EFFECTS OF VARIED MAGNETIC INTENSITIES AND EXPOSURE TIME ON GERMINATION AND GROWTH OF "ROSECOCO" BEANS *[Phaseolus vulgaris* L.*]*

ODHIAMBO OLOO PETER JARED

EGERTON UNIVERSITY LIBRARY

A thesis submitted to graduate school in partial fulfilment for the requirements of the Master of Science degree in physics of Egerton University

EGERTON UNIVERSITY

JULY 2008

EULIB
022 529

2009/78944

DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented for a degree, diploma, fellowship or any other similar title in any other University.

Signature _____ Date 15/07/2008.

Odhiambo O. P. .J.

SM13/0689/02.

Recommendation

This thesis has been submitted with our approval as University supervisors.

Signature _____ Date 15/7/08

Dr. Ndiritu F.G.

Department of Physics and Computer Sciences

Egerton University

Signature _____ Date 15/7/2008

Dr. Wagara I. N.

Department of Biological Sciences

Egerton University

2009/75944

COPY RIGHT
© 2008
Odhiambo Oloo Peter Jared

No part of this thesis may be Produced, Stored in any retrieval system or Transmitted in any form or means: Electronic, Mechanical, Photocopying, Recording or otherwise without prior written permission of the author or Egerton University on that behalf.

DEDICATION

This thesis work is devoted to my cherished wife **Dorcas Nekesa Oloo** and my son **Gabriel Oloo**. God bless both of you.

ACKNOWLEDGEMENTS

The author would like to register his appreciation to the following personalities and organizations for making this process a success. First and foremost the author thanks his parents: James Odhiambo Okello and Rose Adhiambo Odhiambo, for the funds they provided at the start of this programme and for the moral support they provided. Secondly the author would like to thank Board of Postgraduate Studies, Egerton University for allowing him to start his master's programme immediately after completing the undergraduate degree course.

The author also wishes to express his gratitude to the chairman of Physics and Computer Sciences department, Dr. Francis G. Ndiritu for the hope he instilled on the author when things mired in the course of the author's research. Dr. Hussein Golicha (former chairman, Physics Department) cannot be forgotten due to his advice and encouragement. Apart from the back up the author would like to further thank Dr. Ndiritu and Dr. Wagara Isabel (Biological Sciences Department) for accepting to supervise his work. The two personalities inspired the author to a greater academic achievement.

Last but not least the author takes this opportunity to sincerely thank the entire teaching and technical staff, Physics and Computer Science department, Egerton University for the support they offered in terms of equipments and tutorial on how to use the apparatus. Finally the author would like to thank Dr. Mwamburi (Senior Lecturer, Physics Department; Moi University), for the support he offered the author in terms of equipments and his opinion on the way forward. For all those that participated in one-way or the other to make this work a success, receive great 'thank you!' from the author.

ABSTRACT

Many plants respond to external factors such as light or gravity by growing towards or away from the source of stimulus. It has also been noted that magnetic intensities affect the growth of plants by either accelerating or inhibiting growth. Rosecoco beans (*Phaseolus vulgaris* L.) are widely grown and popular in Kenya. This study evaluates the percent germination, initial radicle growth and the change in mass of Rosecoco bean seeds when exposed to static magnetic treatment under laboratory conditions. The effects of different magnetic intensities and exposure time of both Direct Current (DC) and Alternating Current (AC) magnetic field was investigated. Germinating bean seeds were exposed to varying magnetic fields of 50, 100, 300 and 600gauss whereas exposure time was fixed at 3, 4.5 and 6 Hrs per day for the first four days of germination. For each strength of the magnetic field, a given set of sample comprising of 10 seeds per petri dish was placed in four petri dishes lined with moistened serviette. In the case of DC fields; the first petri dish was exposed to a field generated by the Helmholtz coil; the second was exposed to the South Pole whereas the third was exposed to the North Pole of the coil. Seeds in the fourth petri dish were used as control. Another set was exposed to alternating magnetic field generated by the Helmholtz and solenoid coils, of the same strength for the same duration. The germinating seeds were counted, weighted and the length of the radicle was measured after every 12 Hrs for the incubation period of 4 days.

The results show that maximum seed germination was achieved by exposure to North Pole of DC field at strength of 300G for 6hrs after 24hrs of incubation. Optimum germination of beans occurred when they were exposed for 3hrs per day to an AC field generated by Helmholtz coil and incubated for 24hrs at field strength of 300G and 600G. Maximum percent increase in mass of seeds / seedlings exposed to DC fields were achieved by North Pole field at strength of 100G when exposed for 3hrs at 12hrs incubation. Optimum mass increase of beans occurred at an AC field generated by Helmholtz coil at exposure time of 3hrs per day, incubated for 96hrs at field strength of 600G. Maximum seed germination was achieved by Helmholtz DC field at strength of 300G when exposed for 3hrs at 96hrs incubation. Optimum radicle elongation of beans occurred at an AC field generated by Helmholtz coil at exposure time of 3hrs per day, incubated for 60hrs at field strength of 600G. However, there was no significant difference ($P > 0.05$) in seed germination, radicle elongation and change in mass between seeds exposed to magnetic fields and those not exposed.

TABLE OF CONTENTS

CONTENTS PAGE

DECLARATION AND RECOMMENDATION ii
COPY RIGHT iii
DEDICATION iv
ACKNOWLEDGEMENTS v
ABSTRACT vi
TABLE OF CONTENTS vii
LIST OF TABLES ix
LIST OF FIGURES x
LIST OF SYMBOLS AND ABBREVIATIONS xiv
DEFINITION OF TERMS xv
CHAPTER ONE 1
1.0 INTRODUCTION 1
1.1 Bean production 1
1.2 Factors affecting plant growth 1
1.3 Magnetic field 2
1.4 Statement of the Problem 3
1.5 Objectives of the Study 3
1.6 Justification of the Research 3
1.7 Scope and Limitations 4
CHAPTER TWO 5
2.0 LITERATURE REVIEW 5
2.1 Bio-effect of magnetic fields 5
2.2 Origin of magnetic field 7
2.3 Electromagnetism 8
2.4 DC versus AC electromagnetism 8
2.5 Magnetic field flux 9
2.5.1 Magnetic field flux for a straight wire 10
2.5.2 Magnetic field flux on the axis of a circular coil 10
2.5.3 Magnetic field on the axis of a solenoid 11

2.5.4 Helmholtz Coils 13
2.6 Plant growth 14
2.7 Bean seed structure 15
2.7.1 Bean seed germination 16
CHAPTER THREE 17
3.0 METHODOLOGY 17
3.1 Instruments and Calibration 17
3.1.1 Instruments 17
3.1.2 Calibration of magnetic flux density unit and Teslameter 17
3.2 Source of Bean seeds and their preparation 19
3.3 Solenoid preparation 19
3.4 Experimental set up 19
3.5 Data collection and analysis 20
CHAPTER FOUR 21
4.0 RESULTS AND DISCUSSION 21
4.1 LENGTH OF BEAN RADICLE 21
4.1.1 Length of radicle exposed to DC fields 21
4.1.2 Length of radicle exposed to AC fields 31
4.2 Bean Seed Germination 39
4.2.1 Germination of bean seeds exposed to DC fields 39
4.2.2 Germination of bean seeds exposed to AC fields 46
4.3 Mass of Bean Seeds / Seedlings 52
4.3.1 Mass of seed / seedlings exposed to DC fields 52
4.3.2 Mass of seed / seedlings exposed to AC fields 64
CHAPTER FIVE 74
5.0 CONCLUSIONS AND RECOMMENDATIONS 74
5.1 Conclusions 74
5.2 Recommendations 75
REFERENCES 77
APPENDICES 80

LIST OF TABLES

Table 3.1 (a) Teslameter recording (mT) and the corresponding Flux Density measurement with background 18

Table 3.1 (b) Teslameter recording (mT) and the corresponding Flux Density measurement without the background effect 18

Table 4.1: Radicle length (cm) for varying exposure and incubation time exposed to a given DC field strength 22

Table 4.2: Radicle length of seeds exposed to varied AC field strengths at different incubation periods 32

Table 4.3: Percent germinated bean seeds exposed to varied DC field strengths at different incubation and exposure time 39

Table 4.4: The Percentage of the increased germinated seeds after exposure to AC field of varying strengths 46

Table 4.5: Mass of seeds (g) exposed to varied DC field strengths at different incubation and exposure time 53

Table 4.6: Mass of seeds (g) after varying incubation and exposure time for various intensities of AC field 65

LIST OF FIGURES

Fig 2.1: Magnetic material showing domains and dipoles 7
Fig 2.2: Magnetic material in a magnetic field 7
Fig 2.3: Magnetic saturation 8
Fig 2.4: Coil carrying direct current and polarities 9
Fig 2.5: Changing field due to alternating current 9
Fig 2.6 (a) Coil of wire / Fig 2.6 (b) Variation of B_x against x for circular coil 10
Fig. 2.7: Plot of B_X against x for a solenoid 12
Fig. 2.8: Magnetic field around Helmholtz coils 13
Fig 2.9: B_x plotted against x (a) for current in opposite directions in the two coils (b) for current in same direction in the two coils. 13
Fig 2.10: Epigeal germination 16
Fig 3.1: Schematic diagram illustrating calibration of magnetic flux density unit 17
Fig 3.2: Flux density (mV) versus B-field as per Teslameter reading 18
Fig 4.1: Radicle length for varying incubation and exposure time for 50G DC field 24
Fig 4.2: Radicle length for varying incubation and exposure time for 100G DC field 24
Fig 4.3: Radicle length for varying incubation and exposure time for 300G DC field 25
Fig 4.4: Radicle length for varying incubation and exposure time for 600G DC field 25
Fig 4.5: The Percentage of the increased radicle length as a function of incubation and exposure time for each constant magnetic DC field treatment generated by the Helmholtz coil 27
Fig 4.6: The Percentage of the increased radicle length as a function of incubation / exposure time for each constant North Pole field treatment 28
Fig.4.7: The Percentage of the increased radicle length as a function of incubation / exposure time for each constant South Pole field treatment 29
Fig 4.8: Radicle length at varying exposure and incubation time for 50G AC field 33
Fig 4.9: Radicle length at varying exposure and incubation time for 100G AC field 33
Fig 4.10: Radicle length at varying exposure and incubation time for 300G AC field 34
Fig 4.11: Radicle length at varying exposure and incubation time for 600G AC field 34
Fig 4.12: The Percentage of the increased radicle length as a function of incubation and exposure time for each constant AC Helmholtz field treatment 35

Fig. 4.13: The Percentage of the increased radicle length as a function of incubation and exposure time for each constant AC field generated by a solenoid treatment.....36
Fig 4.14: The Percentage of the increased germinated seeds at varying incubation and exposure times for 50G DC field.....40
Fig 4.15: The Percentage of the increased germinated seeds at varying incubation and exposure times for 100G DC field.....40
Fig 4.16: The Percentage of the increased germinated seeds at varying incubation and exposure times for 300G DC field.....41
Fig 4.17: The Percentage of the increased germinated seeds at varying incubation and exposure times for 600G DC field.....41
Fig. 4.18: The Percentage of the increased germinated bean seeds as a function of incubation and exposure time for each constant DC field generated by a Helmholtz coil.....42
Fig 4.19: The Percentage of the increased germinated bean seeds as a function of incubation and exposure time for each constant North Pole field.....43
Fig. 4.20: Percent of germinating bean seeds as a function of incubation and exposure time for each constant South pole field treatment.....44
Fig 4.21: The Percentage of the increased germination at varying incubation and exposure time for 50G AC field.....47
Fig 4.22: The Percentage of the increased germination at varying incubation and exposure time for 100G AC field.....47
Fig 4.23: The Percentage of the increased germination at varying incubation and exposure time for 300G AC field.....48
Fig 4.24: The Percentage of the increased germination at varying incubation and exposure time for 600G AC field.....48
Fig. 4.25: The Percentage of the increased germinated bean seeds as a function of incubation and exposure time for each constant AC field generated by Helmholtz coil.....49
Fig. 4.26: The Percentage of the increased germinated bean seeds as a function of incubation and exposure time for each constant AC field generated by the solenoid treatment.....50

