similarly, the yield of pepper was increased by 64.9% with resonant impulse electromagnetic stimulation [40]. Also, with electromagnetic stimulation of soil, an increase in the yield of soybean from 5 to 25% was seen with a higher quantity of oil and protein which varied from 13.2 to 17.3% in sunflower [41]. Stimulation of soils results in an increase in the total microbial abundance in soil and decreased abundance of fungi, ureolithic microorganisms, denitrifying organisms and urease activity.

As a result the yield of cultivars in trials (sugar beet, corn) was increased [42]. Yoshida et al. [43] treated soybean seeds with microwave rays (2, 45 GHz) for 6 to 12 min for improving the triglycerides distribution in the seed coat. The direct effect of electromagnetic radiation of the microwave range on the germination of cereals (winter and spring wheat, spring barley, and oats) has also been studied. The applied treatment included a wavelength of λ = 1 cm and up to 40 min exposure. Increased germination was observed in all the tested seeds, the optimal stimulating effect being reported at 20 min exposure. Finally, magnetic field of 0.2 - 0.3 *T* has been used for treatment of soybean seeds [44-45].

2.6 Sources of Electromagnetic Fields

Figure 2-4 Anechoic chamber

Sources producing electromagnetic pulses as well as Continuous Wave can be a powerful tool as a bio stimulator. At the ECE Department, we have a number of EM sources which we propose to use as a bio stimulator to optimize soybean production. The one we used was HiPER lab (anechoic chamber). Electromagnetic Radiation Facility at the HiPER Laboratory which uses a log-periodic antenna to generate Continuous Wave in the frequency range: 27 MHz – 4.1 GHz with field strength: 10 V / m max, Maximum DUT size can be 100 × 100 cm^2, and the input RF power: is 150 Watts max, Cell dimension are: 5.7 × 2.6 × 2.4 m^3. A smaller version is shown here in Figure 2-4.

2.6.1 Anechoic chamber Model TC4000B Test Cell

Tests were conducted in an anechoic chamber Model TC4000B Test Cell[49] .Test cell is one of a series of AR cell test cells that bridge the gap between size limited TEM (transverse electromagnetic) cells and anechoic chambers for making pre-compliance radiated immunity and radiated emissions measurements on large test objects [49].

The interior of the AR cell 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, while an (optional) bowtie antenna is used at the lower frequencies. Vertical or horizontal polarization is user selected.

Equipment	Frequency Range	Power/Field
Control Computer	NA	NA
Signal Generator	9 kHz to 1.1 GHz	-140.0 dBm to 13 dBm
RF Amplifier	80 MHz to 1 GHz	0 dBm (max input) Gain +52 dBm
Log-periodic Antenna	80 MHz to 5 GHz	Gain 36 dBm
Semi-Anechoic Test Cell	27 MHz to 4.2 GHz	500 W
E-field Probe	100kHz to 3 GHz	.4 to 660 V/m

Table 2-3 TC4000B Hardware Specifications

The high-efficiency launching device allows 80-4.2 GHz, 10 V/m field strengths with 80% AM modulation to be generated at the preferred 3 meter distance with a 150 watt RF source (Amplifier Research Model 150W1000) for immunity compliance testing. Testing from 27-80 MHz is facilitated by adding the optional Model BT3400 Bow-Tie Antenna.

Figure 2-5 Log Periodic antenna

The launching end of the chamber is a log periodic antenna which gives out EM waves and the receiving end is Field probe to measure the EM field (the E field and H field)

Figure 2-6 Field probe

We also used Helmholtz coil for experiments related to uniform magnetic field. The description for the device is given below.

2.6.2 Helmholtz Coil

The term Helmholtz coils refers to a device for producing a region of nearly uniform magnetic field. It is named in honor of the German physicist Hermann von Helmholtz. A Helmholtz pair consists of two identical circular magnetic coils that are placed symmetrically one on each side of the experimental area along a common axis, and separated by a distance equal to the radius of the coil [50]. Actually, a slightly larger separation improves the field uniformity. Each coil carries an equal electrical current flowing in the same direction. The strength of the magnetic field generated is directly proportional to the number of turns in the coils and the current applied to them.

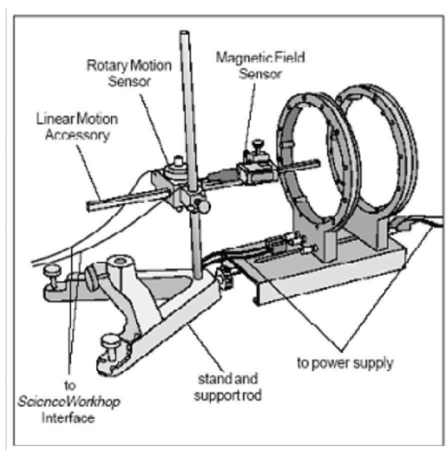

Figure 2-7 Set up of Helmholtz coil

The coils are wound in series so that the magnetic field produced by current flowing in one coil aids the field in the other coil. A cylindrical region extending between the centers of the two coils and approximately 1/5 of their diameter will have a nearly spatially uniform magnetic field. The calculation of the exact magnetic field at any point in space has mathematical complexities and involves the study of Bessel functions.

CHAPTER 3: **LITERATURE SURVEY**

Electromagnetic energy sources in the form of electromagnetic waves can be generated naturally and can also be man-made. As discussed earlier in Chapter 2, these waves consist of oscillating electric and magnetic fields that can be of many different frequencies, are perpendicular to each other, and can travel in vacuum with the speed of light (3x 10^8 m/s). These energy sources interact differently with biological systems such as cells, plants, animals, or human beings. Researchers working in the area electromagnetic energy with animals, plants etc. have different opinions as to their effects. For some EMF radiation is an environmental hazard and is a concern and is often linked to cancer related syndromes and leukemia. Other researchers look at the positive effects, specifically in the growth of plants and seeds. This Chapter describes some of the research in this area and is divided into three sections. First the effects of EMF described which is then followed by a summary of researchers related to the effects of electric and magnetic fields alone.

3.1 Effects of Electromagnetic Field

Accelerated and widespread use of different communication systems and modern electronic equipment has increased the exposure to public and professionals alike to radio and microwave frequency electromagnetic fields (EMFs). These waves also influence plants and seeds and a number of studies were conducted in this area. In the studies, different ranges of frequencies were used with different intensities. Different seeds used were soybeans, gram, duckweed, flax and perennial crops.

3.1.1 Electromagnetic Field on Soybeans

This paper [32] deals with the electromagnetic effects on soybeans plants. It is a case study which uses stress as a means of assessment in plants. Development instability is variation of development within a plant due to local fluctuations in internal or external environmental conditions.

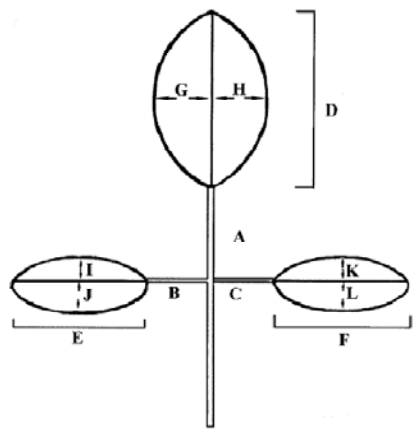

Figure 3-1 Diagram of soybean leaf showing the parameters measured. *J* and *L* are normally greater than *I* and *K*, i.e., the lateral leaflets were directionally asymmetric

Variation often is studied using deviations from perfect bilateral symmetry. External condition here would be associated with electromagnetic fields. The leaves of soybean plant were considered for the experiment. Developmental instability provides a useful means of assessing stress in a wide variety of circumstances. However, one must be able to specify the phenotype that should have developed in the absence of stress. According to this study, EMFs do increase the fluctuating asymmetry of soybeans.

Trait	Size	Asymmetry
Lateral rachilla length (LRL)	(B+C)/2	(B-C)/2
Lateral leaflet length (LLL)	(E+F)/2	E-F
Terminal leaflet width (TLW)	(G+H)/2	G-H
Lateral leaflet top (LLT)	(I+K)/2	I-K
Lateral leaflet bottom (LLB)	(J+L)/2	J-L
Lateral leaflet width (LLW)		I-J and K-L
Terminal rachis length (TRL)	A	. . . .
Terminal leaflet length (TLL)	D	. . . .

Table 3-1 Leaf Traits and Expressions for Size and Asymmetry

The distortions in the leaves were small, and unless careful measurements were taken, these asymmetries would not have been apparent. Nevertheless, fluctuating asymmetry was greater from plants growing under the transmission line than those 50 or 100 m away.

3.1.2 Electromagnetic Field on Gram

This experiment [33] was done to examine the impact on root growth on gram seeds (Cicar arietum) when electric and magnetic fields are applied separately. There was an increase in the transportation of calcium across cell walls under the influence of an electromagnetic field. There was a striking response on the seed germination of the radish seeds when stimulated by EM field. Some seeds could germinate only few days after the fertilization and long before the normal harvesting time. The magnetic and electric field 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 effects of magnetic and electric field on root growth of gram seeds after 4-days of germination were analyzed statistically. Importance of the differences of root lengths between the control and experimental groups could be made significant using the F-Test.

The results reveal that root lengths were increased more when the exposure time was 40 minute at field strength of 0.66 T compared with the other exposure times. At 0.88 T, the root lengths were increased when the exposure times were 40 min and 80 min and with increase of exposure time to 120 min the root length was found to decrease. In presence of magnetic field of 1.1 T the growth of root length was decreased with the increase of exposure time. It was found that the root length was highest at magnetic field of 0.88 T during 80 minutes exposures and it was 49% higher than control. By the application of electric field of 1.5 KV/cm on gram seeds for 20 min the root length was decreased 14% in compared to the control. With the increase of electric field strength the root growth was decreased further.

According to this study, it was found that the growth of root length was highest during the exposure of magnetic field strength of 0.88 T for 80 minutes.

3.1.3 Electromagnetic Field on Duckweed

Duckweed (Lemna minor L.) was used as a model plant for the current experiment [34]. In the present study, duckweed growth and peroxidase activity was evaluated. They were exposed to Gigahertz Transversal Electromagnetic (GTEM) cell to electric fields of frequencies 400, 900 and 1900 MHz. Axenic cultures of duckweed (Lemna minor L.) were maintained in Erlenmeyer flasks with 150 ml of the Pirson–Seidel's nutrient solution. All cultures were grown under 16 hours of light and constant temperature (24±2ºC).

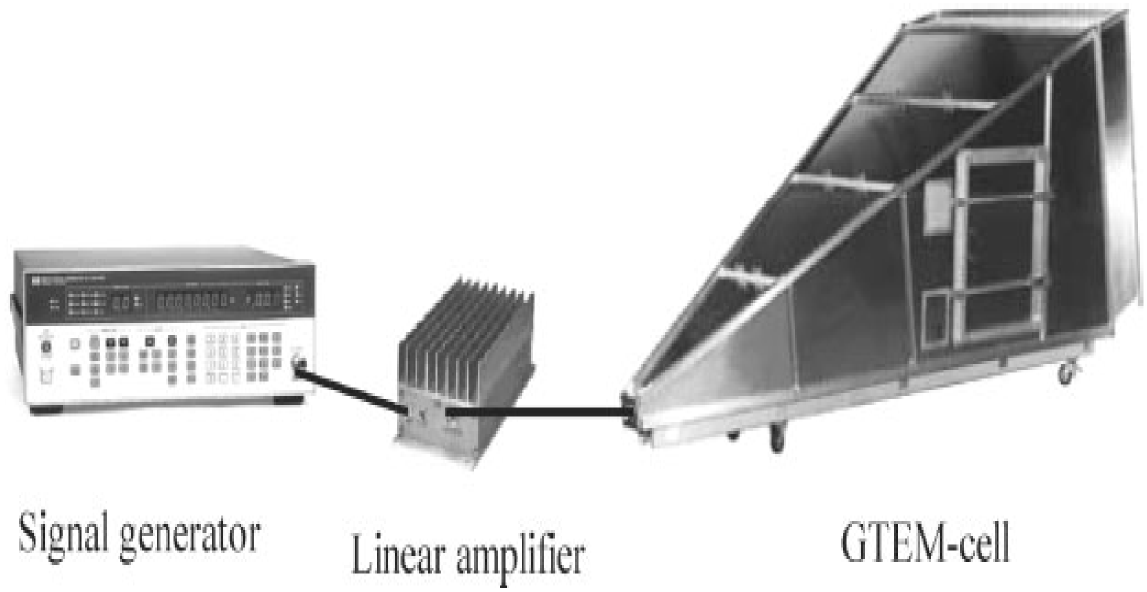

Figure 3-2 Instruments used for the radiofrequencies exposure. Apart from the GTEM cell, HP 8657A signal generator and 5 W Mini Circuits amplifier were used to obtain the chosen frequencies and strengths of electromagnetic field (EMF).

The exposure of electromagnetic fields was done in the GTEM cell. It was constructed to establish standard EMF in a shielded environment. The growth of plants exposed for 2 hours to 23 V/m electric field of 900 MHz significantly decreased in comparison with the control. An electric field of the same strength but at 400 MHz did not have such effect. A modulated field at 900 MHz strongly inhibited the growth, while at 400 MHz modulation did not influence the growth significantly. At both frequencies a longer exposure mostly decreased the growth and the highest electric field (390 V/m) strongly inhibited the growth. Exposure of plants to lower field strength (10 V/m) for 14 hours caused significant decrease at 400 and 1900 MHz while 900 MHz did not influence the growth. Peroxidase activity in exposed plants varied, depending on the exposure characteristics. Observed changes were mostly small, except in plants exposed for 2 hours to 41 V/m at 900MHz where a significant increase (41%) was found.

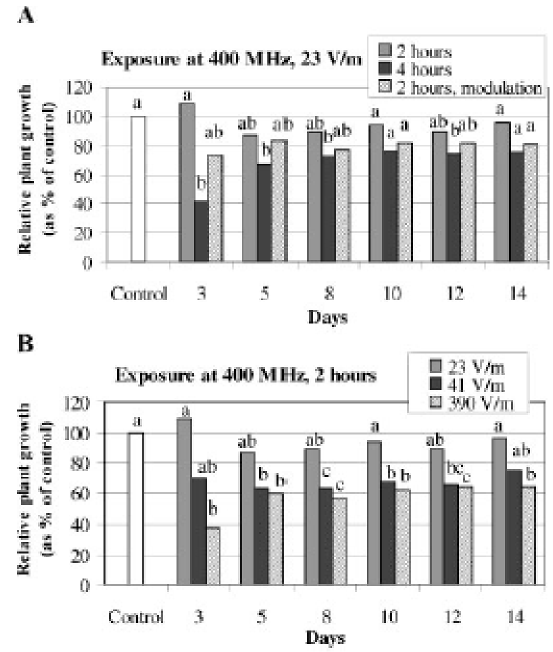

Figure 3-3 The relative growth of Lemna minor plants during 14 days after the exposure to electric field of 400 MHz: (A) strength of 23 V/m for 2 and 4 h and 2 h of modulated field, (B) strengths of 23, 41, and 390 V/m for 2 h. Data represent percentage of control. Different letters on the top of the columns indicate significant differences between treatments at P_.05 by Duncan's New Multiple Range Test (n¼7).

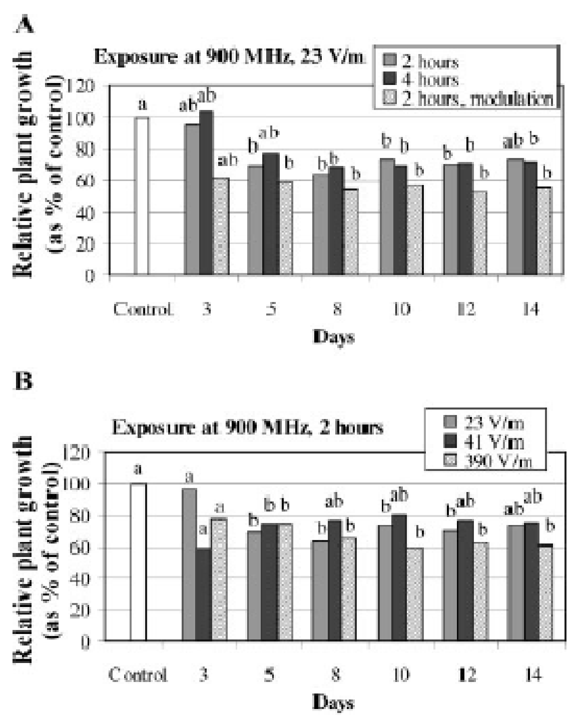

Figure 3-4 The relative growth of Lemna minor plants during 14 days after the exposure to electric field of 900 MHz: (A) strength of 23 V/m for 2 and 4 h and 2 h of modulated field, (B) strengths of 23, 41, and 390 V/m for 2 h. Data represent percentage of control. Different letters on the top of the columns indicate significant differences between treatments at P_.05 by Duncan's New Multiple Range Test (n¼7).

Our results suggest that investigated electromagnetic fields (EMFs) might influence plant growth and, to some extent, peroxidase activity. However, the effects of EMFs strongly depended on the characteristics of the field exposure.

3.1.4 Electromagnetic Field on Flax

This study by Marc Tafforeau, Marie-Claire Verdus, Vic Norris, Glenn J.White, Mike Cole, Maurice Demarty, Michel Thellier, and Camille Ripoll [35] exposed seedlings of the flax, Linum usitatissimum L., to a variety of weak environmental stresses followed by a 2 day calcium deprivation, which in turn triggers the common response of production of epidermal meristems in the hypocotyls, which is the part of the stem between the root and the cotyledons. Actively dividing groups of cells is called epidermal meristems and cotyledons are the pre-existing leaves in the embryo. Plants were grown in a culture room at 22±1ºC under continuous artificial light (6.4 W/m^2 irradiance), except for a 3 day period of germination in the dark.

On day 6, seedlings were exposed to radiation from the Gunn oscillator, which in turn produced an average of seven meristems, 3 weeks (day 29) after the end of the calcium deprivation (Fig. 3-6). The controls which were performed: (1) irradiation without the calcium deprivation step, (2) no irradiation but inclusion of the calcium deprivation step, and (3) no irradiation and no calcium deprivation. Controls 1 (data not given) and 2 (Fig. 3-6) gave an average of less than 0.7 meristems on day 29, while control 3 gave none (data not given). There is no appreciable difference between the results of giving the same treatment in separate experiments. By contrast there is a clear-cut difference between the results of a 2 hour irradiation and the controls, as shown Figure 3-6.

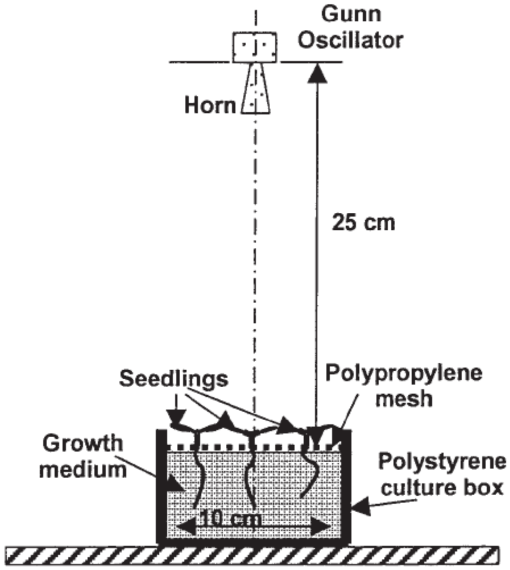

Fig 3-5 Schematic representation of the experimental Apparatus used for the irradiation of flax seedlings. For clarity only three seedlings are represented here; in the actual experiments, approximately 150 seedlings were grown on the polypropylene mesh.

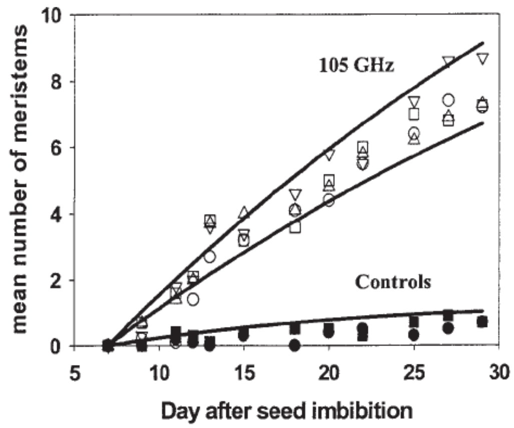

Fig 3-6 Mean number of meristems per hypocotyl as a function of time. A total of 1144 seedlings were analyzed. Each point is the mean of 10 measurements. Each separate experiment is represented by a different symbol. The lines around these points are arbitrarily drawn for visual help to show the difference between irradiated and control seedlings. Irradiation by the Gunn oscillator, open symbols; controls (no irradiation but calcium deprivation), filled symbols.

From these results, the combination of 2 hour irradiation at 105 GHz and a two day deprivation on the plants would be similar to that of other combinations of stimulus such as touch, cold shock, wind, or drought plus calcium deprivation.

3.1.5 Electromagnetic Field on Perennial Crops

This experiment by Aladjadjiyan A [36] studied the effect of microwave irradiation having wavelength 12 cm on the germination energy and germination of seeds. Microwave irradiation had an initial power of 425 and 850 W and exposure time of 30 seconds. Different seeds were considered for the experiment (Gleditschia triacanthos L., Caragana arborescens, Laburnum anagiroides Med., Robinia pseudo acacia L.)

Twenty five seeds of each variety were considered with different microwave electromagnetic treatments. Seeds were initially placed in moist beds and then treated. From table 3-2, we can see gradual increase of germination and germinating energy, proportional to the treatment power for Gleditschia triacanthos and Robinia pseudo acacia.

Species		Caragana	Laburnum	Gleditschia	Robinia
Control	G %	8	12	0	16
	GE%	0.57	2	0	1.14
425 W	G %	24	32	12	36
	GE%	2.36	2.3	1.2	2.57
850 W	G %	16	20	18	44
	GE%	1.71	1.43	1.8	3.12

Table 3-2 Indices of seeds of the studied species after microwave electromagnetic irradiation

For Caragana arborescens and Laburnum anagiroides there was an increase of germination and germinating energy corresponding to a power of 425 W. Seed germination got lower at 850 W when compared to 425 W while the germinating energy of Caragana was lower compared to the control.

Microwave electromagnetic radiation increases the germination energy and germination of Gleditschia triacanthos, Caragana arborescens, Laburnum anagiroides and Robinia pseudo acacia.

3.2 Effects of Electric Field

Plant growth, as well as the biological processes of seeds, can be accelerated or inhibited by high-intensity electric fields [5], [29]. Apart from using an electric field, electrostatic field was also used. Bean, barley, lactobacillus brevis and Cardiospermum halicacabum were the different seeds.

3.2.1 Electric Field on Bean

This paper [9] deals with the effect of high intensity electric field on Bean seeds (Phaseolus vulgare). They find out that an electric field could be an effective substitute for the chemical agents which are used for the growth of the plant. The bean seeds used were naturally infected with Colletotrichum lindemuthianum. They were other microorganisms which were found on the seeds like Fusarium, Alternaria, Penicillium, Aspergilius and Mucor mucedo. The infected seeds were representing only 89 % of the mass of the non-infected seeds and moisture content was 14.5 % ± 0.5 %. Typical setup of the experiment is shown below connected to a fully adjustable high voltage supply.

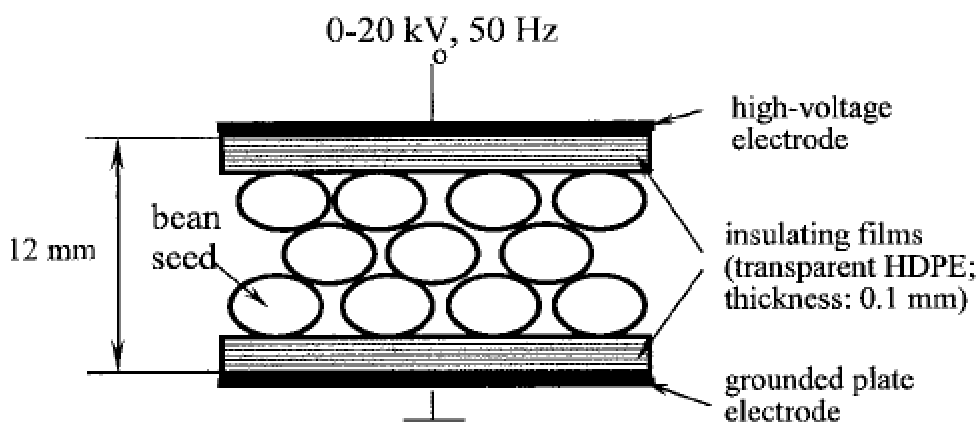

Fig 3-7 Schematic of the experimental setup used to impose electric field treatments on bean seed

Insulating films were used in order to avoid contact with the electrodes. The seeds were subjected to a 50 Hz electric fields ranging from 2 to 16 kV/cm. Exposure times were ranging from 1 to 30 seconds. Germination percentage was only 30 % for seeds without the exposure to electric field and increased to a surprising 99 % when treated. There was also a significant increase in the weight of the bean plant growing from the seeds which were treated with an electric field of 16 kV/cm. The main sterilizing agent for the seeds was the ozone generation by partial discharges, while the activation of OH radicals under the action of the high-intensity electric field may explain the intensification of the biological processes.

3.2.2 Electric Field on Barley

Stefa Lynikiene and Ausra Pozeliene [30] studied the effect of electrical field on barley seed germination stimulation. The objective of this study was to investigate and substantiate possibilities of seed potential energy realisation by using electro physical treatment method (corona discharge field) and means (conveyor electric separator). Tests were done on barley seeds to find out field strength, time from treatment to sowing and seed moisture. Germination tests were done in four replications, 100 seed per replication and seed viability tests were conducted in two replications, 100 seed per replication. The seed was artificially wetted to get the desirable moisture.