Fig 4.27: Mass of seeds (g) at varying incubation and exposure time for 50G DC field 55
Fig 4.28: Mass of seeds (g) at varying incubation and exposure time for 100G DC field 55
Fig 4.29: Mass of seeds (g) at varying incubation and exposure time for 300G DC field 56
Fig 4.30: Mass of seeds (g) at varying incubation and exposure time for 600G DC field 56
Fig. 4.31 (a): Percent mass of germinating bean seeds as a function of incubation period for 3hrs exposure time for each constant DC field generated by the Helmholtz coil.....57
Fig. 4.31 (b): Percent mass of germinating bean seeds as a function of incubation period for 4.5hrs exposure time for each constant DC field generated by the Helmholtz coil.....58
Fig. 4.31 (c): Percent mass of germinating bean seeds as a function of incubation period for 6hrs exposure time for each constant DC field generated by the Helmholtz coil.....58
Fig. 4.32 (a): Percent mass of germinating bean seeds as a function of incubation time at 3hrs exposure for each constant North Pole field treatment 59
Fig. 4.32 (b): Percent mass of germinating bean seeds as a function of incubation time at 4.5hrs exposure for each constant North Pole field treatment 60
Fig. 4.32 (c): Percent mass of germinating bean seeds as a function of incubation time at 6hrs exposure for each constant North Pole field treatment 60
Fig. 4.33 (a): Percent mass of germinating bean seeds as a function of incubation at 3hrs exposure for each constant DC field generated by the Helmholtz coil.....61
Fig. 4.33 (b): Percent mass of germinating bean seeds as a function of incubation at 4.5hrs exposure for each constant DC field generated by the Helmholtz coil.....62
Fig. 4.33 (c): Percent mass of germinating bean seeds as a function of incubation at 6hrs exposure for each constant DC field generated by the Helmholtz coil.....62
Fig 4.34 (a) Mass of bean seeds (g) exposed to 50G for 3hrs for various fields after varying incubation time for AC field.....67
Fig 4.34 (b) Mass of bean seeds (g) exposed to 300G for 4.5hrs for various fields after varying incubation time for AC field.....67
Fig 4.34 (c) Mass of bean seeds (g) exposed to 600G for 6hrs for various fields after varying incubation time for AC field.....68
Fig 4.35 (a): Percent mass of germinating bean seeds as a function of incubation and exposure time at 3hrs incubation for each constant AC field generated by the Helmholtz coil.....69

Fig 4.35 (b): Percent mass of germinating bean seeds as a function of incubation and exposure time at 4.5hrs incubation for each constant AC field generated by the Helmholtz coil.....69
Fig 4.35 (c): Percent mass of germinating bean seeds as a function of incubation and exposure time at 6hrs incubation for each constant AC field generated by the Helmholtz coil.....70
Fig. 4.36 (a): Percent mass of germinating bean seeds as a function of incubation at 3hrs exposure time for each constant AC field generated by the solenoid.....71
Fig. 4.36 (b): Percent mass of germinating bean seeds as a function of incubation at 4.5hrs exposure time for each constant AC field generated by the solenoid.....71
Fig. 4.36 (c): Percent mass of germinating bean seeds as a function of incubation at 6hrs exposure time for each constant AC field generated by the solenoid.....72

LIST OF SYMBOLS AND ABBREVIATIONS

a	Area of the coil
B	Magnetic flux density
d	Distance from the centre
ds	Area around a loop
H	Magnetic field intensity
I	Current in amperes
IAA	Indole Acetic Acid
J_s	Current density
L	Length of wire wound around a soft magnetic material to form a solenoid
m	Magnetic moment
M	Magnetization
N	Number of coils
r	Radius of the coil
x	Distance from the centre of the wire (straight) carrying current
υ	Frequency
μ_o	Permeability of free space
χ	Magnetic susceptibility

DEFINITION OF TERMS

Coils: Wire wound around a core to produce magnetic flux

Development: Refers to changes in the morphology of an organism as it grows.

Electromagnet: A magnet consisting of a coil wound on a soft iron or steel core. When current is passed through the coil a magnetic field is generated.

Electromagnetic induction: The voltage produced in a coil due to relative motion between the coil and magnetic lines of force.

Electromagnetism: Relates to the magnetic field generated around a conductor when current is passed through it

Flux Density: A measure of the strength of a wave (B)

Germination: The initial stage, when a seed starts to grow and develop into a plant. Germination will be considered to have taken place once the tip of the radicle (1-2mm) has emerged from the seed.

Growth: It is permanent (irreversible) increase in size of an organism.

Helmholtz coil: Two similar coils, whose radius is used to separate them as they are, placed side by side. In this case current is carried towards the same side in both coils

Magnetic flux: The magnetic lines of force produced by a magnet

Magnetic susceptibility (χ): It is a dimensionless parameter measuring the ease of magnetizing a magnetic material.

Magnetizing Force (H): Also called magnetic field strength (intensity), it is magneto motive force per unit length at any given point in a magnetic circuit.

Magneto motive force: Force that produces a magnetic field.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Bean production

Bean (*Phaseolus vulgaris* L.) is the major source of protein in the world especially for the poor people (Onchabo, 2002). In Kenya, beans are by far the most important pulse crops cultivated on about 700,000 hectares mainly by small-scale farmers for domestic use. Beans are intercropped with other crops especially maize, potatoes and cassava. In Kenya the major varieties grown are of "Rosecoco" type. This is because of their adaptability, attractive market prices, taste and good cooking properties (Onchabo, 2002).

1.2 Factors affecting plant growth

Many plant organs respond to external factors such as light or gravity, by growing either towards or away from the source of stimulus. This response has mainly been attributed to plant hormones. A series of ingenious experiments discovered that hormone-like chemical compounds, called Auxins regulate plant growth (Roberts, 1982). The most widely distributed auxins are Indole-acetic Acid (IAA). Experiments have shown that in oat coleoptiles auxins is formed in the extreme tip (apical meristem) before being translocated to the region of elongation, where it's effects can be felt in both shoots and roots (Roberts, 1982). It has been shown that although auxins act only on a cell with active living content, it's movement is unique because it exhibits definite polarity (Brook, 1964; Sengbusch, 2005). Two other hormones have been shown to regulate growth, i.e. kinetins and gibberellins. Kinetins in conjunction with auxins promote cell division in plant tissues (Sengbusch, 2005). They co-influence acceleration of seed germination as well as causing the formation of buds and shoots. Gibberellins make plants to grow much taller than normal, though with reduced vigour and fertility. Gibberellins have a similar effect to that of auxins; they promote cell division and elongation (Sengbusch, 2005). The major difference is that gibberellins in no way inhibit growth compared to auxins, which inhibit growth when their concentration is high. Gibberellins are responsible for promoting growth in the embryo of a seed and as a result, they are responsible for the germination. It has been found that gibberellins, unlike auxins and kinetins, produce their response in both cell divisions at the apical meristem as well as in cell elongation region (Sengbusch, 2005).

1.3 Magnetic field

Magnetic field is defined as the area around a magnet where the magnet's pull and repulsion effect is felt (Zemansky, 1970; Mc' Graw Hills, 1982; White, 1987; Duffin, 1990; Chabay and Sherwood, 1995). The field is stronger near the poles of the magnet and weaker further away from the poles (Duffin, 1990; Chabay and Sherwood, 1995). Earlier studies have shown that static magnetic field has no influence on the growth of plants (Ruzic *et al.*, 1998a; Gutzeit, 2001). Furthermore, it had been suggested that common magnets do not generate forces that affect biological systems, although biological materials have small magnetic susceptibility (Hasenstein, 2004). Physicists have argued that 60Hz wavelengths are simply too long for most organisms to absorb and that even thermal effect would be very small (Freeman *et al.*, 1999). However, recent studies have identified membrane ion channels that allow for signal amplification via stochastic resonance. As a result Extremely Low Frequency (ELF) fields are known to interact with tissues by inducing electric fields and currents in them (Kruglikov and Dertinger 1994; Bezrukov and Vodyanoy 1997; Galvanovskis and Sandblom 1997). A study done on the effect of magnetic field on growth of spinach plants (Avon hybrid) in the year 1996-1997 showed that heights of spinach seedlings depended on polarity (Segal, 2004). According to earlier studies, auxins exhibit definite polarity whereby its is seen to respond to magnetic fields (Brook, 1964; Sengbusch, 2005). It has been realized that magnetic gradients induce forces, which affect biological materials. This has been attributed to biological materials having small magnetic susceptibility regardless of whether they are diamagnetic or paramagnetic (Hasenstein, 2004). Strong magnetic gradients induce curvature in roots and shoots of plants.

An experiment done in the United States of America on effect of magnetic field on growth of spinach has raised a lot of questions. Thirty spinach plants were exposed to the South Pole field, thirty to north magnetic field and thirty seedlings were left unexposed to act as control. The results revealed that the plants exposed to the South Pole had the greatest average height of 4.8 cm, followed by the control with average of 3.9 cm, and finally, the plants exposed to the North Pole with an average height of 2.3 cm (Segal, 2004). Extremely low frequency electromagnetic fields (ELF-EMF) of 26mT; 50Hz on spruce delayed seeds germination at pH 2 and 3, the length of the seedlings reduced slightly at pH 2, whereas at pH 6 and 7 there were no effects on germination and length of the seedlings (Ruzic *et al.*, 1998 a).

All these discoveries go against the earlier research findings, which indicated that magnetic field has no influence on growth of plants, hence the need for further research. The main aim of carrying out this study was, therefore, to determine whether electromagnetic field has an effect on germination and growth of beans. This study also aimed at finding the optimum magnetic condition that will accelerate germination and growth of Rosecoco beans.

1.4 Statement of the Problem

Rosecoco bean varieties are widely grown and popular with most farmers in Kenya because of their adaptability, attractive market prices, taste and good cooking properties (Onchabo, 2002). All plants including beans have auxins, which are known to have an effect on plant growth. Auxins exhibit definite polarity (Brook, 1964; Sengbusch, 2005) and therefore it is expected that they can be affected by magnetic fields. Much controversy whether magnetic fields have an effect on growth of plants is still oblique. The proposed study was therefore intended to throw more light as to whether magnetic field affect plant growth, in addition to determining the optimal magnetic condition for germination and growth of Rosecoco beans.

1.5 Objectives of the Study

The main objective of this study was to determine whether magnetic field has any effect on the germination and growth of beans. The specific objectives were:

(i) To study the effect of North and South Pole fields on germination of bean seeds.

(ii) To determine the effective exposure time to magnetic field for faster radicle growth

(iii) To determine the optimal magnetic condition for accelerating germination in beans.