The treatment for seeds with electrical field gave a remarkable increase in seed germination for the first fraction of the electric separator compared to the untreated control seeds. The differences were not significant for seed germination in the second fraction and in the control. Viability and germination difference between the control seed and the seed that passed into the first fraction of the electric separator was significant.

The same difference between control seed and second fraction’s seed germination averages was insignificant. The greatest effect of the strength of the electric field was on the seed germination of the first fraction, while moisture content of the seed had the greatest impact on the seed germination of the second fraction.

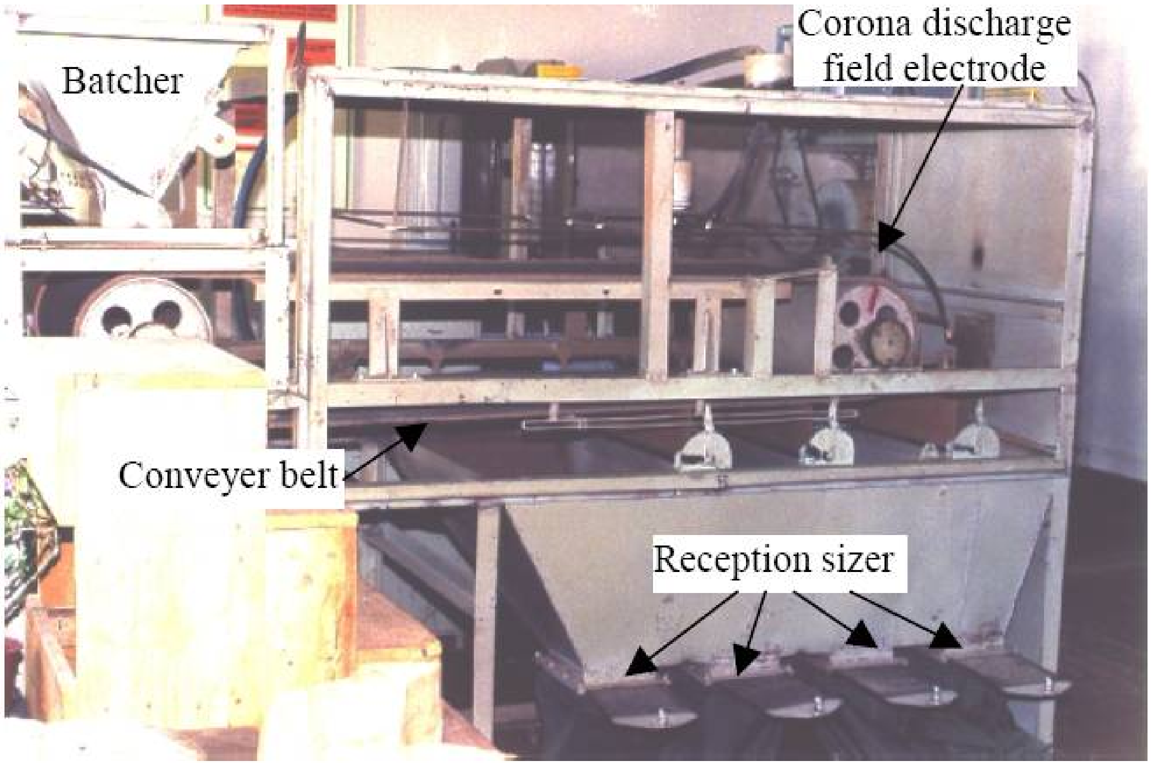

Fig 3-8 Conveyer type electric separator

The difference between the germination values obtained experimentally and by equations did not exceed permissible deviation from the mean.

3.2.3 Electric Field on Lactobacillus Brevis

This study [11] was conducted to find out the effects of high electric field pulses on a microorganism at different temperatures. The technique used in this study called electroporation which is a significant increase in the electrical conductivity and permeability of the cell plasma membrane caused by an externally applied electric field. This had a non-thermal lethal effect on the bacterial cells of Lactobacillus (L.) brevis which were suspended in a buffered phosphate solution.

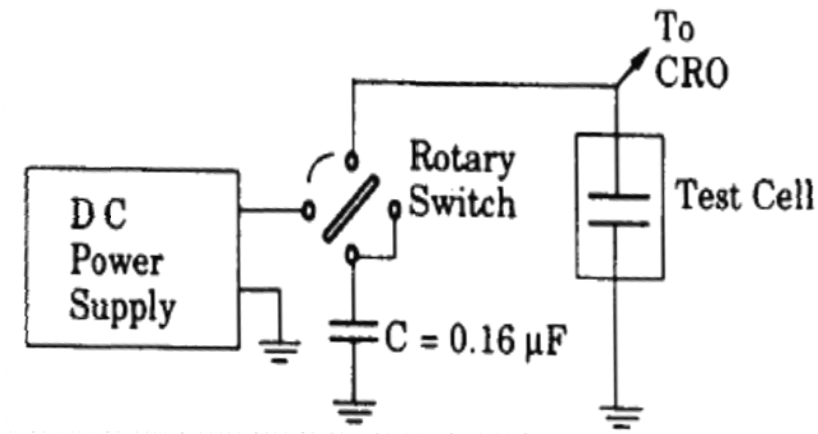

Fig 3-9 Schematic of experimental setup

The L. brevis cells were grown in Lactobacilli MRS broth in an incubator for 48 hours at 30 º C in a carbon dioxide enriched atmosphere. Different field strengths were used (25 kV/cm and 30 kV/cm) and different temperatures were used (24, 30, 45 and 60 ºC)

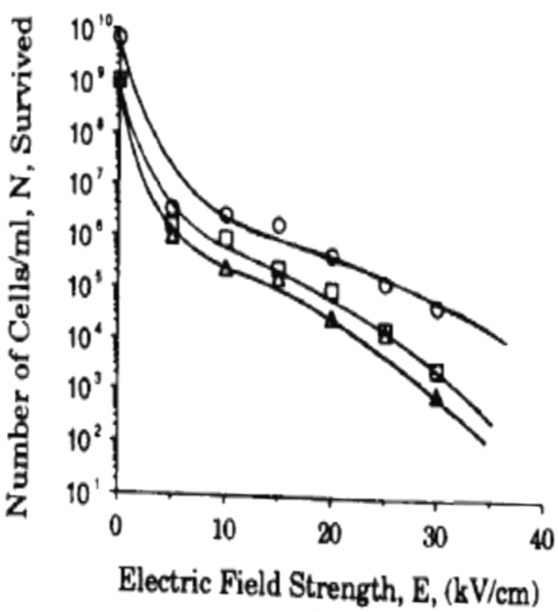

Fig 3-9-1

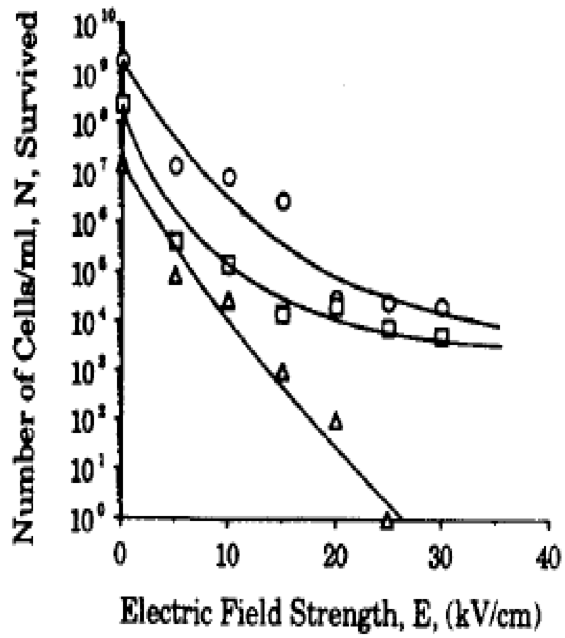

Fig 3-9-2

Fig 3.9.1 and 3.9.2 represent the survivability of L. brevis cells as a function of electric field strength at different pulse numbers (P_n) for 2(a) (P_n=30(o), 45(□) and 60(Δ) at temperature 24 ºC) and at different temperatures for 2(b) (30 ºC(o), 45 ºC(□) and 60 ºC(Δ) at P_n=60).

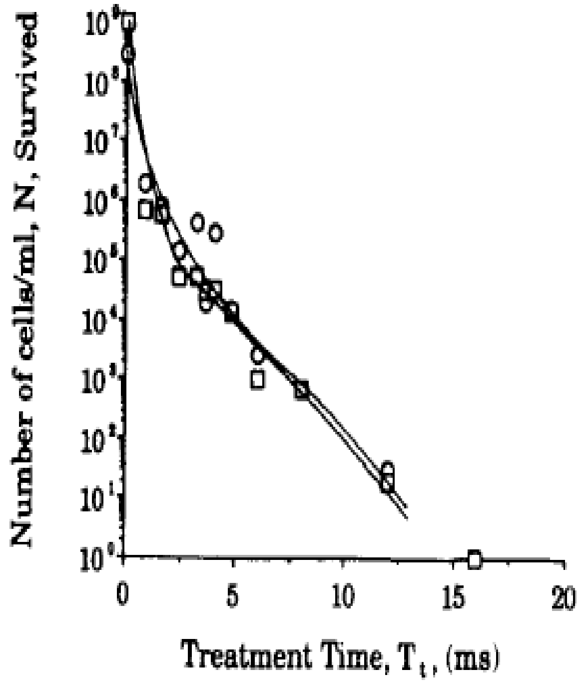

Fig 3-9-3

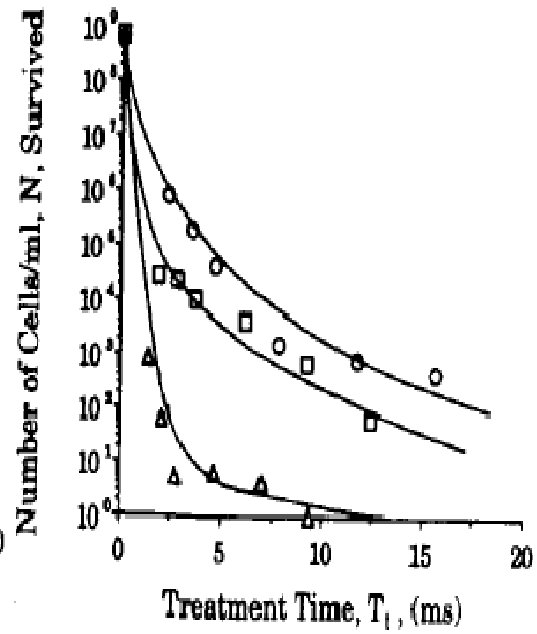

Fig 3-9-4

Fig 3.9.3 and 3.9.4 represent the survivability of L. brevis cells as a function of treatment time at different field strengths for 3(a) (25 kV/cm (o) and 30 kV/cm (□) at temperature 24 ºC) and at different temperatures for 3(b) (30 ºC(o), 45 ºC(□) and 60 ºC(Δ) at 25 kV/cm).

Experimental results show that the viability, which means germinating under favorable conditions of L. brevis declines exponentially with treatment time and is electric field and temperature dependant. Above 45 ºC, the rate at which microorganisms were killed increased rapidly in the liquid medium and similar results were obtained as the electric field strength and the exposure time to high field, was decreased. L. brevis when exposed to an electric pulse treatment (E=25 – 30 kV/cm; pulse numbers = 150 – 200) were killed to a level of 10^{-2} - 10^{-1} and temperature rise due to the electric pulse treatment was less than 10 ºC. The most efficient treatment with reference to different temperatures and pulse numbers, combination of 60 ºC and 25 kV/cm exposed to 8 – 10 minutes killed 10^{0} L. brevis.

3.2.4 Electric Field on Cardiospermum Halicacabum

This experiment [8] was done to determine the germination process for one seed using the measurements of the dielectric constant and conductivity of a seed. This type of measurement methods had advantages which were noninvasive and successive. The time dependence of the dielectric constant and the conductivity of a dielectric cell consisting of one seed and de-ionized water were measured.

Fig 3-10 Cardiospermum halicacabum L

A schematic view of the experimental apparatus is shown in Fig 3-11. De-ionized water was pumped into the dielectric cell to keep the conductivity constant. Cardiospermum halicacabum L was the sample seed used and it was placed at the center of the dielectric cell which had a diameter of 5.5 mm.

Seed was placed on a wet cotton wool and was kept at a temperature of 25ºC. Every day, the dielectric constant and the conductivity of the system consisting of a seed and de-ionized water were measured in the range of 1 kHz to 10 MHz At the same time, the interior of other seeds (Abelmoschus esculentus Moench) under the same experimental conditions was directly observed with a microscope and the average size of cells was measured.