1.6 Justification of the Research

Animal proteins are very expensive and an ordinary Kenyan is not in a position of supporting himself / herself when it comes to balanced diet. This leaves us with plant proteins as the only cheap protein source. Beans are one of the plant proteins. If accelerated to germinate and grow, the deficit of beans experienced in this country would cease. Furthermore faster growth of beans would reduce hunger and improve the health of Kenyans in addition to boosting the economy of the country.

1.7 Scope and Limitations

Scope

Basing on previous researches (Freeman *et al.,* 1999), this research measured fields ranging between 50G and 600G, exposure duration ranging between 3hrs and 6hrs while maximum incubation period was 96hrs (4 days).

Limitations

The following limitations were experienced

- The field strengths were exposed to the specimen tangential to it, horizontal exposure of the field was not considered.
- The research was done at room temperature and slight fluctuation of room temperature may have occurred.
- There was a limitation in considering uniform humidity throughout the experiment. The experiment was carried out from February to August 2006 yet through different levels of humidity.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Bio-effect of magnetic fields

Knowledge on effects of magnetic fields on living cells dàtes back to around 2000BC when Hindu scripture of the Vedas described the ability to heal disease with lodestone (Anon, 2004). In Greece Galen in 200 BC used magnets to purge illness. In 1791 Galvani coined the term animal magnetism which was replaced eight years later with Bio-magnetism by a Dutchman Brigman, after noting the reaction of organisms to earth's magnetic field (Anon, 2004). Campbell (1935) and Bingenheimer (1936) showed the effect of magnetic field on small animals and living organisms (Anon, 2004).

Investigations on the effects of electromagnetic field (EMF) on organism started in early 1980s when epidemiological studies linked breast cancer, leukaemia and brain tumours to extensive EMF exposure (Freeman *et al.,* 1999). The effects of 50Hz Extremely Low Frequency Electromagnetic Field (ELF-EMF) suggests that low frequency magnetic fields have some adverse effects on fertility of both male and female rats (Al-Akhras *et al.,* 2001). Furthermore pulsed ELF-EMF between 33-50Hz might impair mammalian female reproductive potentiality by reducing the capacity of the follicles to reach developmental stage that is an essential pre-requisite for reproductive success (Cecconi *et al.,* 2000). Much of early controversy centred on common 60Hz and Physicists argued that these wavelengths are simply too long for most organisms to absorb and that even their thermal effect would be very small (Freeman *et al.,* 1999). However recent works have identified membrane ion channels that allow for signal amplification via stochastic resonance. Consequently, ELF fields are known to interact with tissues by inducing electric fields and currents in them (Kruglikov and Dertinger 1994; Bezrukov and Vodyanoy 1997; Galvanovskis and Sandblom 1997). Furthermore, it has been realized that EMF exposure results in enhanced secretion of melatonin by the pineal gland, consequently altering the action of certain drugs and aiding in the healing of certain tissues (Freeman *et al.,* 1999).

The study of bio-effect of magnetic field in plants started much later after the realization of magnetic bio-effect in animals. Davies (1996) reported increased growth in radish seedlings exposed to 60Hz EMF tuned to the ion cyclotron resonance for calcium. Magone (1996)

identified a reduction in the vegetative growth and life span of duckweed grown near a 160MHz radio frequency EMF. Furthermore Inoue *et al.* (1985) found that a 60Hz field adversely affected root growth in *Pisum sativum* L. Magnetic field applied to spruce seedlings and chestnut buds grown in tissue culture showed that magnetic field alone had no significant influence on the growth of plants (Ruzic *et al.*, 1993; Jerman *et al.*, 1998; Ruzic *et al.*, 2000; Gutzeit, 2001; Hasenstein, 2004). Although no statistical significance of growth was shown it has been realized that magnetic gradients can induce forces, which affect biological materials. This has been attributed to biological materials having small magnetic susceptibility regardless of whether they are diamagnetic or paramagnetic (Hasenstein, 2004). Strong magnetic gradients induce curvature in roots and shoots of plants.

Magnetic technologies, a company in plant growing, have come up with a method of magneto-hydro dynamical activation of natural waters (Magnetic Technologies, 2004). It has been realized that the advantages of using magnetic water as compared to normal water are so enormous, for example, crop production increase from 15 - 20% to 100% and in some cases even more. Plant disease rates drastically decrease and taste of agricultural product improves (Magnetic Technologies, 2004). It has been reported that magnetizing causes physical-chemical changes of natural water parameters, resulting in improvement of filtration properties and in an increase of dissolving properties of water (Ruzic *et al.*, 1998 b). These changes result in an increased ability of soil to get rid of salts leading to better assimilation of nutrients and fertilizers in plants during the growing cycle (Magnetic Technologies, 2004). The most interesting discovery is that magnetizing seeds before sowing and by irrigating them with magnetic water, reduces replanting of seeds that did not germinate due to seed stress consequently, leads to the planting seed material decrease by 30%. This can be attributed to the ability of magnetic field to alleviate heat stress in seeds, e.g. in cress seedlings (Ruzic and Jerman, 2002). All plants including beans have hormones, which are known to accelerate the rate of plant growth. Auxins, one of plant hormones, exhibit definite polarity (Sengbusch, 2005) and therefore it is expected that they can be affected by magnetic fields. Much controversy whether magnetic fields have an effect on growth of plants is still oblique. The proposed study was therefore intended to throw more light as to whether magnetic field affects plant growth.

2.2 Origin of magnetic field

The effect of a magnetic field is caused by magnetic force (Cook, 1977). Magnetic force is defined as pull or push impacted by a magnet on other magnets or magnetic materials (Blum and Roller, 1982). The existence of a magnetic field is shown diagrammatically by use of imaginary lines called magnetic lines of force (magnetic field lines). A group of field lines around a magnet constitutes magnetic flux (Chabay and Sherwood, 1995). Magnetism, which results to magnetic field, has been explained based on the domain theory. According to this theory a magnetic material contains individual atoms that behave as tiny atomic magnets (Blum and Roller, 1982). A group of such atomic magnets, with their magnetic axes parallel, forms magnetic domains. Each domain has millions of tiny or atomic magnets called dipoles, lined up with their north poles in one direction. In different domains the dipoles point in different and random directions, so that in unmagnetised magnetic material the resultant magnetism of all the domain is zero (Chabay and Sherwood, 1995), because the dipoles cancel each other as shown in Fig 2.1

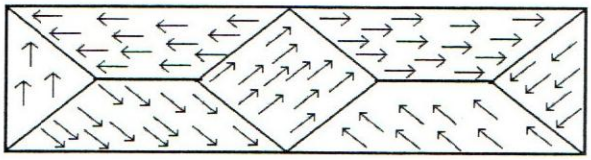


Fig 2.1: Magnetic material showing domains and dipoles

When the material is placed in a magnetic field during magnetization, most of the domains are aligned in one direction as shown in Fig 2.2.

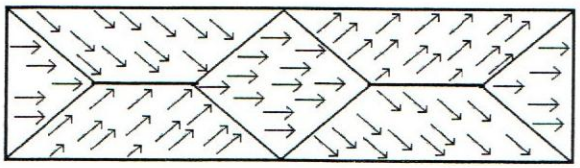


Fig 2.2: Magnetic material in a magnetic field

When the alignment has taken place, the material is magnetized. If the magnetizing field is strong enough, all the domains are aligned in one direction and the material is said to be magnetically saturated and magnetization cannot be enhanced further (Fig 2.3).

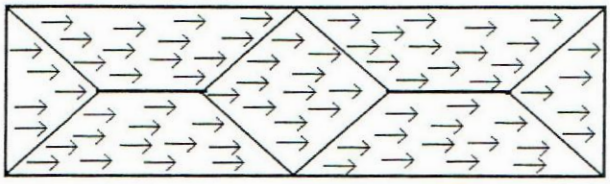


Fig 2.3: Magnetic saturation

Each individual atom behaves as a tiny magnet called dipole. The dipoles are attributed to orbital motions and spin of the electrons of the atom resulting to magnetic dipole moment. Orbital motion of electrons and electric current spin are equivalent of tiny electric current loops and whenever there is a current, a magnetic field is always produced (White, 1987; Duffin, 1990; Chabay and Sherwood, 1995).

2.3 Electromagnetism

Electromagnetism relates to the magnetic field generated around a conductor when current is passed through it. Every orbiting electron in motion around its nucleus generates a magnetic field. When electrons are forced to leave their parent atom by voltage and flow towards the positive polarity, they are all moving in the same direction and each electron's magnetic field will add to the next. The accumulation of these entire electron fields will create the magnetic field around the conductor (Duffin, 1990; Chabay and Sherwood, 1995).

2.4 DC versus AC electromagnetism

An electromagnet consists of a coil wound on a soft iron or steel core. When current is passed through the coil a magnetic field is generated and the core is strongly magnetized to concentrate the magnetic field. A coil is defined as the number of turns of wire wound around a core to produce magnetic flux (an electromagnet) or to react to a changing magnetic flux (an inductor). It is known that a magnetic field results whenever a current flows through any piece of conductor or wire. If many coils are wound in the same direction, an electromagnet is formed (Duffin, 1990; Chabay and Sherwood, 1995). A Direct Current (DC) voltage produces a fixed current in one direction and therefore generates a magnetic field in a coil of fixed polarity, as determined by left hand rule (Chabay and Sherwood, 1995). For a coil carrying direct current, we find the polarity as shown in Fig 2.4.

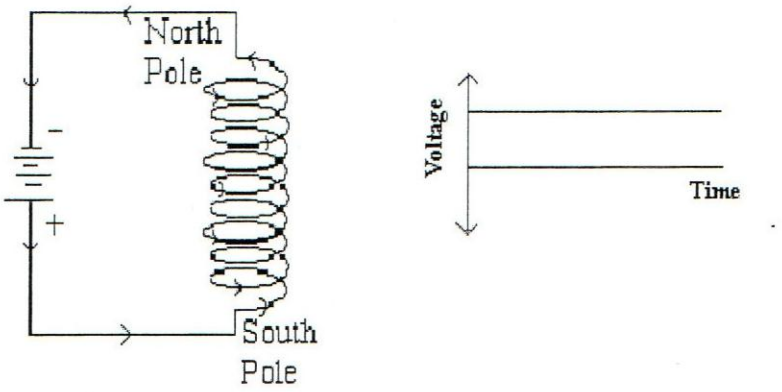


Fig 2.4: Coil carrying direct current and polarities

Alternating Current (AC) is continually varying and as the polarity of the magnetic field is dependent on direction of current flow (left-hand rule) the magnetic field will also be alternating in polarity as shown in Fig 2.5

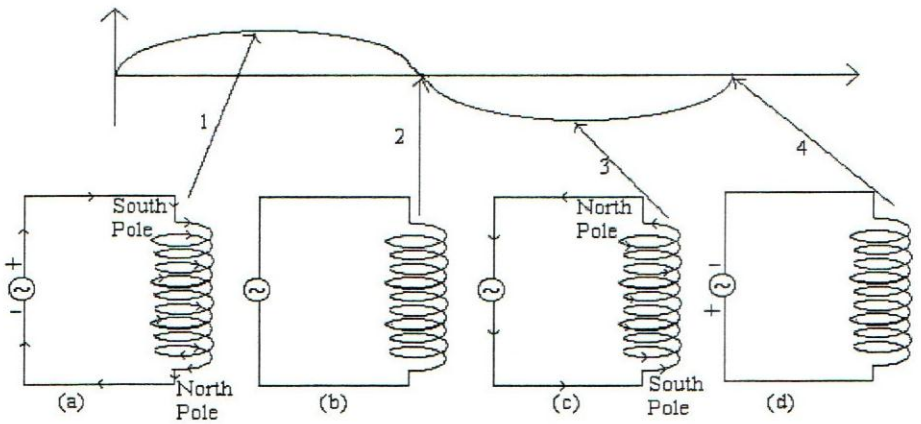


Fig 2.5: Changing field due to alternating current

2.5 Magnetic field flux

Magnetic field flux (B) is used in determining the strength of a given magnetic field. Magnetic flux has been derived from Biot-Savart law as shown in the equation 2.1(a) and (b) (Duffin, 1990; Chabay and Sherwood, 1995).

$$B = \frac{\mu_o}{4\pi}.\frac{qvXa}{a^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{2.1(a) for a single moving particle}$$

$$B = \frac{\mu_o}{4\pi}\int\frac{IdlXa}{a^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{2.1(b) for current distribution}$$

2.5.1 Magnetic field flux for a straight wire

For a straight wire of length L and conventional current I at a distant x from the centre of the wire and by applying Biot-Savart law (Duffin, 1990; Chabay and Sherwood, 1995), we get;

$$B_{wire} = \frac{\mu_o}{4\pi} \cdot \frac{ilXa}{x\sqrt{x^2 + \left(\frac{L}{2}\right)^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.2$$

For a very long wire, L>>x

$$B_{wire} = \frac{\mu_o}{4\pi} \cdot \frac{il}{x\sqrt{\left(\frac{L}{2}\right)^2}} = \frac{\mu_O}{4\pi} \cdot \frac{2i}{x} = \frac{\mu_o I}{2\pi x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.3$$

2.5.2 Magnetic field flux on the axis of a circular coil

The field due to circular coil with two elements at opposite ends of a diameter of the coil shown in the Fig 2.6 can be derived by applying Biot-Savart law.

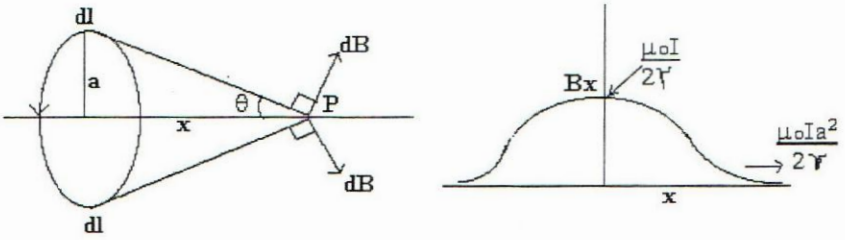


Fig 2.6 (a) Coil of wire / Fig 2.6 (b) Variation of B_x against x for circular coil

The Magnitude of the field due to the element will be given by

$$dB = \frac{\mu_o}{4\pi} \cdot \frac{idl}{\sqrt{x^2 + r^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.4$$

The components of dB resolved perpendicularly to the axis will cancel, while those resolved along the X-axis will add up. This applies to every such pair of elements. The total field at P is simply the sum of the resolved parts along x- axis. This is shown to give along the coil axis a magnetic magnitude given by equation 2.5

$$B_x = \frac{\mu_o I \pi r^2}{2\pi^2 r\left(r^2 + x^2\right)^{3/2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.5$$

Where B_y and B_z are equal to zero

In Fig. 2.6 (b), B_x is plotted against x; when x=0 at the centre of the coil axis

$$B = \frac{\mu_O I}{2\pi r^2} = \frac{\mu_O I}{2a} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.6$$

Where 'a' is the area of the coil equals to πr^2.

2.5.3 Magnetic field on the axis of a solenoid

A long coil of wire with a small diameter is called a solenoid. We can calculate the magnetic field along the axis of a solenoid consisting of lots of circular loops. It turns out that the magnetic field is nearly the same in magnitude and direction throughout the interior of the solenoid, as long as one doesn't get too near the ends. One of the uses of a solenoid is to make a uniform magnetic field (Duffin, 1990; Chabay and Sherwood, 1995). Consider a solenoid wound on a soft magnetic material. If the solenoid has "N" turns and the length of the solenoid is "L" whereas the radius of the solenoid is "r". Suppose that the magnetic field B_x is acting along the x direction, then B_y=0 and B_z=0. The magnetic field at a location in the x-direction amounts to

$$B_x = \frac{\mu_o}{4\pi} \cdot \frac{2\pi a^2 I}{\left[(d-x)^2 + a^2\right]^{3/2}} \cdot \frac{N}{L} \Delta X \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.7$$

The net magnetic field lies along the x-axis and is the summation of all the B_x contributed by all the loops.

$$B_x = \sum \Delta B_x = \sum \frac{\mu_o}{4\pi} \frac{2\pi a^2 IN}{L} \cdot \frac{\Delta X}{\left[(d-x)^2 + a^2\right]^{3/2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots 2.8$$

Many of these quantities are the same for every piece; therefore we can take summation as a common multiplicative factor

$$B_x = \frac{\mu_o}{4\pi} \frac{2\pi a^2 IN}{L} \sum \frac{\Delta X}{\left[(d-x)^2 + a^2\right]^{3/2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.9$$

This can be simplified into an integral, with x ranging from –L/2 to +L/2

$$B_x = \frac{\mu_o}{4\pi} \frac{2\pi a^2 IN}{L} \int_{x=-1/2}^{x=+1/2} \frac{dx}{\left[(d-x)^2 + a^2\right]^{3/2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.10$$

Let u = d-x, in which case dx = -du, and the limits for u = d- ($-^{L}/_{2}$) to u = d- ($+^{L}/_{2}$)

$$B_x = \frac{\mu_o I}{4\pi}\frac{2\pi a^2 IN}{L}\int_{u=+L/2}^{u=-L/2} -\frac{du}{\left(u^2+a^2\right)^{3/2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.11a$$

$$B_x = \frac{\mu_o I}{4\pi}\frac{2\pi a^2 IN}{L}\int_{d=-L/2}^{d=+L/2} -\frac{du}{\left(u^2+a^2\right)^{3/2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.11b$$

Where d- distance from the centre

These integrals can be found in standard tables of integrals

$$B_x = \frac{\mu_o I}{4\pi}\frac{2\pi a^2 IN}{L}\left[\frac{u}{a^2\sqrt{u^2+a^2}}\right]_{u=d+\frac{L}{2}}^{u=d-\frac{L}{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.12a$$

$$B_X = \frac{\mu_o I}{4\pi}\frac{2\pi a^2 IN}{La^2}\left[\frac{d+L/2}{\sqrt{\left(d-L/2\right)^2+a^2}} - \frac{d-L/2}{\sqrt{\left(d-L/2\right)^2+a^2}}\right] \quad \ldots\ldots\ldots\ldots 2.12b$$

Fig. 2.7 is a plot of equation 2.12 for B_x for a particular solenoid as a function of the distance from the centre of the solenoid. It is noticed that magnetic field is nearly uniform inside the solenoid and non-uniform near the ends. The field is even more uniform for solenoids that are longer and/or thinner than this one (Duffin, 1990; Chabay and Sherwood, 1995).

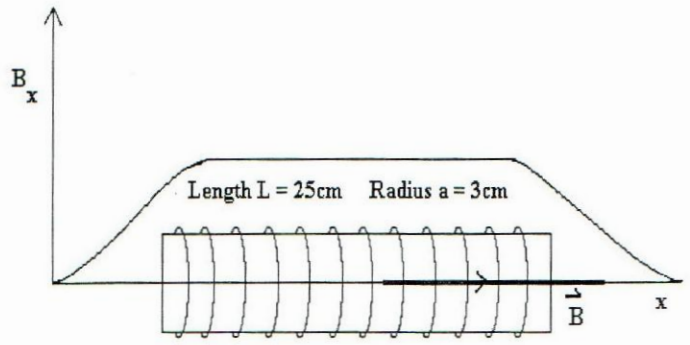


Fig. 2.7: Plot of B_X against x for a solenoid

If the radius (a) is small compared to the length (L) (a<L) and at the centre (d=0) the equation 2.12, becomes:

$$B_X = \frac{\mu_o IN}{L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.13$$

If n is number of turns (N) per unit length (L) i.e. n= N/L.

The equation 2.13 becomes,

$$B_x = \mu_o In \text{, if } Js = In \text{, then } B_x = \mu_o Js \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.14$$

This solenoid has a nearly uniform magnetic field, and one capable of producing much stronger fields over larger volumes than Helmholtz coils.

2.5.4 Helmholtz Coils

While there are numerous ways of producing uniform magnetic fields the methods commonly employed in the research laboratory are few in number. One of this is shown in Fig. 2.8.

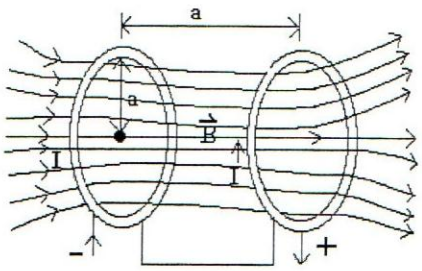


Fig. 2.8: Magnetic field around Helmholtz coils

In this case, two circular coils of same radii are arranged such that the distance from one coil to the other is the radius of the coils as shown in Fig. 2.8. This is known as Helmholtz coils. A highly uniform field will be produced at the axial point midway between the coils if the distance apart is properly adjusted. When current is allowed to flow in opposite directions in the Helmholtz coil, the resultant field is so small as shown in Fig. 2.9 (a). When the current in both coils flows towards the same direction, then magnetic field strength is of a bigger magnitude as shown in Fig. 2.9 (b).

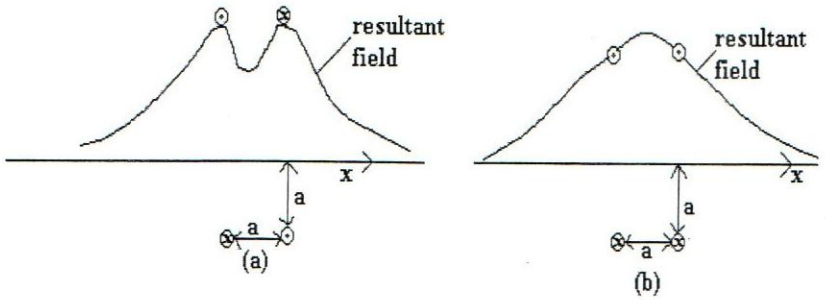


Fig 2.9: B_x plotted against x (a) for current in opposite directions in the two coils (b) for current in same direction in the two coils.

If one considers equation 2.5, for the magnetic field flux on the axis of a circular coil, then by replacing $x = r^{1/2}$ we get

$$B_X = \frac{\mu_o I r^2}{2\left(r^2 + \left(r/2\right)^2\right)^{3/2}} = \frac{\mu_o I r^2}{2\left(5/4 r^2\right)^{3/2}} = \left(4/5\right)^{3/2} \frac{\mu_o I r^2}{2r^3} = 0.717 \frac{\mu_o I r^2}{2r^3} \quad \ldots \; 2.16$$

If N is the number of turns in one of the two identical coils then

$$B_X = 0.717 \frac{\mu_o IN}{2r} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 2.17$$

Since the two coils contribute equal amount to the field at the centre, then

$$B = 2X0.717 \frac{\mu_o IN}{2r} = 1.43 \frac{\mu_o IN}{2r} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.18$$

When r – radius of the coils

I – current through the coils in the same direction

Note: Since resultant field strengths thus produced depends a great deal upon the nature of the iron coil itself, the magnitude of B between the poles is usually measured by experimental methods.