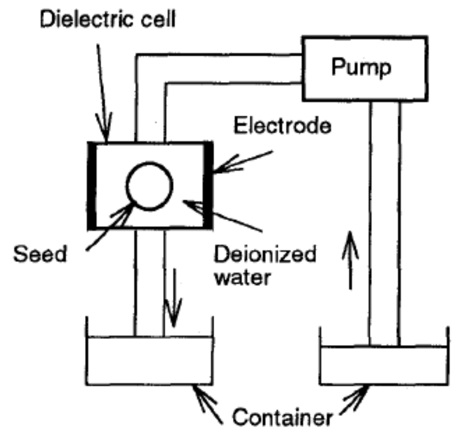

Fig 3-11 Schematic view of experimental apparatus

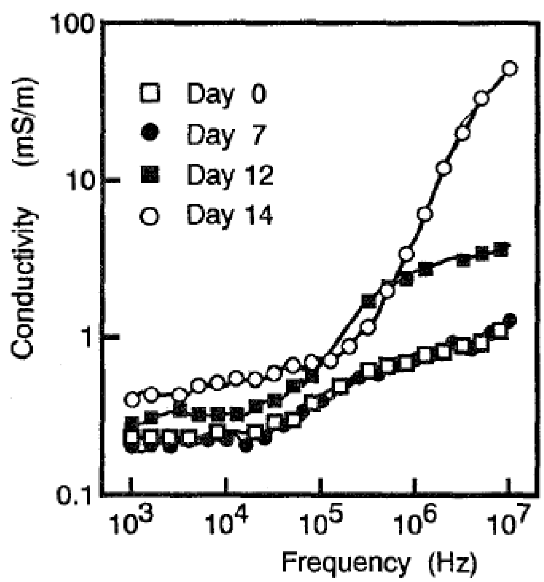

Fig. 3-12 Relationship between conductivity of a seed and time.

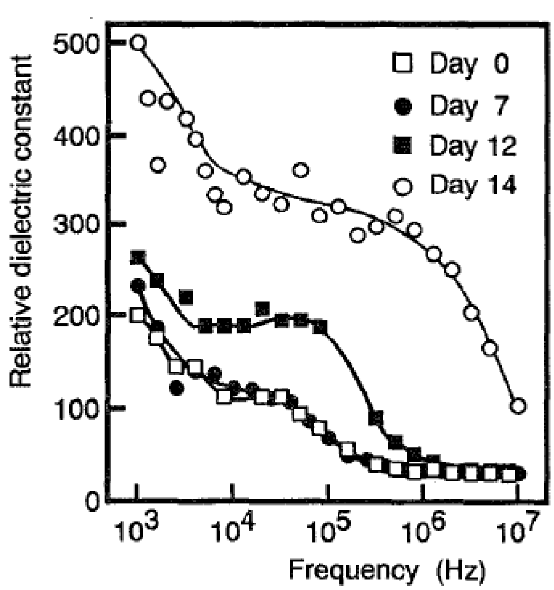

Fig 3-13 Relationship between relative dielectric constant of a seed and time

Fig 3-13 and Fig 3-12 show the relative dielectric constant and the conductivity of the system consisting of a cell and de-ionized water as a function of frequency. When both the dielectric constant and the conductivity of the system consisting of one seed and de-ionized water began to increase, it was found that the hollow parts in the seed decreased and the average size of cells became large. After those mutations, the dielectric constant slightly increased and the conductivity increased abruptly at a frequency of 1 MHz and above each day. The dependence of the dielectric constant and the conductivity of the seed on time were similar to those of the system. When the relative dielectric constant and the conductivity begin to increase, the absorption of water begins. When the relative dielectric constant and the conductivity of the seed increase at a frequency of 1 MHz and above, and the relaxation frequency increases abruptly, the growth of organizations occurs.

3.3 Effects of Magnetic Field

The effects of magnetic field on living systems, particularly the effect on germination of seeds and growth of plants, have been the object of numerous researches. Magnetic fields used were alternating, stationary, AC and DC. Different seeds which were used were wheat, tomato, strawberry and hornwort.

3.3.1 Magnetic Field on Wheat

Exposure of the magnetic field with germination energy (GE), germination (G), fresh weight (m) and shoot length (l) of the maize (Zea Mais) seeds was studied by A. Aladjadjiyan [26]. Magnetic field of 15000 Gauss (0.15 Tesla in SI Units) has been used for the experiment. Different exposure times were used 10 min, 15 min, 20 min and 30 min. The experiment had 25 seeds in each variant.

Data in table 3-3 shows that maize seeds had optimal effects at 10 min for a magnetic field of 0.15 T. There was an increase of shoot fresh weight by 72 % when compared to the control. There was also an increase of germination energy by 24 %, germination by 14 % and shoot length by 25 % when compared to the control.

Table 3-3 Seed Vitality of Zea Mais, Treated by magnetic field

Variety	GE %	G %	l		m	
			mm	%	g	%
Control	56	85	15.2	100	0.59	100
10 min	80	100	20.2	125	1.01	172
15 min	64	100	18.4	110	0.72	122
20 min	48	100	19.9	108	0.68	115
30 min	44	100	18.2	110	0.76	129

Weight (m) being considered in grams (g) and length (l) being considered in millimeters (mm)

Maize samples when exposed to a magnetic field, there specific electro conductivity increased by 15 %. Due to the presence of the magnetic field, extinction of the maize seed extract is increased which is evident from the increased permeability of the seed cover.

D. Bhatnagar and A. R. Deb [21] studied the effect of pre-germination exposure of wheat seeds to magnetic field. The effect of magnetic field did not increase the overall germination percentage but increased the rate of germination. Five to six month old seeds of wheat (cv. Sonalika) were used in the study having 7.3 % moisture content. Magnetic fields of 500, 1000, 1500, 2000 and 3000 oersted (CGS unit of magnetic field strength) were used for the experiment. The fields which were more effective were 1500 and 1000 Oersted. Experiment was conducted with 200 seeds for 6 different treatments (control, 500 oe, 1000 oe, 1500 oe, 2000 oe, 3000 oe). The whole experiment was repeated 3 times. From the table below, we can say that there is cumulative percentage increase in germination. On completion of 4, 6, 8 and 10 days, measurements of shoot lengths, maximum root length and total root length per seedling were taken.

Table 3-4 Influence of pre-germination exposure of wheat seeds to magnetic field on germination

Field Intensity (Oersted)	Cumulative Percentage germination on days after sowing							Coefficient of velocity of germination	Percent-age of control
	3	4	5	6	7	8	9		
Control	0.00	0.00	33.00	66.83	82.66	96.66	99.66	16.13	100.00
500	0.00	7.66	55.49	86.65	93.81	97.97	98.97	18.02	111.65
1000	0.00	12.00	66.50	92.50	98.00	99.50	99.83	18.83	116.74
1500	0.00	18.00	89.50	93.83	97.16	99.82	99.82	19.96	123.74
2000	0.00	5.50	59.00	81.50	95.50	98.83	99.49	17.92	111.09
3000	0.00	0.33	42.33	73.83	90.66	97.82	99.65	16.83	104.34

Treated seedling had higher shoot length, maximum root length and total root length when compared to the control seedling. The percentage increase of shoot length increased until the 8th day for control and then started declining. The decline commenced after the 4th day for roots.

Effects of germination and early growth [27] were measured when maize seeds were exposed to stationary magnetic fields. Laboratory conditions were used for this experiment. Rate of germination and germination were the main areas of concern. Maize seeds used were of Ramda variety. Each treatment had 20 seeds and had five replications which got the seed count to 100. Hereby, groups of 100 seeds were used for every magnetic treatment and same for the control. Experiment was conducted based on the guidelines issued by the International Seed Testing Association (ISTA, 2004) with slight changes. Ring magnets were used as sources of magnetic fields with magnetic field induction values 125 milli Tesla (mT) and 250 mT. Filter paper had seeds which were glued using non toxic adhesive stick having long axes vertical.

Every filter paper having seeds was rolled and then was placed in vessel having distilled water. After four hours, when seeds were soaked, every roll was treated with magnetic field. They did not add any other substance to the distilled water when conducting the experiment.

Two different magnetic field strengths and 6 different exposure times (1 min, 10 min, 20 min, 1 hour, 24 hour, continuous exposure) finally getting 12 different combinations were used. Every roll had 4 seeds; they used 5 rolls for every magnetic treatment. Mean germination time (MGT) was used in determining the rate of germination and time required to germinate 10, 25, 50, 75 and 90 % of seeds (T_{10}, T_{25}, T_{50}, T_{75} and T_{90}).

Table 3-5 Effect of the magnetic field on the germination of maize seeds

Dose	T10 (h)	T25 (h)	T50 (h)	T75 (h)	T90 (h)	MGT (h)	Gmax (%)
B = 125mT							
D1	32.4±1.9	36.7±1.7	41.3±1.4	46.1±1.0	50.9±0.7	40.1±1.4	96±0
D2	38.4±1.2*	41.0±1.0	43.9±0.7	46.8±0.5	49.4±0.5	43.7±0.7	98±1
D3	31.4±1.0*	36.0±0.7**	41.0±0.5**	46.3±0.2*	52.3±0.7	40.3±0.5**	94±1
D4	38.6±0.5	40.8±0.5	43.2±0.5	45.8±0.2*	48.2±0.2	43.2±0.5	98±1
D5	25.0±0.2***	28.8±1.0***	33.8±1.7***	39.6±2.4***	47.5±3.1	34.3±1.0***	96±2
D6	26.4±0.5***	30.7±0.5***	35.8±1.2***	41.3±1.4***	48.5±3.4	35.8±0.2***	96±2
Control	35.3±1.9	39.3±1.4	43.2±1.0	47.5±0.7	51.8±12.5	42.7±1.0	96±2
B = 250mT							
D7	31.4±1.0*	35.5±0.7**	40.1±0.5**	44.6±0.2**	49.2±1.0	39.8±0.7***	97±2
D8	38.2±0.7*	40.1±0.7	43.9±0.7	47.1±0.7	50.6±1.2	43.4±0.7	94±2
D9	30.7±0.5**	35.0±0.5**	39.8±0.5**	44.6±0.5**	49.2±0.5	39.4±0.5**	97±1
D10	33.1±1.9	37.0±1.7	41.5±1.2	45.8±0.7*	50.0±0.5	41.0±1.2	96±0
D11	27.1±0.5***	28.8±0.2***	31.2±1.2***	36.2±1.9***	53.8±1.9	35.8±0.5***	98±1
D12	26.6±0.2***	27.8±0.2***	29.8±0.4***	32.9±1.2***	41.7±4.8	32.2±1.4***	98±1

Time of exposure: 1 min (D1, D7), 10 min (D2, D8), 20 min (D3, D9), 60 min (D4, D10), 24 h (D5, D11), continuous exposure (D6, D12) and untreated (C). *G*max (percentage of germinated seeds). *T*10, *T*25, *T*50, *T*75, *and T90*: time required to obtain 10, 25, 50, 75 and 90% of geminated seeds expressed in hours. MGT ≡ mean germination time.

The time needed to germinate 10 %, parameter T_{10}, of the seeds exposed to 125 mT for 20 min (D3), 24 hour (D5), continuous (D6) and exposed to 250 mT for 1 min (D7), 20 min (D9), 24 hour (D11) and continuous (D12) were below control. But for T_{10} for doses D5, D6, D11 and D12 it was significantly lower than the control. From the table above, we can say that germination percentage was not affected by the magnetic field but rate of germination was. Exposure of maize seeds to magnetic field increases germination rate and first stages of growth in plants.

3.3.2 Magnetic Field on Tomato

This study by Jae-Duk Moon and his colleagues [4], determined the optimal conditions for increasing the rate of germination using different intensities and exposure time of AC electric field and AC magnetic field. Using percent germination rates, comparison was made between treated and untreated seeds. AC Electric fields ranged from 4 to 12kV/cm while AC Magnetic flux densities were in the range of 3 to 1000 G. They were exposed to three different time periods varying from 15 sec to 60 sec and had equal rest time periods.

Tomato seeds (Lycopersicun esculentum L.) were selected for the experiment. They stored the uncovered seeds in an incubator at 4°C, 50% RH for one month prior to the experiment. Each treatment had 50 seeds, which were then exposed to different fields and time periods followed by corresponding rest time. Germination of treated and untreated seeds was done identically in a water-bedded Petri dish in a temperature and relative humidity-controlled incubation room (20°C, 75% RH). Length of the root tip had to be 1.0 mm for the seed to be considered germinated. Every experiment had 3 replications.

The percent germination began to increase gradually in 4 days but rapidly elevated after 5–7 days and then saturated after 7 days, and most seeds were germinated.

When lower fields of 4 and 6 kV/cm were applied, enhancement of the maximum percent germination rate was obtained at an exposure time of 30 s; however, at 15 s the percent germination was low. In the case of higher fields of 8 and 10 kV/cm and longer treatment time of 30 and 45 s, the enhanced percent germination responses were obtained. When the very high field of 12 kV/cm was applied with a shorter exposure time of 15 s, the highest germination enhancement was obtained. However, electric field intensity higher than 14 kV/cm and exposure time longer than 90 s indicated an inhibitory effect upon the germination of the seed.

The seeds exposed for short time periods of 15 and 30 s and relatively higher electric fields showed better germination than the seeds exposed to the relatively lower electric fields.

Sarveshwar Dayal and R. P. Singh [24] examined the effect of the tomato plant (Lycopersicum Icopersicum) on the growth response when exposed to different magnetic field strengths. They had non-magnetic materials in a container which was then subjected to uniform magnetic field. By changing the current flow in the magnetic coils magnetic field strength was monitored. Calibration was done based on Hall Probe method and field strength was expressed in Gauss (GA).