2.6 Plant growth

Growth is regulated by the plant's response to the environment through complex activities called irritability (Roberts, 1982). Irritability manifests itself as a growth curvature called tropism or nastic movement. In animals this is a form of nervous activity. Some of the tropisms include:

(i) Phototropism:

This is a situation whereby plant organs grow towards or away from light. Plant shoots show positive phototropism while roots exhibit negative phototropism. When shoots are placed in a horizontal position, just like roots, auxins accumulate on the lower side (Brook, 1964; Sengbusch, 2005). The shoot tip is responsible for directional movement by the plant in response to sunlight, as this is the area where auxins are found. Sunlight causes redistribution of auxins on the shoot of plants. The part of the shoot tip of the plant that is receiving direct sunlight will have the least amount of auxins. Light slows growth on the side without auxins and encourages faster

division of cells on the lower side with auxins (Roberts, 1982; Sengbusch, 2005). The extra auxins present on the lower side promote more cell division and elongation, causing the plant to bend towards the sunlight. Consequently, the shoots grow towards the light. In roots, like in shoots, light causes imbalance on auxins distribution. Auxins in roots accumulate on the lower side of the plant, the opposite side of light application. Auxins in roots inhibit faster growth and consequently, the side with little concentration of auxins experience faster cell division resulting to negative phototropism (Sengbusch, 2005).

(ii) Geotropism:

This is a situation whereby plant organs grow towards or away from the earth's gravitational field. Roots grow towards stimulus of gravity whereas shoots exhibit negative geotropism. As with phototropism, geotropism is due to unequal distribution of auxins (Sengbusch, 2005). When a plant is placed in a horizontal position, the even distribution of auxins is interfered with; resulting to the accumulation of auxins on the lower side of the plant while the upper side has very little concentration (Roberts, 1982; Sengbusch, 2005). The accumulation of auxins on the lower side of roots inhibits cell division resulting in the roots showing positive geotropism, whereas auxins encourage faster cell division in shoots resulting to negative geotropism.

Nastic movements:

This is a situation whereby certain plant organs exhibit movements, which are independent of direction of the stimulus. Such nastic movements are not due to growth but are commonly caused by changes in turgor of specialized group of cells (Roberts, 1982).

Tactic movements:

This is movement of small motile primitive plants, which commonly consists of only a single cell in response to an external stimulus. Some of this includes phototaxis due to light and chemotaxis due to chemicals (Roberts, 1982).

2.7 Bean seed structure

A bean seed is made up of the following parts:

The testa: - This is the outer covering.

Cotyledons: - These are the food storage tissues. They form the first leaves.

The embryo consists of the following:

(i) Plumule or embryonic shoot.

(ii) Radicle or embryonic root.

Epicotyl: - connects the plumule to the cotyledons

Hypocotyl: - connects the radicle to the cotyledon.

2.7.1 Bean seed germination

Germination is the first stage of growth and development of a seedling. Germination is considered to have taken place once the tip of the radicle (1-2mm) has emerged from the seed (Moon and Chung, 2000). Growth is a permanent (irreversible) increase in the size of an organism (Roberts, 1982). Development refers to changes in the morphology of an organism as it grows. The following factors are necessary for germination to take place:

Moisture: - Before a seed germinates, it absorbs water by imbibition. This water softens the testa and activates the enzymes that break down the food reserves in the cotyledons.

Oxygen: - It is required for oxidation of food substances stored in the seed. During respiration, energy is liberated. The energy is used for cell division and growth.

Suitable temperature: - Enzymes work well at a given temperature; for bean seed the best temperature for germination is between 18°C and 37°C (Roberts, 1982).

There are two types of germination i.e. epigeal and hypogeal germination. Epigeal germination is a type of seed germination in which the plumule and the cotyledons are thrust above the ground as a result of the elongation of the hypocotyl. The cotyledons develop chlorophyll and begin to photosynthesise (Acland, 1971; Blum and Roller, 1982; Roberts, 1982). This is experienced in bean seed as shown in Fig 2.10. Hypogeal germination is a type of seed germination where cotyledon is left below the ground.

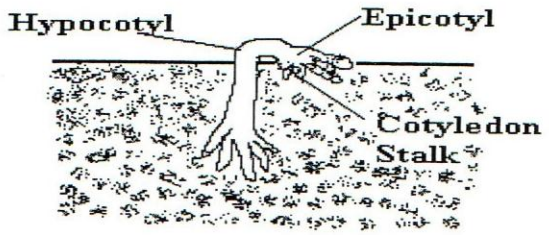


Fig 2.10: Epigeal germination

CHAPTER THREE

3.0 METHODOLOGY

3.1 Instruments and Calibration

3.1.1 Instruments

Magnetic flux density unit (model unilab 612.002) connected to multimeter (model ALDA AVD830B) was used in measuring magnetic flux. A variable transformer supplied power (model unilab, Low voltage power unit 022.317: 0-25V, 8.5A rms max). The Helmholtz coil used was model PHWE 06990.10; 320 turns, 2A, radius 7cm. The mass of the seeds was measured using a beam balance (model Ohaus, cent-0-gram balance 311grams capacity).

3.1.2 Calibration of magnetic flux density unit and Teslameter

Magnetic flux density unit unilab 612.002 was calibrated using Group3 DTM-151 Digital teslameter with IEEE-488 GP1B Interface and DTMG V6 soft ware. This teslameter was supplied with power from Danfysik model system 8000. Magnetic field was produced by 100mm electromagnet GMW model 3472-70. In calibrating the magnetic flux density, first the output portion of this flux density was connected to the two terminals of ALDA model multimeter AVD830B and the multimeter placed in the mV knob so that it can record any voltage output generated by the flux density. The flux density was then fixed to the power supply. On the other hand, group 3 DTM-151 Digital teslameter with IEEE-488 GP1B interface was connected to DTMG V6 Software after which it was connected to the Danfysik model system 8000 power supplier (Fig 3.1). After fixing magnetic flux density at 1000mT position, the power was switched on, on both the magnetic flux density and the Danfysik model system 8000.

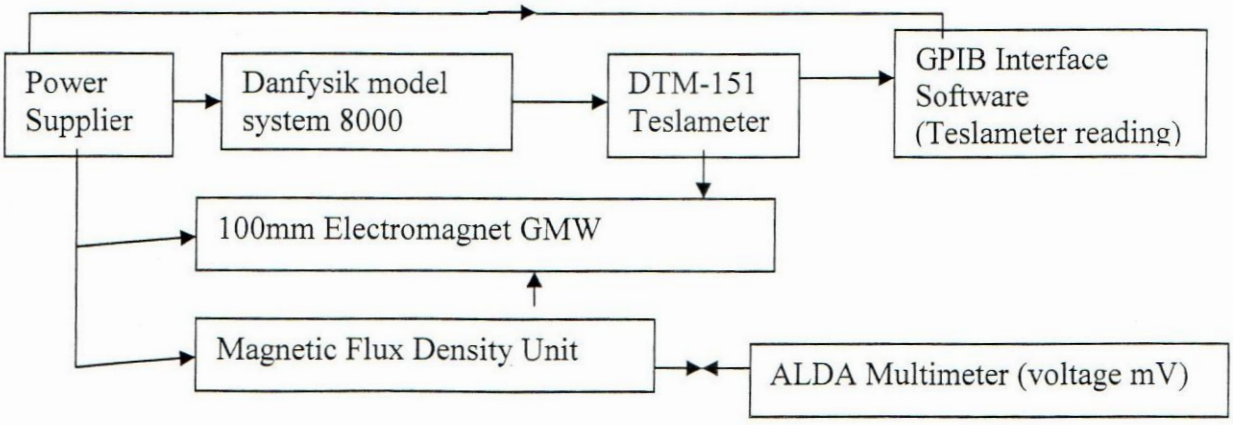


Fig 3.1: Schematic diagram illustrating calibration of magnetic flux density unit

The probes of both the digital teslameter and the magnetic flux density, side by side, were inserted in the middle of 100mm electromagnet GMW model 3472-70. The background magnetic field was recorded by the teslameter as the flux density voltage output was also recorded. The power supplier to 100mm electromagnet GMW model 3472-70 was switched on. Controlling the amount of current supplied to the electromagnet varied the strength of the field and its value recorded as voltage output was read from ALDA model multimeter. Table 3.1 (a) and (b) gives the results obtained.

Table 3.1 (a) Teslameter recording (mT) and the corresponding Flux Density measurement with background

		Attempts				
	Background	1	2	3	4	5
Teslameter readings (mT)	3.28	10.09	16.90	23.73	30.57	37.40
Flux density (mV)	-5	5	16	26	37	47

Table 3.1 (b) Teslameter recording (mT) and the corresponding Flux Density measurement without the background effect

Teslameter readings (mT)	0	6.81	13.62	20.45	27.25	34.12
Flux density (mV)	0	10	21	31	42	52

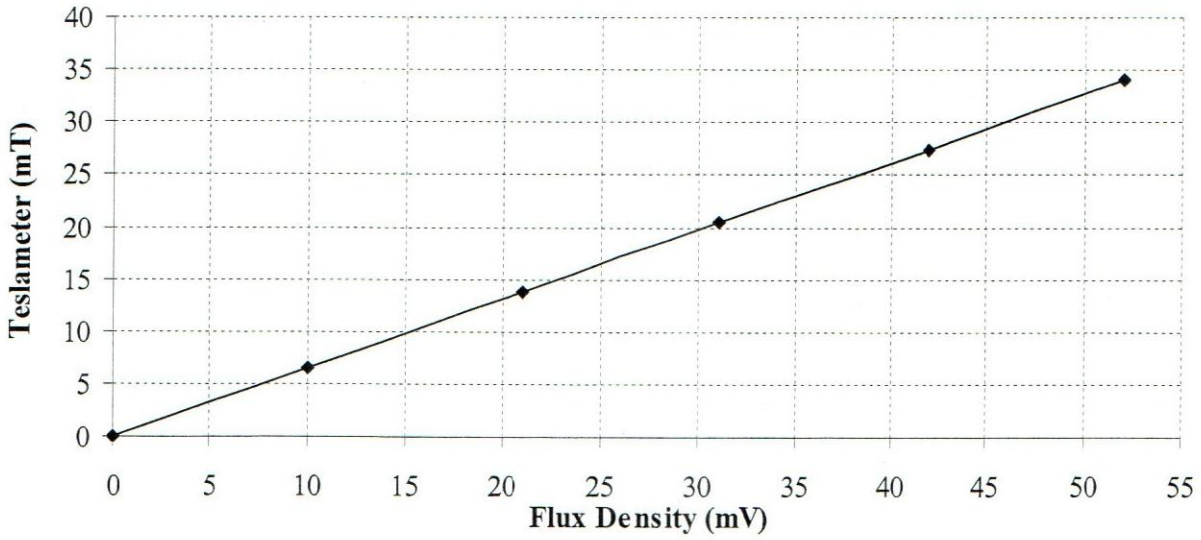


Fig 3.2: Flux density (mV) versus B-field as per Teslameter reading

Fixing the value of the strength of a magnetic field, the probe of the flux density unit was placed at a position in which the field was to be determined and the value of the voltage used in

determining the strength of the field. The strengths of the fields at 50, 100, 300 and 600G, was determined from voltage (Fig.3.2) and fixed at 7.35, 15, 45 and 90mV respectively. In terms of Tesla, 50, 100, 300 and 600G were 5, 10, 30 and 60mT respectively. {10,000 Gauss (G) is equal to 1Tesla (T)}.

3.2 Source of Bean seeds and their preparation

Two kilograms of viable Rosecoco GLP-2 seeds were purchased from Kenya Seed Company and assumed to have same moisture content. Bean seeds of nearly the same size and colouration were selected and grouped in tens. The mass of each group of 10 seeds was weighed and recorded. Each group of 10 seeds was then soaked for 2hrs before being transferred to a petri dish lined with a lean sheet of serviette. A thin sheet of serviette was used to cover the seeds and distilled water was sprinkled on top to soak the serviette. For one such set of experiment, four petri dishes were prepared and labelled as follows:

H- used in field produced by Helmholtz coil

S- placed on South Pole of a magnet (one of the poles for AC current).

N-placed on the North Pole of a magnet (the other pole for AC current)

C-served as a control.

The experiment was replicated three times.

3.3 Solenoid preparation

A cuboid soft magnetic material made of soft iron, whose thickness is a square of 1cm and length of 50cm, was used. This soft magnetic material was wound 700 times on each side by a coated copper wire.

3.4 Experimental set up

Magnetic field strength for the Helmholtz coil was set at 50G with the aid of a magnetic flux density unit (PHWE 612.002) and by varying current in the coil. Petri dish labelled H was placed in between the two pairs of Helmholtz coils. Using Fleming's left-hand rule of electron flow, the polarity of the solenoid was determined. A north pole of a permanent magnet was brought close to the determined north pole of the magnet. Experiencing repulsion ascertained the

presence of the polarity. Petri dish labelled S was placed on South Pole of the solenoid while petri dish N was placed on the north pole of the solenoid. The exposure time for magnetic field intensity was 3 hours for every 24 hours period. The petri dish labelled C served as a control under same conditions except the fact that it was not exposed to magnetic field.

3.5 Data collection and analysis

The number of germinating seeds, their mass and the length of radicle were recorded after every 12 hours for the first four days (96 hours) after inception of the experiment. The magnetic field strength was fixed at 50G, 100G, 300G and finally 600G and the above procedure was repeated for each case. Exposure time was varied from 3, 4.5 and 6 hours for each set of magnetic field. The experiments were replicated three times.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

The results are divided into various sections based on the three parameters that were investigated. The parameters include

Strength of the magnetic field

50G, 100G, 300G and 600G.

Time of exposure

3hrs, 4.5hrs and 6hrs.

For each parameter, length of the radicle, mass of the seeds (seedlings), and number of seeds that germinated after a given time were investigated.

Type of field

HA: - Average of results exposed to either AC or DC field generated by Helmholtz coil

FA: - Average of results exposed to AC field generated by solenoid

CA: - Average of results not exposed to any field (control)

NA: - Average of results exposed to North Pole field

SA: -Average of results exposed to South Pole field

The type of field has been grouped into two major categories i.e.

- Alternating fields generated by AC currents.
- Direct current fields generated by DC currents.

4.1 LENGTH OF BEAN RADICLE

4.1.1 Length of radicle exposed to DC fields

4.1.1.1 Results

The length of the radicle under different fields within a given field exposed for a certain number of hours per day for the direct current field is shown in table 4.1 and figures 4.1, 4.2, 4.3 and 4.4.

EGERTON UNIVERSITY LIBRARY

Table 4.1: Radicle length (cm) for varying exposure and incubation time exposed to a given DC field strength

	(a)		50G					(b)		100G				
Time of Exposure (hrs)	Field	Incubation time (hrs)						Field	Incubation time (hrs)					
		24	36	48	60	72	84	96		24	36	48	60	72	84	96
3	HA	1.77	16.37	27.80	45.53	55.53	69.07	73.93	HA	0.00	1.70	10.33	24.80	39.90	54.40	65.00
	NA	1.83	15.23	25.93	43.73	52.43	64.80	70.73	NA	0.17	3.17	15.80	29.13	45.07	59.27	71.33
	SA	1.83	15.93	26.70	44.10	52.87	64.47	68.53	SA	0.00	1.33	10.80	24.50	39.63	54.13	65.23
	CA	1.97	16.40	25.83	39.30	46.17	54.30	57.87	CA	0.00	0.33	7.23	21.33	36.83	53.63	63.40
4.5	HA	1.37	11.70	19.13	29.77	37.63	44.90	49.77	HA	3.17	12.20	26.67	38.67	54.97	61.50	73.43
	NA	0.73	13.17	20.77	33.83	43.20	51.30	57.00	NA	1.97	10.70	24.03	36.83	53.80	60.43	69.70
	SA	0.47	11.40	19.23	29.67	36.50	43.70	47.87	SA	2.43	11.13	24.63	36.63	51.30	57.13	66.93
	CA	0.60	13.07	20.33	33.43	41.60	48.57	53.20	CA	2.10	9.73	22.17	33.67	47.97	53.73	63.13
6	HA	1.13	14.73	26.93	43.30	52.70	66.07	69.60	HA	0.17	2.77	12.37	27.80	38.80	51.07	62.10
	NA	0.70	14.20	25.80	41.73	52.23	62.93	67.27	NA	0.27	5.20	14.80	31.50	44.30	59.93	69.40
	SA	0.83	16.33	26.40	39.53	49.07	58.77	62.03	SA	0.37	5.83	16.40	32.47	43.47	56.27	64.17
	CA	0.87	14.60	25.07	39.23	46.93	58.43	62.33	CA	0.37	3.47	13.70	28.90	41.80	58.07	66.00

Table 4.1 continued

	(c)	300G							(d)	600G						
Time of exposure (Hrs)	**Field**	**Incubation time (hrs)**							**Field**	**Incubation time (hrs)**						
		24	**36**	**48**	**60**	**72**	**84**	**96**		**24**	**36**	**48**	**60**	**72**	**84**	**96**
	HA	1.53	13.37	24.77	42.53	54.87	68.83	80.07	HA	0.00	1.70	10.33	24.80	39.90	54.40	65.00
	NA	1.10	10.67	20.80	37.87	50.07	60.33	70.17	NA	0.17	3.17	15.80	29.13	45.07	59.27	71.33
	SA	1.40	10.20	22.17	40.33	51.70	65.97	75.43	SA	0.00	1.33	10.80	24.50	39.63	54.13	65.23
3	CA	1.90	11.90	23.30	37.40	48.03	59.60	69.60	CA	0.00	0.33	7.23	21.33	36.83	53.63	63.40
	HA	3.10	11.27	24.47	36.00	47.50	54.80	66.20	HA	3.17	12.20	26.67	38.67	54.97	61.50	73.43
	NA	2.50	10.30	22.90	33.77	48.67	57.77	69.90	NA	1.97	10.70	24.03	36.83	53.80	60.43	69.70
	SA	2.50	11.57	24.27	35.47	48.50	56.97	66.10	SA	2.43	11.13	24.63	36.63	51.30	57.13	66.93
4.5	CA	2.67	10.87	23.47	34.50	43.60	53.27	61.90	CA	2.10	9.73	22.17	33.67	47.97	53.73	63.13
	HA	0.67	7.17	23.67	39.03	54.37	68.33	79.90	HA	0.17	2.77	12.37	27.80	38.80	51.07	62.10
	NA	0.67	4.07	12.13	26.37	42.27	50.80	58.73	NA	0.27	5.20	14.80	31.50	44.30	59.93	69.40
	SA	0.33	5.57	19.50	32.37	45.70	57.47	64.27	SA	0.37	5.83	16.40	32.47	43.47	56.27	64.17
6	CA	0.10	5.33	17.93	28.80	42.83	54.90	57.93	CA	0.37	3.47	13.70	28.90	41.80	58.07	66.00

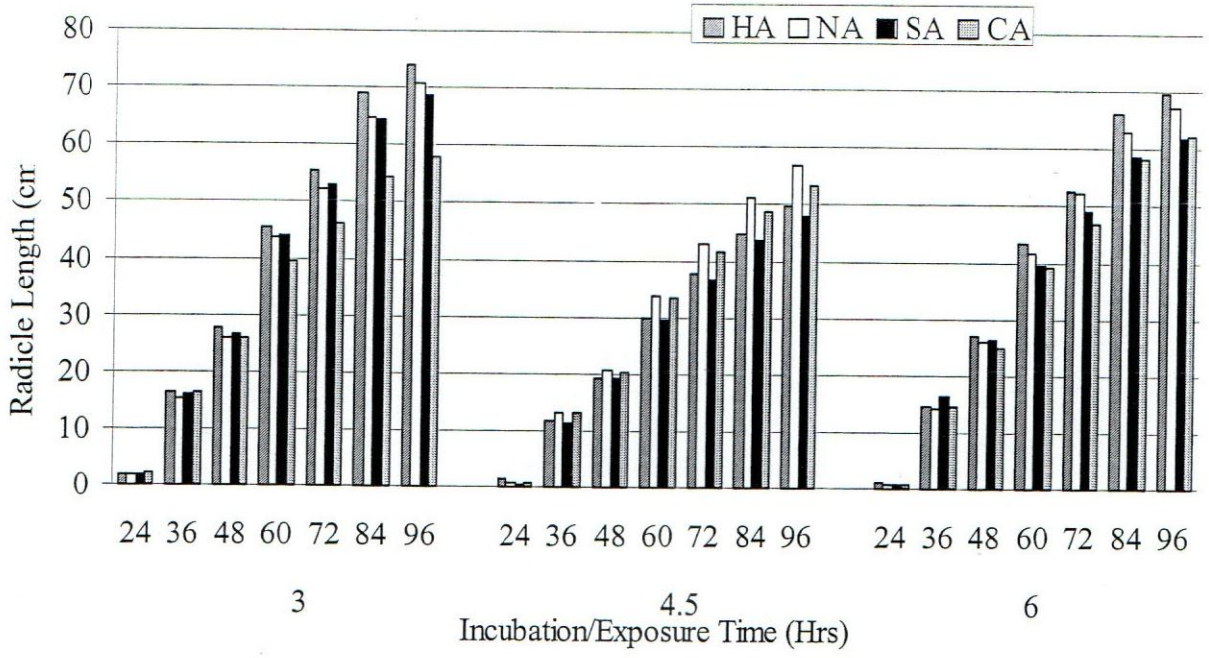


Fig 4.1: Radicle length for varying incubation and exposure time for 50G DC field