Table 3-6 Influence of magnetic field seed treatment on the height of 'Pusa Early Dwarf' and 'Pusa Ruby'

	Untreated		Treated	
	Pusa Early Dwarf	Pusa Ruby	Pusa Early Dwarf	Pusa Ruby
Mid height	16.53	20.93	22.56	25.75
Final height	22.66	30.19	29.31	29.53

Different magnetic field strengths of 150 GA, 200 GA, 500 GA, 900 GA, 1250 GA and 1550 GA were used for the experiment. Each treatment had 50 tomatoes and this was replicated three times. They had two different exposure times 15 min and 30 min.

Pusa Early Dwarf and Pusa Ruby were the different tomato seeds used for the experiment. The seeds were soaked in water for 45 min and then were taken into a container which could be exposed to different magnetic fields. After the stipulated time the seeds were immediately planted in plastic pots with soil. The height of the treated plants was recorded to be 27.5 cm to that of untreated plants which was 18.63 cm which confirmed the study done by Bhatnagar and Debb (1977). At very low and high magnetic field strengths rate of increase of height was less. Pusa Early Dwarf had greater increase in height when compared to Pusa Ruby. The maximum increase in height was observed at 1250 GA and exposure time of 15 min.

3.3.3 Magnetic Field on Strawberry

This journal [28] deals with the magnetic field effects on strawberry plant. By alternating the magnetic field, its effects on the yield and ion accumulation in the leaves of strawberry was studied. Different magnetic field strengths of 0.096, 0.192 and 0.384 Tesla were used on short day strawberry cv. Camarosa plants in heated greenhouse conditions. Greenhouse had natural light and was under controlled temperature. It had a minimum temperature of 10 – 11 º C and maximum of 20 - 21 º C. Soil used for the experiment was peat and perlite (1:1) in 20 cm polyethylene pots, and each pot had one plant. All the plants were given 250 ml of water once every week. For generating a variable magnetic field, a number of electric wires were used 30 cm above the plants.

At the plant level, magnetic field strength was measured. This experiment was completely randomized; it had 10 plants in each replication and in total 4 replications.

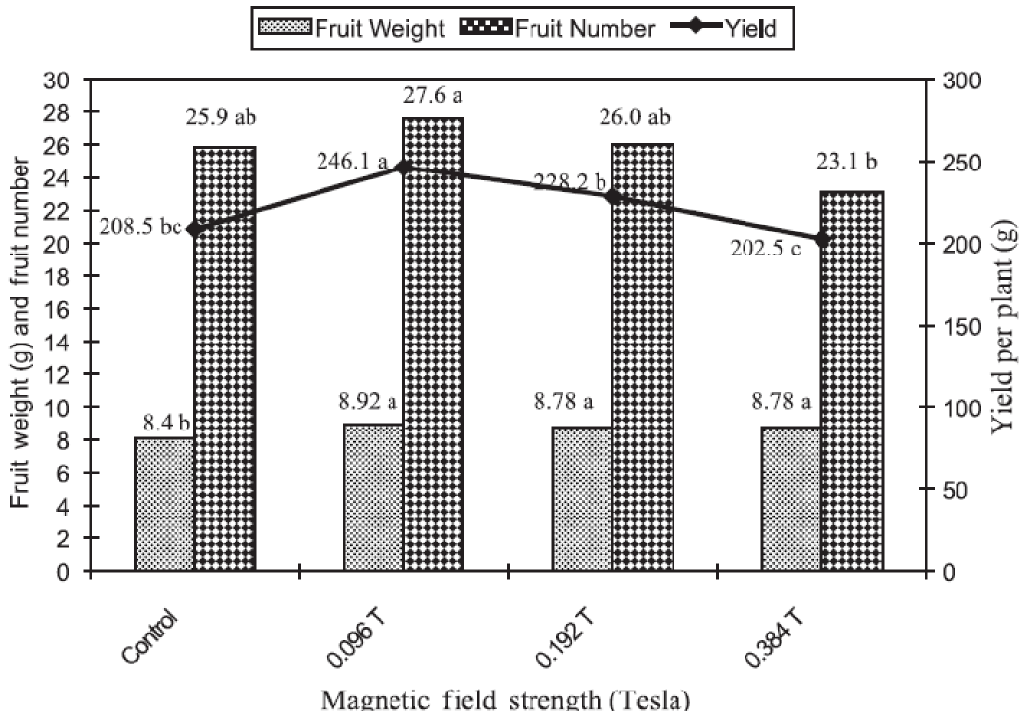

Fig 3.14 Effects of alternating magnetic field on yield per plant, fruit weight and fruit number per plant in strawberry cv. Camarosa

From the above figure, we can see that for 0.096T there is an increase in fruit number, fruit weight and yield when compared to control. Fruit yield increased from 208.5 grams (control) to 246.1 grams (0.096T) and it decreased when magnetic field was increased from 0.096 T to 0.364 T. In the same way, fruit number increased from 25.9 (control) to 27.6 (0.096 T) and then decreased when MF was increased from 0.096 T to 0.364 T. Though, fruit weight increased for all the three different magnetic fields.

Nutrient element composition of leaves in strawberry had a significant effect under the influence of the MF. Ionic concentration of Nitrogen (N), Potassium (K), Calcium (Ca), Magnesium (Mg), Iron (Fe), Manganese (Mn) and Zinc (Zn) had increased and that of Phosphorous (P) and Sulfur (S) had decreased.

3.3.4 Magnetic Field on Hornwort Seed

The exposure of seeds of Hornwort with time varying sinusoidal and extremely low frequency (ELF) magnetic fields was done for this study [31]. Four different frequencies were used f = 3.5, 7.0, 10.5, 14.0 Hz and two different field intensities were used 500 μT and 750 μT. Magnetic fields (AC) were in combination with the local geomagnetic field (DC). All the three directions of the AC magnetic field were considered namely; the vertical (magnetic flux density $\vec{B}_{ACV}$), parallel direction ($\vec{B}_{AC\parallel}$) and perpendicular direction ($\vec{B}_{AC\perp}$) to the direction of the total geomagnetic field ($\vec{B}_G$) in the geomagnetic plane. Seeds were exposed to the magnetic fields for 16 days and 24 hours a day. Controls consisted of seeds exposed to zero AC magnetic fields in combination with the DC magnetic fields.

Normal germination time for hornwort seeds is 5-6 days under normal temperatures (20 – 25°C) and they generally have high rate of germination. They had seeds in water for 12 hours with different treatments of magnetic fields. The $\vec{B}_{ACV}$ in combination with $\vec{B}_G$ effectively promoted the germination of hornwort seeds when applied at 750 μT (RMS) at 7 Hz or 500 μT (RMS) at 14 Hz. The $\vec{B}_{AC\parallel}$ promoted the germination of hornwort seeds more effectively than the $\vec{B}_{AC\perp}$ in combination with $\vec{B}_G$ when 500 and 750 μT at 7 Hz were applied.

CHAPTER 4: **RESULTS AND DISCUSSIONS**

In Chapter 3, section 3.1 a brief description of the experimental results for the effects of electromagnetic fields on soybeans was discussed. The experiments were carried out by D. Carl Freeman, John H. Graham, Mary Tracy, John M. Emlen, and C. L. Alados [32]. The focus of that research was the development of instabilities due to local fluctuations in internal or external environmental conditions. Leaf traits and expressions for size and asymmetry were considered. This study was focused towards seed germination, with the goal that better germination would result in better biofuel resource. This chapter describes experiments on the effects of magnetic and electromagnetic effects on soybean germination.

Two types of experiments were carried out for the germination studies of soybeans using electromagnetic field and magnetic fields. Three types of experiments were conducted that involved the use of a model TC4000B test cell, permanent magnet and Helmholtz coil. A detailed description of the TC4000B test cell and the Helmholtz Coil was described earlier in Chapter 2, while the permanent magnet used in the experiment was borrowed from another laboratory. There are a large number of soybean seed varieties. The seeds used in the experiments were provided by the Soybean Center located at the

Health Science Center of the University of Missouri-Columbia. The four different kinds of soybean seeds used for the experiments were Magellan, Maverick, SS97-6946 and Williams82. The seeds were exposed to various strengths of Magnetic fields, EM fields of different frequencies and power levels with varying exposure times. Different exposure times were used; 10 min, 20 min, 30 min and 40 min. Germination rate, fatty acid content, proteins and oil concentrations of soybean seeds were some of the parameters analyzed. Figure 4.1 shows the various sources used in the experiments to study the effects of electromagnetic and magnetic fields on soybeans.

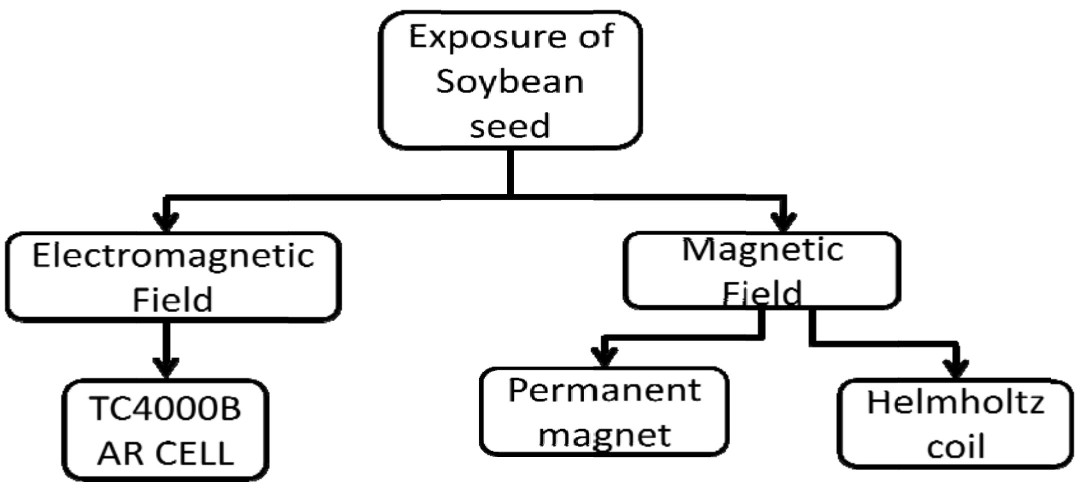

Figure 4-1 Stages of soybean exposure

4.1 Effects on Soybeans using Electromagnetic Field

Germination studies using electromagnetic fields were carried out using an anechoic chamber of Model TC4000B Test Cell. This cell can operate from the MHz to GHz frequency range with the maximum power going up to 150 Watts. The cell was already calibrated and the seeds were placed at a specific location for various times as discussed in the section below.

4.1.1 Effects on Soybeans using Model TC4000B Test Cell

In this TC4000B test cell soybean seeds were exposed to electromagnetic fields. Three different parameters Power (P), Frequency (F) and Time duration (T) were considered as shown in the figure 4-2.

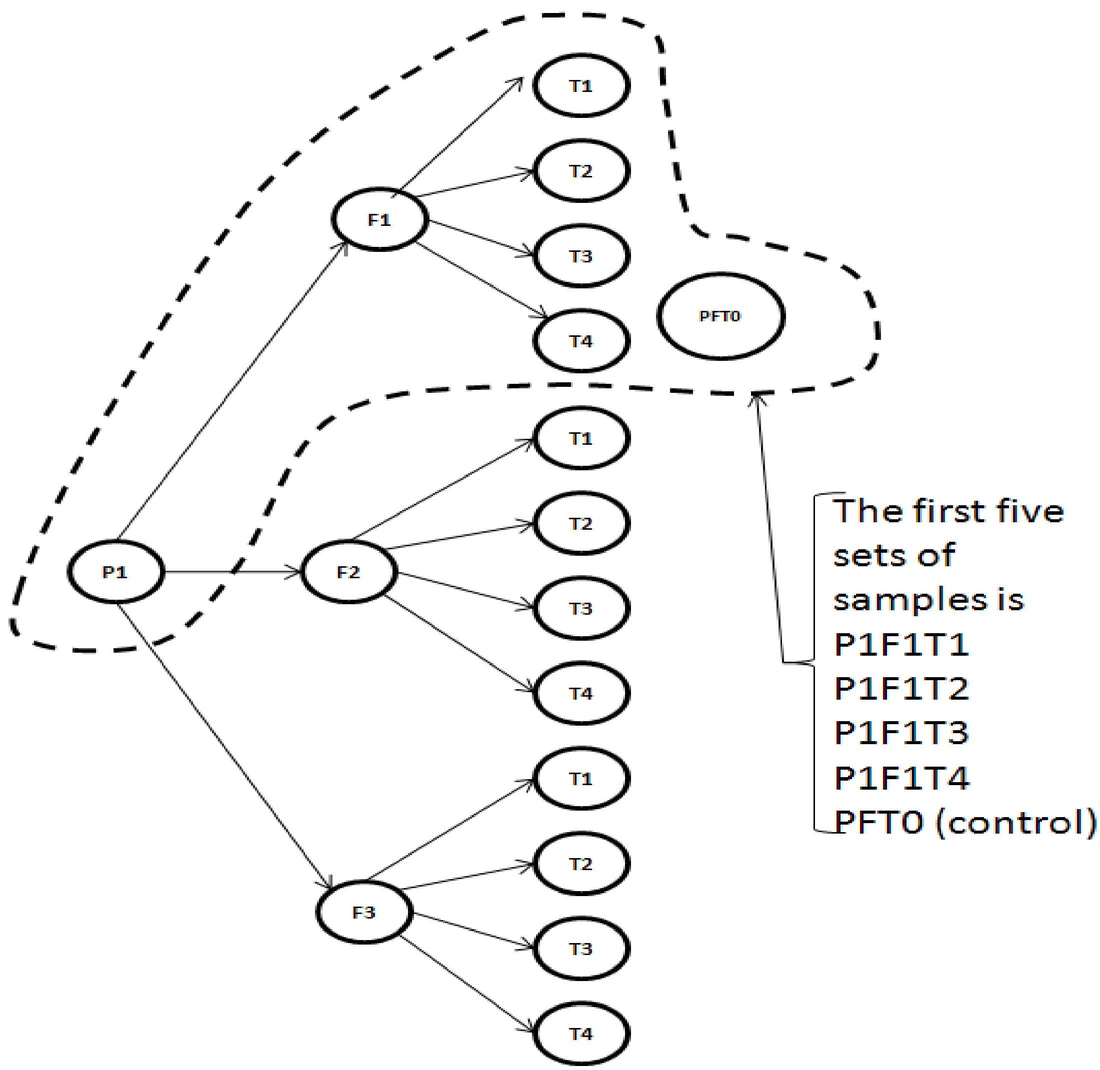

Figure 4-2 PFT (Power Frequency Time duration) scheme for Soybean seeds EM Field Exposure

Only one power level was used which was measured at the probe i.e. 150 watt. The only frequency used for this model was F1=100 MHz, as indicated in the dotted part of the figure 4-2. As electric field probe was used, electric field with sine and cosine angles would represent x and y directions. These experiments could be repeated by using two different frequencies F2 and F3 as future work. T1, T2, T3 and T4 represent four different time durations 10 min, 20 min, 30 min and 40 min. PFT0 would represent the control seeds. These seeds were not exposed to any field which implies P, F and T being zero.

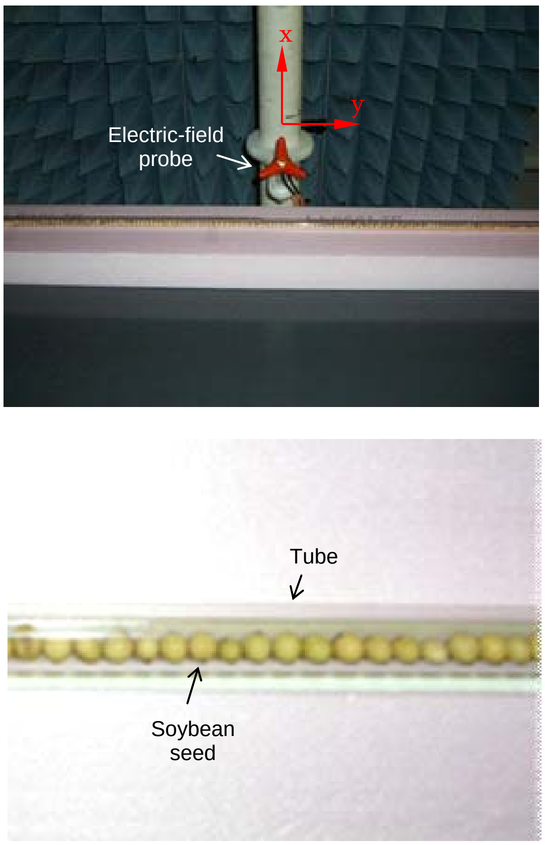

Figure 4-3 Electromagnetic field exposure setup inside the anechoic chamber.

Magellan seeds were used in the first experiment in order to find the best exposure time. For the electromagnetic field exposure test, the experiment was set up inside a semi-anechoic chamber. The monitoring and recording of the signals were controlled through a PC based Lab VIEW interface. A computer controlled RF signal amplifier feds the antenna, which was at a distance of 3 m from the conducting sheet to meet the far field condition at low frequencies. The frequency measurement was set to 100 MHz and power level was close to 126 W at the probe. Four sets of 110-seed groups were subjected to a variation in exposure duration while the fifth group was the control. Figure 4-3 shows the experiment setup with the electric-field probe and the tube aligned on the y axis across the chamber width. The tube was filled with soybean seeds placed inside the tube along the horizontal direction. The number of soybean seeds that could be accommodated inside the tube was 110. All seeds were aligned without overlapping as to expose with the maximum level of the electromagnetic field. The tube was made of vinyl and has a length of 63.5 cm. The tube was supported by a thick nonconductive material, so we assume a relatively low level of wave reflection. The time was varied from a minimum duration of 10 minutes to a maximum duration of 40 minutes with an increment of 10 minutes between experiments.

Exposure type	**Date**	**Power (Watts)**	**Frequency (MHz)**	**Time (minutes)**	**Number of Seeds**
PFT0 (control)	02/05/2007	0	0	0	110
P1F1T1	02/05/2007	126	100	10	110
P1F1T2	02/05/2007	128	100	20	110
P1F1T3	02/05/2007	128	100	30	110
P1F1T4	02/05/2007	130	100	40	110

Table 4-1 Effects of Magellan seeds using 110 seeds

After exposure treatments, the seeds were germinated according to the procedures established by the American Association of Seed Analysts. Control seeds were also sent which were the same number as the treated seeds.

Exposure Type	**Percentage of Germination**
PFT0 (control)	92 %
P1F1T1	99 %
P1F1T2	94 %
P1F1T3	95 %
P1F1T4	95 %

Table 4-2 Results from crop association for Magellan seeds using 110 seeds

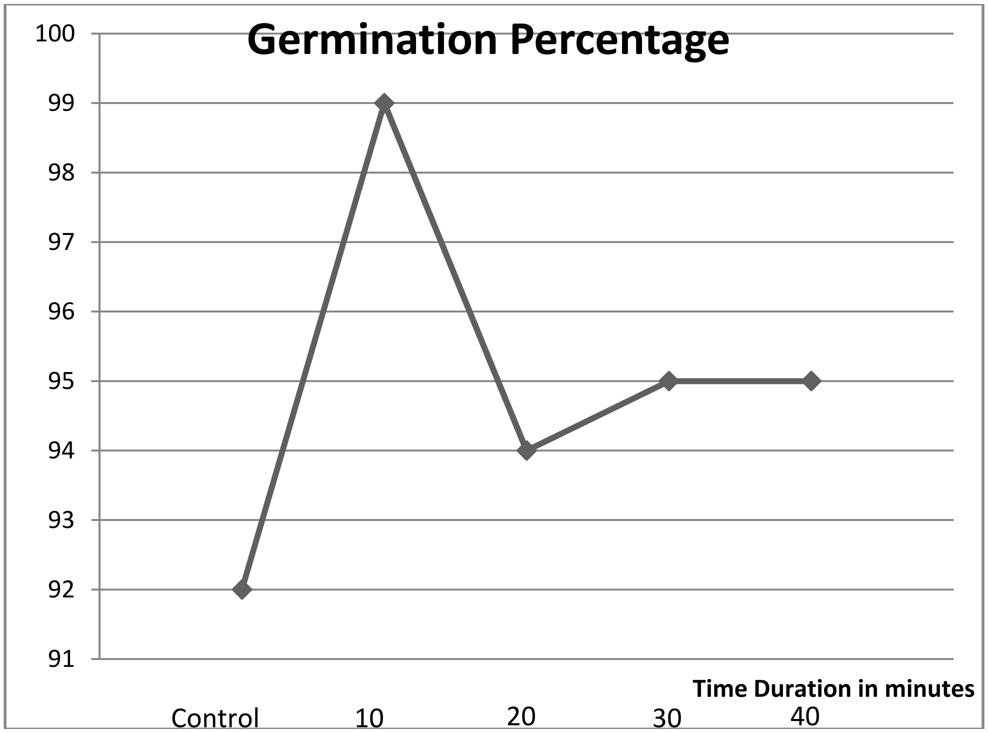

Figure 4-4 Graph showing the germination percentage

From Table 4-2 and Figure 4-4, we can see that 10 minutes had the best germination results. Table 4-3 has the statistical values and the range for average ± Standard error which would help us in determining the statistical significance. Standard error is nothing but Standard deviation divided by the square root of number of seeds used for the experiment. To know if these values are statistically significant, we need to compare these values. When we compare the ranges of control with other treatments, we could see that for P1F1T1 its range was much higher when compared to others. Hence, we can say that it was statistically significant.

Type of Soybean seed	Treatment	Average	Standard Error	Average ± Standard Error (Range)
Magellan	P1F1T1	0.99	0.0127	0.9773 - 1.0027
Magellan	P1F1T2	0.94	0.0232	0.9168 - 0.9632
Magellan	P1F1T3	0.95	0.0216	0.9284 - 0.9716
Magellan	P1F1T4	0.95	0.0216	0.9284 - 0.9716
Magellan	PFT0 (Control)	0.92	0.0261	0.8939 - 0.9461

Table 4-3 Table showing the statistical values for experiment conducted with 110 seeds

Treated seeds from each group were germinated according to these procedures and the percent germination was recorded. Another ten seeds from each treatment, including controls, were manually crushed and placed in separate test tubes for fatty acid analyses. All treated seeds and control seeds were planted into the greenhouse located at the University of Missouri-Columbia. Plants were grown to maturity and the seed harvested.

Figure 4-5 (Left) potted plants in the greenhouse, (Center) near infrared spectroscopy for protein, oil, and moisture tests, and (Right) gas chromatograph for fatty acid test.

Fig. 4-5 (left) demonstrates potted planting in the greenhouse. Harvested seed were analyzed for protein, moisture and oil concentration using near infrared spectroscopy as the instrument setup is shown in Fig. 4-5 (center). Concentrations of palmitic, stearic, oleic, and linolenic fatty acids were analyzed using gas chromatography as shown in Fig. 4-5 (right).

Genotype	Replication	Treatment	16:0	18:0	18:1	18:2	18:3
Magellan	Av. 3 reps	P1F1T1	10.27	4.03	22.87	55.66	7.17
Magellan	Av. 3 reps	Control	10.14	4.05	22.13	56.12	7.57
Maverick	Av. 3 reps	P1F1T1	10.84	4.24	20.76	56.56	7.60
Maverick	Av. 3 reps	Control	10.69	4.21	21.51	55.96	7.63
SS97-6946	Av. 3 reps	P1F1T1	9.53	4.09	21.00	56.78	8.60
SS97-6946	Av. 3 reps	Control	9.54	3.96	20.52	57.25	8.73
Williams82	Av. 3 reps	P1F1T1	10.07	4.02	22.58	56.16	7.18
Williams82	Av. 3 reps	Control	10.11	4.04	22.18	56.44	7.23

Table 4-4 Fatty acid analysis for soybean samples treated with electro-magnetic force (3 reps average) 05/03/2007

Genotype	Replication	Treatment	16:0	18:0	18:1	18:2	18:3
Magellan	Rep 1	P1F1T1	10.53	4.06	21.52	56.38	7.51
Magellan	Rep 2	P1F1T1	10.33	3.76	21.97	56.65	7.28
Magellan	Rep 3	P1F1T1	9.94	4.27	25.11	53.95	6.72
Magellan	Av. 3 reps	P1F1T1	10.27	4.03	22.87	55.66	7.17
Magellan	Rep 1	Control	10.28	3.99	21.28	56.36	8.08
Magellan	Rep 2	Control	9.94	3.92	21.61	56.98	7.56
Magellan	Rep 3	Control	10.18	4.25	23.49	55.01	7.06
Magellan	Av. 3 reps	Control	10.14	4.05	22.13	56.12	7.57
Maverick	Rep 1	P1F1T1	10.91	4.18	19.72	57.03	8.16
Maverick	Rep 2	P1F1T1	10.74	4.54	22.17	55.32	7.22
Maverick	Rep 3	P1F1T1	10.87	4.01	20.38	57.33	7.41
Maverick	Av. 3 reps	P1F1T1	10.84	4.24	20.76	56.56	7.60
Maverick	Rep 1	Control	10.78	4.40	19.76	57.19	7.87
Maverick	Rep 2	Control	10.70	4.03	19.88	57.54	7.85
Maverick	Rep 3	Control	10.59	4.19	24.90	53.16	7.15
Maverick	Av. 3 reps	Control	10.69	4.21	21.51	55.96	7.63
SS97-6946	Rep 1	P1F1T1	9.80	4.15	22.06	55.64	8.35
SS97-6946	Rep 2	P1F1T1	9.48	4.19	20.47	57.11	8.75
SS97-6946	Rep 3	P1F1T1	9.32	3.93	20.46	57.58	8.70
SS97-6946	Av. 3 reps	P1F1T1	9.53	4.09	21.00	56.78	8.60
SS97-6946	Rep 1	Control	9.60	4.12	20.72	57.11	8.45
SS97-6946	Rep 2	Control	9.72	3.82	19.76	57.45	9.25
SS97-6946	Rep 3	Control	9.31	3.94	21.08	57.19	8.48
SS97-6946	Av. 3 reps	Control	9.54	3.96	20.52	57.25	8.73
Williams82	Rep 1	P1F1T1	10.03	3.99	23.59	54.94	7.44
Williams82	Rep 2	P1F1T1	10.16	3.94	21.33	57.42	7.15
Williams82	Rep 3	P1F1T1	10.00	4.12	22.81	56.12	6.95
Williams82	Av. 3 reps	P1F1T1	10.07	4.02	22.58	56.16	7.18
Williams82	Rep 1	Control	10.23	3.75	22.41	56.93	6.67
Williams82	Rep 2	Control	10.00	4.30	21.94	55.81	7.94
Williams82	Rep 3	Control	10.10	4.08	22.18	56.58	7.06
Williams82	Av. 3 reps	Control	10.11	4.04	22.18	56.44	7.23