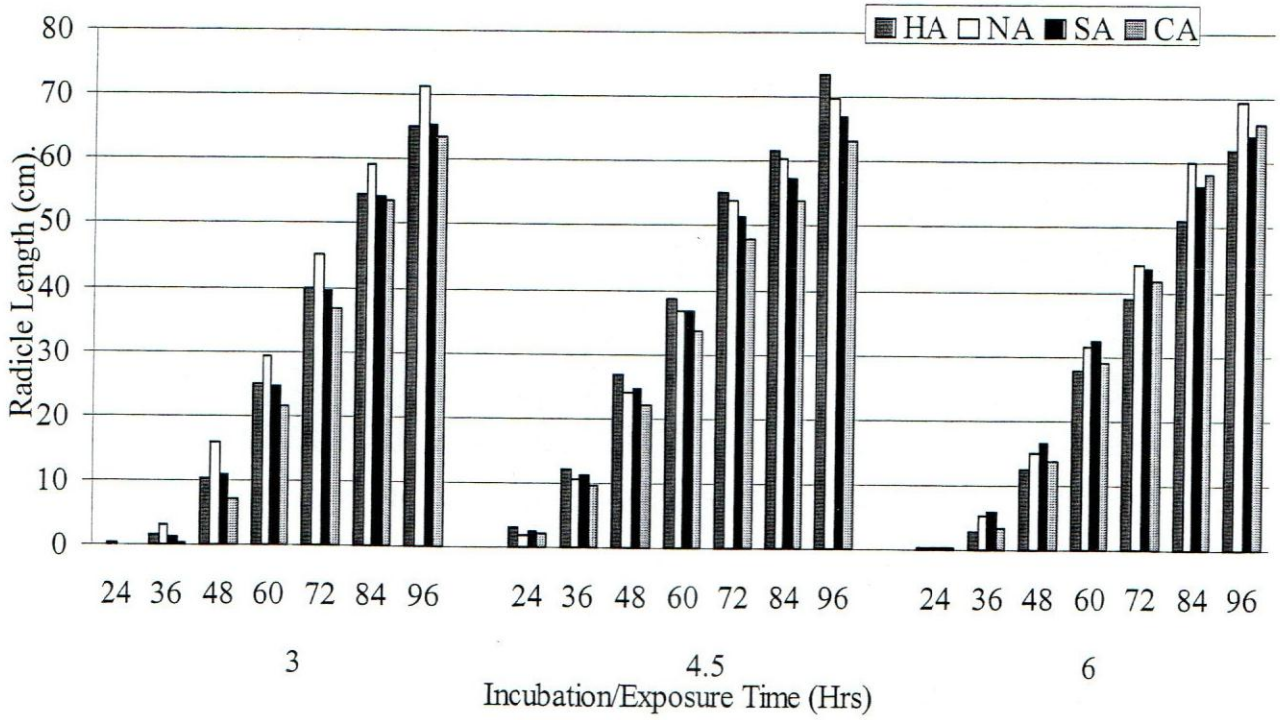


Fig 4.2: Radicle length for varying incubation and exposure time for 100G DC field

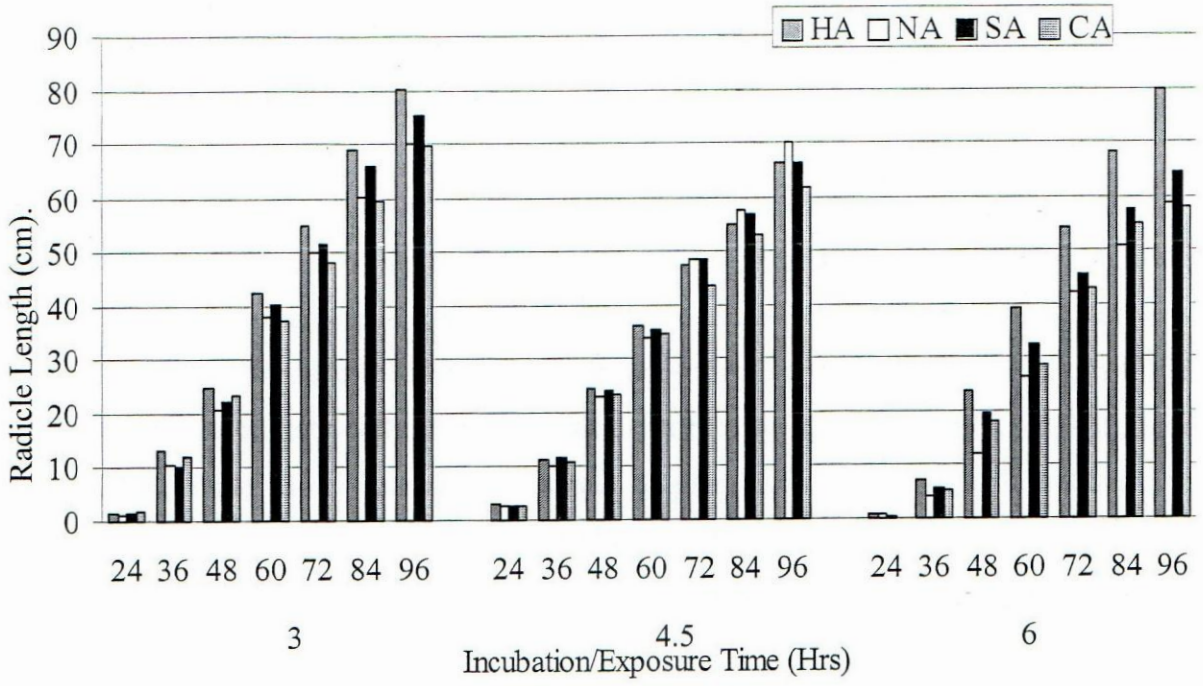


Fig 4.3: Radicle length for varying incubation and exposure time for 300G DC field

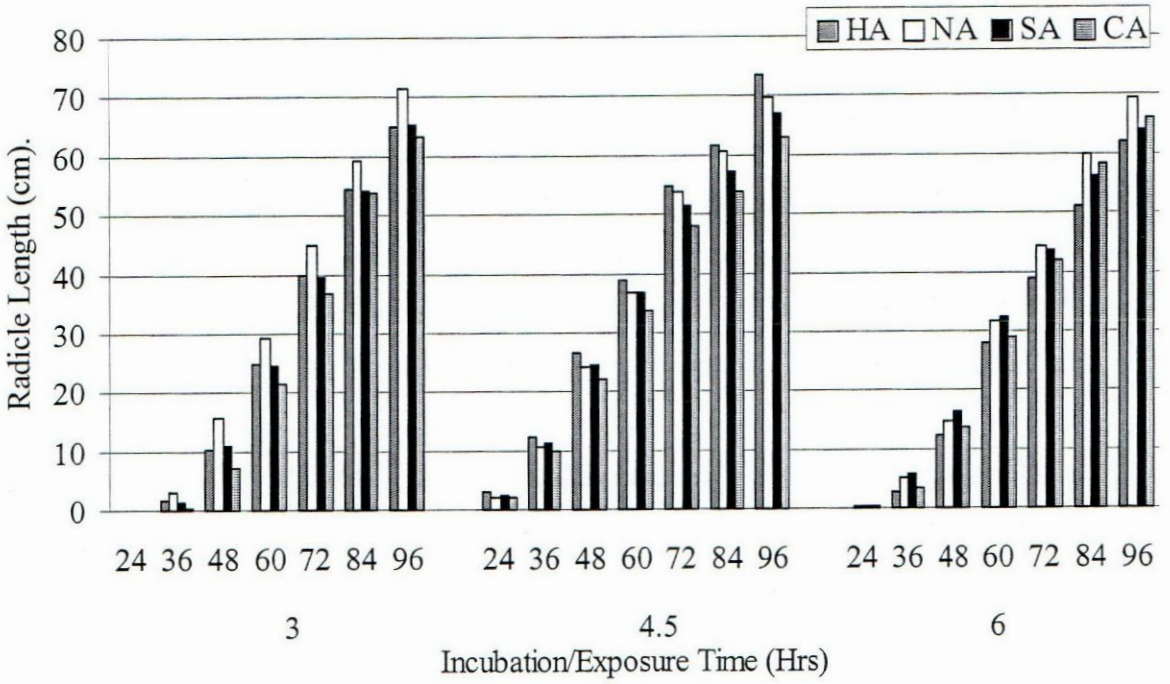


Fig 4.4: Radicle length for varying incubation and exposure time for 600G DC field

4.1.1.2 Data analysis

The radicle length was compared after 60hrs exposure time for seedlings exposed to DC fields. At this time 100% germination had occurred hence comparing them at this time gives a fair comparison.

Radicle length of bean seeds exposed to the DC fields generated by Helmholtz coil

The descriptive analysis of seedlings exposed and those not exposed to the DC field generated by Helmholtz coil, where a sample of 108 seeds gives the mean as 27.43cm, standard deviation as 25.96 and standard error mean of 2.50 is shown in appendix 1(a). Exposure of seedlings to DC field generated by Helmholtz coil did not statistically affect the length of radicle, $p>0.05$, t-test (appendix 1(b)). Evans (1972) compared the rate of plant growth, comparing the change in measured growth parameter of the plants exposed to a certain treatment and the control in ratio form. Evans formula was modified to give a comparison of the same in percent form (Equation 4.1).

$$\text{Percent of control} = \frac{E - nE}{nE} X100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 4.1$$

Where E: Seedlings exposed to a field treatment

nE: Seedlings not exposed to a field treatment yet other conditions as in E (control)

Fig. 4.22 shows the percent of increased radicle length calculated from equation 4.1, as a function of incubation and exposure time for each constant DC field treatment generated by the Helmholtz coil. At 50G DC field and exposed for 3hrs, the radicle elongated by 66% of control to any field after 84hrs incubation. Exposure to 100G for 3hrs inhibited radicle elongation by 14% after 84hrs incubation (Fig. 4.5). Seedlings growing under Helmholtz coil fields achieved maximum percent growth compared to the control of 143% when exposed for 6hrs per every 24hrs of it's growth within the 4 days at field strength of 300G measured after 96hrs incubation period (Fig 4.5). For the field of 600G strength exposure of the growing seedlings for 6hrs per day inhibited growth by 24% compared to the control after 84hrs incubation.

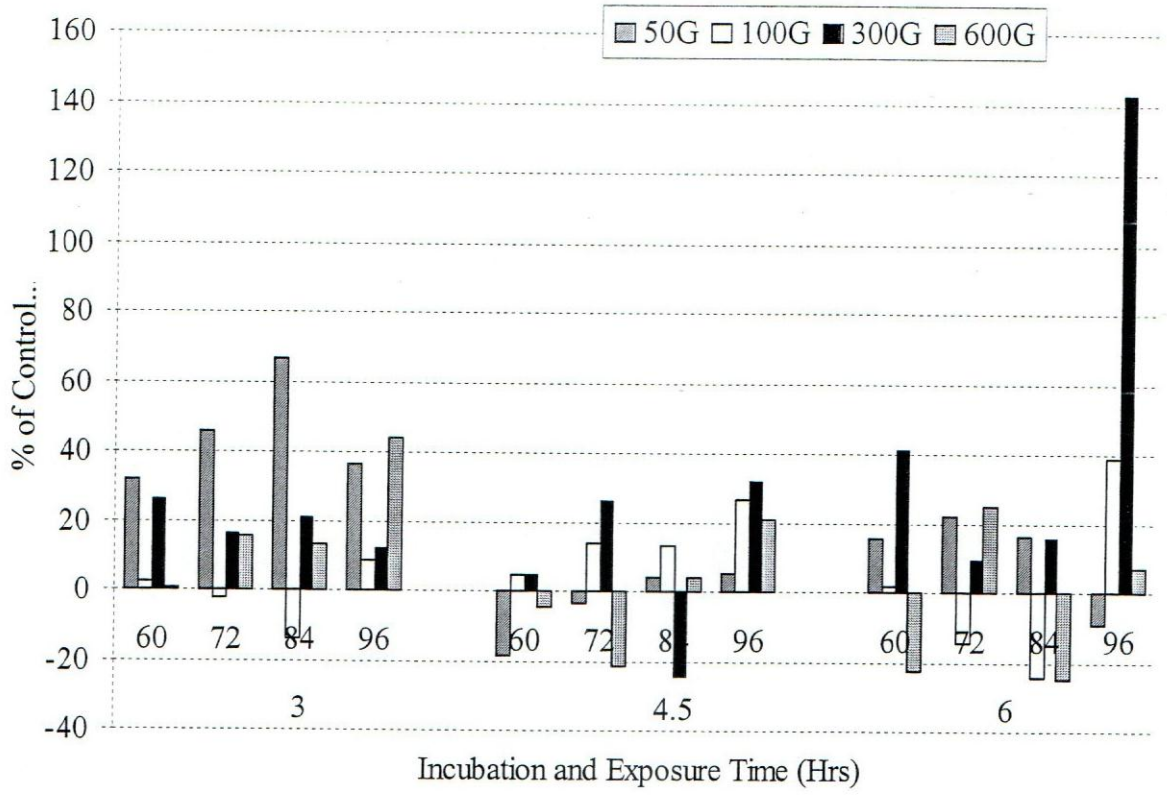


Fig 4.5: The Percentage of the increased radicle length as a function of incubation and exposure time for each constant magnetic DC field treatment generated by the Helmholtz coil

Radicle length of seeds exposed to the North Pole fields

The descriptive analysis of seedlings exposed and those not exposed to the North Pole field where radicle of seedlings gives the mean of 26.54cm, standard deviation of 25.03 and standard error mean of 2.41 as shown in appendix 3(a). Exposure of seedlings to North Pole field did not statistically ($p=0.64$) affect the length of radicle, $p>0.05$, t-test (appendix 3(b)). Fig. 4.6 shows the Percentage of the increased radicle length as calculated from equation 4.1, as a function of incubation and exposure time for each constant North Pole field treatment. The figure shows that seedlings exposed to the North Pole achieved maximum radicle length elongation of 66% compared to the control at field strength of 50G and 300G exposed for 3hrs and 6hrs per day

respectively, incubated for 96 hrs. Radicle length elongation was inhibited by 29% compared to the control at 300G exposed for 6hrs when incubated for 84hrs.