Table 4-5 Fatty acid analysis for soybean samples treated with electro-magnetic forces 05/03/2007

Ten seeds from each treatment, including controls, were manually crushed and placed in separate test tubes for fatty acid analyses. Crushed seed were extracted in 5 ml chloroform: hexane: methanol (8:5:2, v/v/v) overnight. Derivatization was done by transferring 100 uL of extact to vial and adding 75 uL of methylating reagent (0.25 M methanolic sodium methoxide: petroleum ether: ethyl ether, (1:5:2, v/v/v). Hexane was added to dilute samples to approximately 1 ml. An Agilent (Palo Alto, CA) series 6890 capillary gas chromatograph fitted with a flame ionization detector (275 °C) was used with an AT-Silar capillary column (Alltech Associates, Deerfield, IL). Standard fatty acid mixtures (Animal and Vegetable Oil Reference Mixture 6, AOACS) were used as calibration reference standards.

Table 4-2 shows the results for the germination tests. From these results, the best exposure type was P1F1T1 which corresponds to time duration of 10 min. The Second experiment was conducted using four varieties of soybean seeds Magellan, Maverick, SS97-6946 and Williams82. For this experiment, the Power used was close to 126 W, the Frequency was 100 MHz and time duration was 10 min. To confirm the positive effects of Electromagnetic fields, at least 1000 seeds had to be used for the experiments. Based on the first experiment which used 110 seeds, germination effects cannot be confirmed. It was our plan of study to increase the number of seeds with every experiment and finish with more than 1000 seeds.

Exposure Group	Date	Name of the Soybean seed	Power (Watts)	Frequency (MHz)	Time (minutes)	Number of Seeds
P1F1T1	04/18/2007	Magellan	126	100	10	200
P1F1T1	04/18/2007	Magellan	125	100	10	200
P1F1T1	04/18/2007	Magellan	125	100	10	200
P1F1T1	04/18/2007	Maverick	125	100	10	200
P1F1T1	04/18/2007	Maverick	125	100	10	200
P1F1T1	04/18/2007	Maverick	125	100	10	200
P1F1T1	04/18/2007	SS97-6946	124	100	10	200
P1F1T1	04/18/2007	SS97-6946	125	100	10	200
P1F1T1	04/18/2007	SS97-6946	125	100	10	200
P1F1T1	04/18/2007	Williams82	125	100	10	200
P1F1T1	04/18/2007	Williams82	125	100	10	200
P1F1T1	04/18/2007	Williams82	125	100	10	200

Table 4-6 Effects of four different soybean seeds

This experiment was conducted using 600 seeds for each variety, which was divided into three parts of 200 seeds. As the tube could take only 110 seeds at a time, the procedure was repeated twice for every part. The same numbers of control seeds were also taken for every variety of soybean seeds. After the experiment we had 1200 seeds of Magellan, Maverick, SS97-6946 and Williams82, of which 600 were the seeds exposed to the electromagnetic field and other 600 were control seeds. These seeds were sent to the crop association for germination tests.

Genotype	Replication	Treatment	P1F1T1	Control	Control
		12-day	6-day	12-day	6-day
Magellan	1	91	88	89	85
	2	92	92	85	82
	3	91	89	85	82
	3 reps average	**91.3**	**89.7**	**86.3**	**83**
Maverick	1	98	97	99	98
	2	99	97	98	97
	3	98	96	97	96
	3 reps average	**98.3**	**96.7**	**98**	**97**
SS97-6946	1	91	88	92	83
	2	92	86	90	75
	3	92	91	91	86
	3 reps average	**91.7**	**88.3**	**91**	**81.3**
Williams82	1	93	93	96	95
	2	96	96	98	96
	3	96	96	96	93
	3 reps average	**95**	**95**	**96.7**	**94.7**

Table 4-7 Germination of four soybean genotypes treated with electro-magnetic field (germination % counted at 6 and 12 days by Missouri Seed Association) 05/10/2007

Genotype	Treatment P1F1T1	Control
Magellan	91.3	86.3
Maverick	98.3	98
SS97-6946	91.7	91
Williams82	95	96.7

Table 4-8 Results considered for 12 days

Table 4-8 has the germination test results for four different seeds. Out of the four, Magellan had a more positive effect when compared to the others. The other three had zero or no effect of electromagnetic field as we could see that both the control and treated seeds had the same germination percentage. From the Table 4-9, we can see that for Magellan, if you compare the ranges between treated (P1F1T1) and control there was difference between them which was statistically significant. For all others varieties of soybean, ranges between treated (P1F1T1) and control were pretty similar.

Type of Soybean seed	Treatment	Average	Standard Error	Average ± Standard Error (Range)
Magellan	P1F1T1	0.91	0.0116	0.8984 - 0.9216
Magellan	PFT0 (Control)	0.86	0.014	0.8460 - 0.8740
Maverick	P1F1T1	0.98	0.00554	0.9744 - 0.9855
Maverick	PFT0 (Control)	0.98	0.00554	0.9744 - 0.9855
SS97-6946	P1F1T1	0.92	0.011	0.9090 - 0.9310
SS97-6946	PFT0 (Control)	0.91	0.0116	0.8984 - 0.9216
William82	P1F1T1	0.95	0.00885	0.9411 - 0.9588
William82	PFT0 (Control)	0.97	0.00696	0.9630 - 0.9769

Table 4-9 Table showing the statistical values for experiment conducted with 600 seeds

In the first experiment only 110 seeds were considered when compared to the 600 seeds for the second experiment. Magellan was the seed used in both of the experiments. For the first experiment difference between the percentages of treated (99) and the control seeds (92) was 7. For the second experiment it came down to 5 (treated seeds 91.3 control 86.3)

So, we see a decline of 2 percent when numbers of seeds were increased from 110 to 600. This prompted us to conduct an experiment with more Magellan seeds. A third experiment was conducted using only Magellan seeds. The number of seeds used here was 1200 which was double the number of seeds used in experiment 2. As in the second experiment the 1200 seeds were broken down into 6 groups of 200 each. PFT values used in this experiment were P = 126 W, frequency 100 MHz and T = 10 min.

Exposure Group	Date	Name of the Soybean seed	Power (Watts)	Frequency (MHz)	Time (minutes)	Number of Seeds
P1F1T1	05/13/2007	Magellan	126	100	10	200
P1F1T1	05/13/2007	Magellan	125	100	10	200
P1F1T1	05/13/2007	Magellan	125	100	10	200
P1F1T1	05/13/2007	Magellan	125	100	10	200
P1F1T1	05/13/2007	Magellan	125	100	10	200
P1F1T1	05/13/2007	Magellan	125	100	10	200

Table 4-10 Effects of six groups of Magellan

Genotype	Replication	Treatment P1F1T1	Control
		6-day	6-day
Magellan	1	92	93
	2	97	97
	3	91	90
	4	91	96
	5	96	97
	6	95	95
	6 reps average	**94**	**95**

Table 4-11 Results for six groups of Magellan

Type of Soybean seed	Treatment	Average	Standard Error	Average ± Standard Error (Range)
Magellan	P1F1T1	0.94	0.00685	0.9331 - 0.9468
Magellan	PFT0 (Control)	0.95	0.00629	0.9437 - 0.9562

Table 4-12 Table showing the statistical values for experiment conducted with 1200 seeds

From the table 4-11, we see that when number of seeds were increased, germination percentages of both the treated and control seeds were identical, which would imply no effect of electromagnetic field even on Magellan. Also from Table 4-12, even the ranges for treated (P1F1T1) and control were similar reconfirming that there was no effect of Electromagnetic field on Magellan variety of soybean.

4.2 Effects on Soybeans using Magnet Field

In the chapter 3.3, positive effects of magnetic field on wheat, tomato seeds, strawberry and hornwort seeds were discussed. We conducted two different experiments for magnetic field, one using a permanent magnet and another using Helmholtz coil. In both the cases we used a low magnetic field for exposure.

4.2.1 Effects on Soybeans using Permanent Magnet

A permanent magnet was used as a source of magnetic field. Magnetic field strength was measured using a FW Bell 5100 series Gauss meter. Magnetic field strength at the center of the magnet was 0.47 Tesla and it decreases moving towards the poles of the magnet. After a series of measurements the magnetic field strength was averaged over the area of where the seeds were placed on the magnet. We used plastic slides to vary the magnetic field strength. Plastic slides were kept on the magnet and seeds were kept of the plastic slides. By increasing the number of plastic slides, magnetic field strength was reduced.

Five points were considered to determine the average for a given area. Table 4-13 shows the magnetic field strengths when number of plastic slides were increased.

Directionality and frequency were not considered for this experiment. Exposure times were 10 min, 20 min, 30 min. Seeds were placed on the surface of the magnet and plastic slides for exposure as shown in fig 4-6. Magellan was the soybean genotype used in this experiment. 10 seeds were used for each treatment.

Number of Plastic slides	**Magnetic Field Strength (Tesla)**		
	Minimum	Maximum	Average
0	0.41 T	0.47 T	0.42 T
1	0.3 T	0.33 T	0.33 T
2	0.213 T	0.246 T	0.245 T
3	0.17 T	0.17 T	0.17 T
4	0.125 T	0.136 T	0.125 T
5	0.09 T	0.1 T	0.09 T

Table 4-13 Different field strengths used

Figure 4-6 Seeds on the plastic slides

Figure 4-6 shows the experimental setup where there was permanent magnet below the plastic slides and seeds placed on top of the plastic slides. Table 4-14 shows the results for the germination tests.

Table 4-15 shows the statistical values and for all the three different exposure times' 10 min, 20 min and 30 min, range for control had a higher value when compared to the treated. So, we can say that there was no statistical significance for these set of results.

Magnetic field strength (Tesla)	Number of seeds used (Magellan)	Number of seeds germinated for 10 minutes	Number of seeds germinated for 20 minutes	Number of seeds germinated for 30 minutes
control	10	10	8	10
0.42 T	10	6	8	4
0.33 T	10	8	8	8
0.245 T	10	10	8	8
0.17 T	10	2	7	10
0.125 T	10	9	8	8
0.09 T	10	8	4	9

Table 4-14 Exposure results using a permanent magnet

Type of Soybean seed	Magnetic Field Strength	Average 10 minutes	Standard Error 10 minutes	Average ± Standard Error (Range) 10 min
Magellan	0.42 T	0.6	0.1546	0.4454 - 0.7546
Magellan	0.33 T	0.8	0.126	0.6740 - 0.9260
Magellan	0.245 T	1	0	1
Magellan	0.17 T	0.2	0.126	0.0740 - 0.326
Magellan	0.125 T	0.9	0.094	0.8060 - 0.994
Magellan	0.09 T	0.8	0.126	0.6740 - 0.926
Magellan	(Control) 0 T	1	0	1
Type of Soybean seed	**Magnetic Field Strength**	**Average 20 minutes**	**Standard Error 20 minutes**	**Average ± Standard Error (Range) 20 min**
Magellan	0.42 T	0.8	0.126	0.674 - 0.926
Magellan	0.33 T	0.8	0.126	0.674 - 0.926
Magellan	0.245 T	0.8	0.1448	0.6552 - 0.9448
Magellan	0.17 T	0.7	0.126	0.574 - 0.826
Magellan	0.125 T	0.8	0.1546	0.6454 - 0.9546
Magellan	0.09 T	0.4	0.126	0.2740 - 0.526
Magellan	(Control) 0 T	0.8	0.126	0.674 - 0.926
Type of Soybean seed	**Magnetic Field Strength**	**Average 30 minutes**	**Standard Error 30 minutes**	**Average ± Standard Error (Range) 30 min**
Magellan	0.42 T	0.4	0.1546	0.2454 - 0.5546
Magellan	0.33 T	0.8	0.126	0.674 - 0.926
Magellan	0.245 T	0.8	0.126	0.674 - 0.926
Magellan	0.17 T	1	0	1
Magellan	0.125 T	0.8	0.126	0.674 - 0.926
Magellan	0.09 T	0.9	0.094	0.806 - 0.994
Magellan	(Control) 0 T	1	0	1

Table 4-15 Table showing the statistical values for experiment conducted with 10 seeds

Germination of control seeds was more than the treated seeds which would imply a negative effect of magnetic field on germination.

4.2.2 Effects on Soybeans using A Helmholtz Coil

A Helmholtz coil was used as a source of magnetic field. Helmholtz coils produce uniform magnetic field over a certain area. Magnetic field direction was considered in this experiment. The scar, visible on the seed is called the hilum as shown in the figure 4-7. Magnetic field enters the hilum and then passes through the seed.

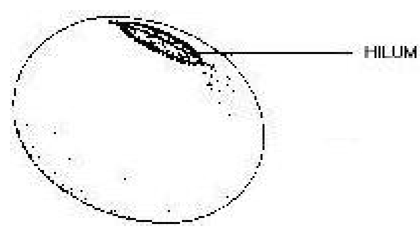

Figure 4-7 Soybean seed showing HILUM

Figure 4-8 shows the experimental setup which shows the soybean seeds aligned with the direction of the magnetic field. A limited area in the Helmholtz coil can produce uniform magnetic field, and therefore the seeds were aligned in that particular area.

Figure 4-8 Magnetic field exposure setup using Helmholtz coil

Magnetic fields of 1 Gauss, 5 Gauss and 10 Gauss were used in this experiment. Different exposure times of 1 min, 5 min, 10 min and 20 min were used in this experiment. Twenty five seeds were used in every treatment.

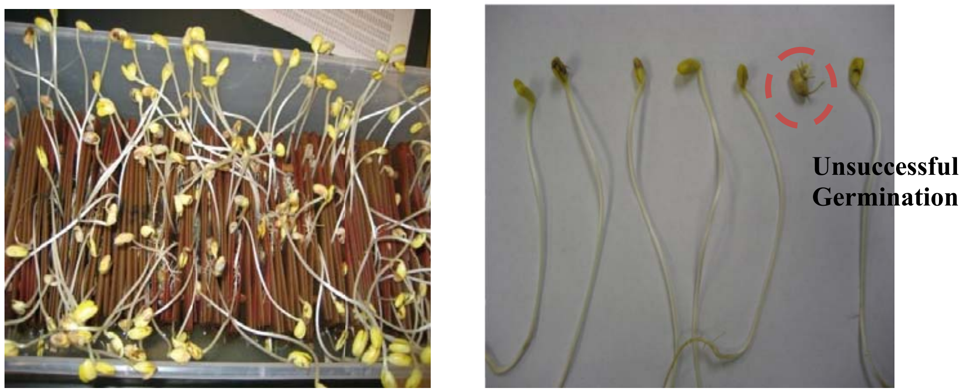

Figure 4-9 Germinated seeds on the fifth day of germination

Figure 4-9 shows the germinated seeds and one seed with unsuccessful germination among the successful ones. Germination tests were conducted on the fifth day of germination.

Number of seeds used (Magellan)	**Magnetic field strength (Gauss)**	**Exposure time (minutes)**	**Number of seeds Germinated**
25	1	1	10
25	1	5	12
25	1	10	16
25	1	20	15
25	0 (control seeds)	0 (control seeds)	12
Number of seeds used (Magellan)	**Magnetic field strength (Gauss)**	**Exposure time (minutes)**	**Number of seeds Germinated**
25	5	1	18
25	5	5	15
25	5	10	16
25	5	20	22
25	0 (control seeds)	0 (control seeds)	15
Number of seeds used (Magellan)	**Magnetic field strength (Gauss)**	**Exposure time (minutes)**	**Number of seeds Germinated**
25	10	1	20
25	10	5	15
25	10	10	15
25	10	20	21
25	0 (control seeds)	0 (control seeds)	12

Table 4-16 Germination results for different magnetic fields

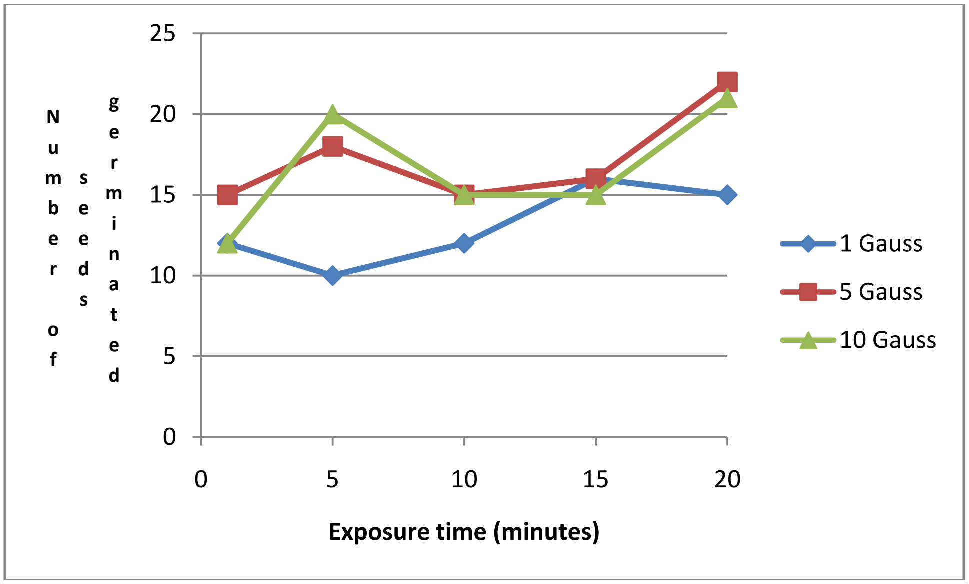

Figure 4-10 Graph showing the comparison between different exposure times and seeds germinated

Type of Soybean seed	Magnetic field strength (Gauss)	Exposure time (minutes)	Average	SD Error	Average ± Standard Error (Range)
Magellan	1	1	0.4	0.097	0.303 - 0.497
Magellan	1	5	0.48	0.099	0.381 - 0.579
Magellan	1	10	0.64	0.096	0.544 - 0.736
Magellan	1	20	0.6	0.097	0.503 - 0.697
Magellan	0 (control seeds)	0 (control seeds)	0.48	0.099	0.381 - 0.579
Type of Soybean seed	**Magnetic field strength (Gauss)**	**Exposure time (minutes)**	**Average**	**SD Error**	**Average ± Standard Error (Range)**
Magellan	5	1	0.72	0.0897	0.6303 - 0.8097
Magellan	5	5	0.6	0.097	0.5030 - 0.697
Magellan	5	10	0.64	0.096	0.5440 - 0.736
Magellan	5	20	0.88	0.064	0.8160 - 0.944
Magellan	0 (control seeds)	0 (control seeds)	0.6	0.097	0.5030 - 0.697
Type of Soybean seed	**Magnetic field strength (Gauss)**	**Exposure time (minutes)**	**Average**	**SD Error**	**Average ± Standard Error (Range)**
Magellan	10	1	0.8	0.08	0.720 - 0.88
Magellan	10	5	0.6	0.097	0.503 - 0.697
Magellan	10	10	0.6	0.097	0.503 - 0.697
Magellan	10	20	0.84	0.073	0.767 - 0.913
Magellan	0 (control seeds)	0 (control seeds)	0.48	0.099	0.381 - 0.579

Table 4-17 Table showing the statistical values for experiment conducted with 10 seeds

Table 4-16 shows the results for different magnetic field strengths and figure 4-10 depicts the graph for table 4-16. For germination tests of all the three different magnetic fields 1 Gauss (0.1 milli Tesla), 5 Gauss (0.5 milli Tesla) and 10 Gauss (1 milli Tesla) the number of germinated treated seeds were greater than the number of germinated control seeds. This shows the positive effect of magnetic field for magnetic field strengths of 5 G and 10 G on germination. This positive effect could be reconfirmed by the Table 4-17. This table has the statistical values and we can see the ranges for all the three different field strengths 1G, 5 G and 10 G. For 1 G, ranges for both the treated and control were pretty similar. For 5 G and 10 G, there was a difference between the ranges of treated and control. Range for treated had higher values when compared to control for 5 G and 10 G reconfirming the positive effects of magnetic field on germination of Magellan seeds.

In the experiment using the permanent magnet, magnetic field strength was higher (0.09 Tesla – 0.42 Tesla) when compared to experiment using a Helmholtz coil (0.1 milli Tesla – 1 milli Tesla). Alignment of direction of the magnetic field with the soybean was done for this experiment whereas it was not done for the experiment using the permanent magnet. These were the two differences between the two experiments, permanent magnet and A Helmholtz coil.

CHAPTER 5: **CONCLUSIONS**

Natural or visible light belongs to a family of electromagnetic waves known as the electromagnetic (EM) spectrum. Each member of the EM family is defined by its unique frequency or wavelength. Natural light plays an important role in the growth and survival of species in our eco-system. For example, trees and plants have a number of light absorbing molecules that enable organisms to respond to changes in the natural light environment. Light signals thus regulate changes in structure and form, such as seed germination, leaf expansion, stem elongation, flower initiation and pigment synthesis. These photomorphogenic responses give an enormous survival advantage on organisms. It is therefore of interest to determine whether other members of the EM family besides visible light have any effects on plants and seeds. Specifically we need to determine whether EM waves can be utilized in the growth of some energy producing resources that are necessary for the survival of mankind. This research was conducted in order to answer the questions posed earlier.

In this study we have exposed different varieties of soybean seeds to EM radiation at a frequency other than that of light. The objective was to determine changes in the germination rate, if any, under the influence of electromagnetic field of a given frequency, power and exposure time. Soybean was chosen because earlier experiments (by others) had indicated that compared to corn and other prospective sources of bio-energy, soybean produced the maximum energy/gram/sec and therefore would a potential candidate for Bio-fuel. A high germination rate would result in a greater production rate of this important biofuel resource. Besides being a source for energy soybeans can be processed to get soy flour, infant formula, substitute for existing products such as soy milk, soy yogurt and soy cream cheese.

Besides EM fields from an antenna in an Anechoic chamber, we have also exposed the seeds separately to magnetic fields. The motivation to use the magnetic field was due to the fact that the earth has a permanent magnetic field and its existence must have influenced the growth of plants and seeds for many, many years. Therefore it would of interest to see if any change in the magnetic field brings about any change in the soy seeds, specifically its germination rate.

The results we have obtained can be described as inconclusive at best, both for EM radiation and for magnetic fields. For EM radiation, results show that for a power level of 128 Watts, frequency of 100 MHz and exposure time of 10 minutes one variety of soybeans (Magellan) had seven percent increase in the germination rate. This increase in germination rate was observed for a batch of 110 seeds and for an exposure time of 10 min. The increase in germination rate was statistically significant for Magellan variety for a 10 min exposure time.

The next set of experiments was conducted with 600 seeds, and a single exposure time of 10 min where four different varieties of soybean seeds namely Magellan, Maverick, SS97-6946 and Williams82 were used. With this increase in the number of seeds per batch, the percent increase of germination for Magellan got down to five while for the other three types there was no change. There was statistical significance for germination of Magellan even for this experiment. As the percent increase in germination decreased with an increase in batch size, more statistical analysis was required and so the next experiment was conducted with 1200 seeds. This showed that there was no percent increase in germination. For a larger sample this variety showed some improvement but again there was no net increase in germination for a much larger sample. Germination rate of Magellan of Electromagnetic wave generation could not be improved using power level of 126 Watts, Frequency 100 MHz and exposure time 10 minutes. So the results were inconclusive. However some changes in the germination rate were found for a known seed variety, at a given frequency of exposure, exposure time and power at source. It is quite possible that there exists a frequency, exposure time and power level in the electromagnetic spectrum that could contribute positively to the germination rate.

For magnetic field experiments, results for the permanent magnet showed no effects of magnetic field on Magellan. Six different field strengths were used for this experiment 0.42 T, 0.33 T, 0.245 T, 0.17 T, 0.125 T, and 0.09 T and three different exposure times were used 10 min, 20 min and 30 min. The number of seeds used for this experiment was 10. The limit on the number of seeds was due to the restrictive area where seeds could be placed. With such a small number in the data set, there was no statistical significance on germination for all the six different magnetic field strengths and 3 different exposure times used in the experiments.

Experiments conducted using a Helmholtz coil showed positive effect with magnetic field strengths of 5 Gauss and 10 Gauss. Three different field strengths were used 1 G, 5

G and 10 G and the four different exposure times were used for this experiment 1 min, 5 min, 10 min and 20 min. The number of seeds used for this experiment was 25 and variety of soybean seeds used was Magellan. This was also confirmed when statistical analysis showed that for 5 G and 10 G field strengths the germination rate was significant.

In conclusion it may be stated that EM radiations, static and uniform magnetic field have large frequency ranges. With a limited experiment one cannot specifically determine the fields, power level and exposure time for the maximum germination rate for the species. On the other hand soybean seeds come in large variety, so in conclusion we can say that Electromagnetic and Electric and Magnetic field could be productive in improving the germination but it requires more experiments.

For Future work, we suggest similar experiments with other frequencies and different exposure times and power levels.

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