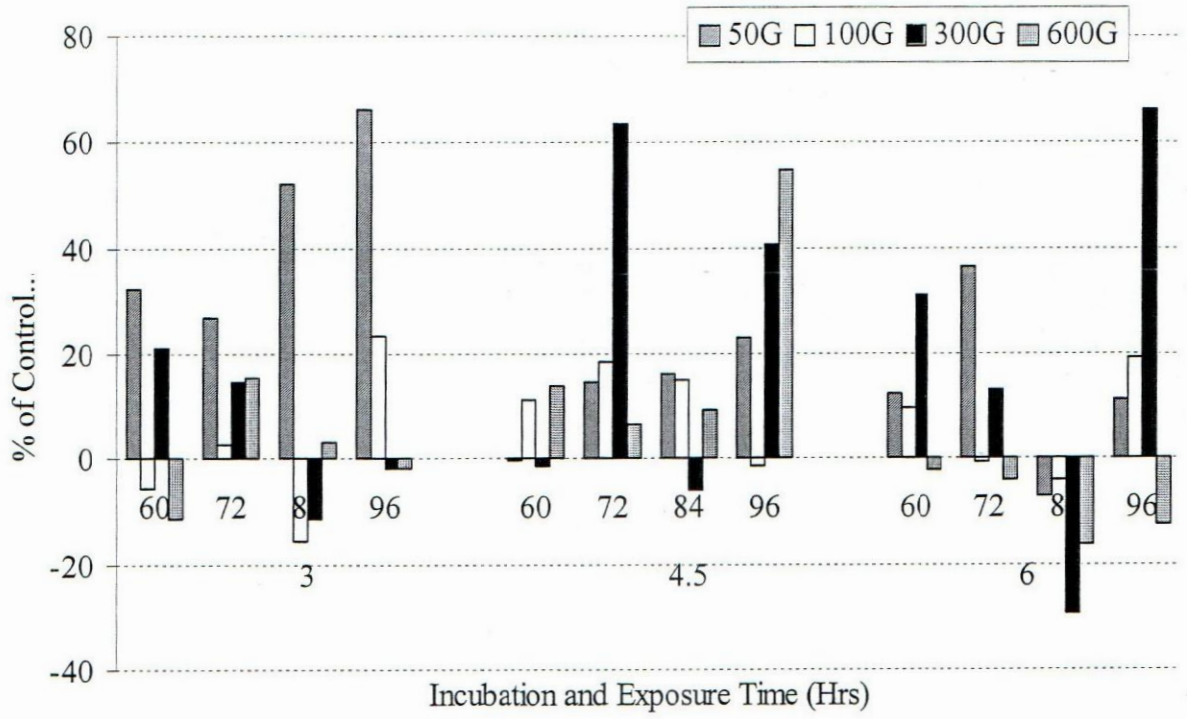


Fig 4.6: The Percentage of the increased radicle length as a function of incubation / exposure time for each constant North Pole field treatment

Radicle length of seeds exposed to the South Pole fields

Radicle of seedlings exposed to the South Pole field gives the mean of 25.84cm, standard deviation of 25.03 and standard error mean of 2.41 as shown in appendix 4(a). The significance (2-tailed) was 0.80 indicating that exposure did not statistically affect the length of radicle, $p>0.05$, t-test (appendix 4(b)). Fig. 4.7 shows the percent of radicle length as calculated from equation 4.1, as a function of incubation and exposure time for each constant South Pole field treatment. The South Pole field achieved a maximum percent radicle growth of 43% at field strength of 300G exposed for 4.5hrs per day incubated for 72hrs. The South Pole field inhibited elongation by 25% compared to the control at 600G exposed for 6hrs per day measured after 96hrs incubation.

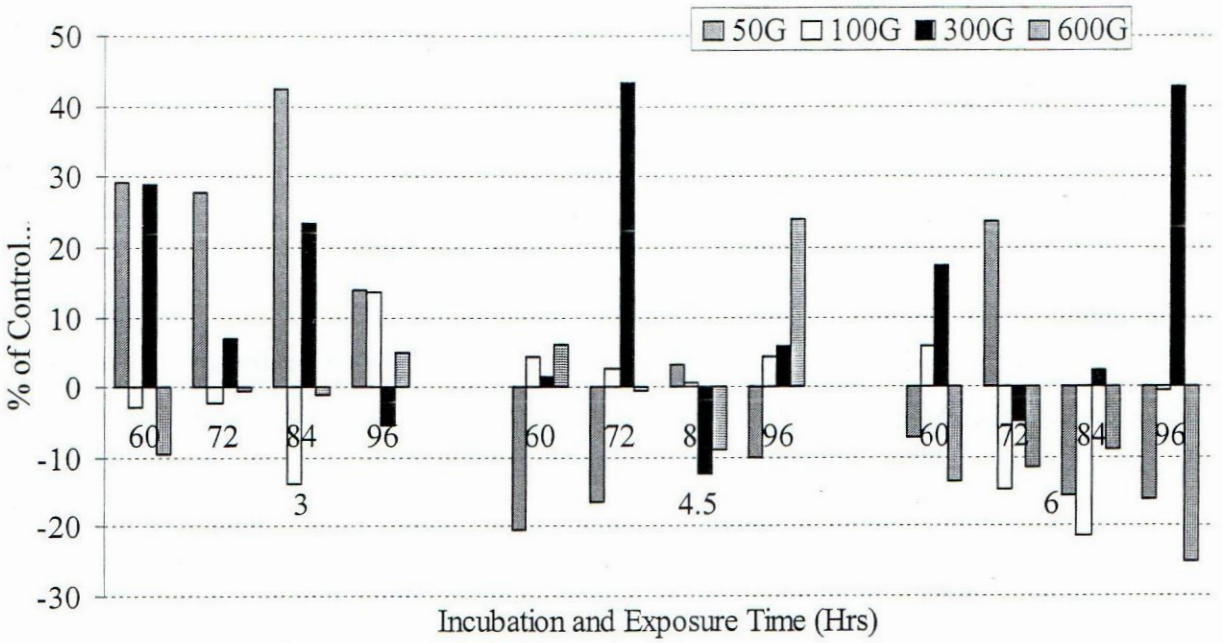


Fig.4.7: The Percentage of the increased radicle length as a function of incubation / exposure time for each constant South Pole field treatment

4.1.1.3 Discussion

Radicle length of bean seeds exposed to DC fields

For 3hrs exposure, the three fields i.e. Helmholtz DC field, North Pole field and South Pole field stimulated faster radicle growth, especially after 60hrs incubation period. The effects of magnetic or electromagnetic plant growth enhancements in root and shoot growth was also observed by Phitke *et al.* (1996), whereas O'Kiely and O'Riordan (1998) observed that magnetically treated water did affect grass growth. Helmholtz DC field and South Pole field inhibited radicle elongation when exposed for 4.5hrs per day whereas as time of exposure was increased, the inhibition by Helmholtz DC field diminished. Inhibition of South Pole field fluctuated until it exhibited characteristics like those of beans not exposed to any field (6hrs exposure, 96hrs incubation). Earlier studies on magnetic field applied to spruce seedlings and chestnut buds grown in tissue culture showed that magnetic field alone had no statistical influence on the growth of plants (Ruzic *et al.*, 1993; Jerman *et al.*, 1998; Ruzic *et al.*, 2000; Gutzeit, 2001; Hasenstein, 2004). When the strength of the field was increased to 100G, the three

fields i.e. Helmholtz DC field, North Pole field and South Pole field stimulated faster radicle growth compared to the control exposed for 3 and 4.5hrs. As exposure time was increased to 6hrs, the Helmholtz DC and South Pole fields started inhibiting radicle elongation as incubation time progressed; it was only the North Pole field that still stimulated faster radicle elongation. Further increase of the field to 300G showed that Helmholtz DC field and South Pole field stimulated faster radicle elongation whereas North Pole field inhibited the elongation. Lawlor and Leahy (1998) noted that seedling of Impatiens, Dahlia and Salvia were much greener when watered with magnetised water compared to similar seedlings watered using college water. No visible difference in colour was apparent between the seedlings of Marigold for either the magnetised or college water treatments. The magnetised water seedlings grew faster. From the observation made by Lawlor and Leahy (1998), and from the results above it is clear that different plants have different DC field strengths where optimum radicle or shoot length elongates.

As exposure time was increased from 3hrs to 4.5hrs, all the three fields (i.e. Helmholtz DC field, North Pole field and South Pole field) encouraged radicle elongation. At 4.5hrs exposure time, as incubation time increased the three fields continued stimulating elongation. When exposure time was increased to 6hrs per day, the North Pole inhibited elongation whereas Helmholtz DC field and South Pole field increased it. The stimulation by Helmholtz DC field surpassed by far that of the South Pole field at 6hrs exposure period. When the field strength was increased to 600G, all the fields encouraged radicle length elongation, although North Pole field surpassed other fields at 3hrs exposure and Helmholtz DC field surpassed others at 4.5hrs exposure time. As exposure time increased to 6hrs, apart from North Pole field, the other field types inhibited elongation as incubation time increased from 24hrs to 96hrs.

DC field experiments were carried out in February, March and April 2006 whereas that of AC fields was carried out during May, June and July 2006. The room temperature and humidity level during the periods account for the difference in radicle elongation. High radicle elongation for seedlings exposed to DC fields was due to field generated by a pair of Helmholtz coil (143%), followed by the seedlings exposed to the North Pole (66%) and finally that one exposed to the South Pole (43%) compared to the control. This is contrary to earlier observation by Segal (2004) where greatest average height of 4.8 cm was recorded for thirty spinach plants exposed to South Pole field, followed by the control with average of 3.9 cm, and finally, the

North Pole field with an average height of 2.3 cm. The difference in observation might be due to the fact that Segal (2004) was measuring shoot length contrary to the radicle length measured in this study.

Comparing the strength of the field that elongates seedlings, 300G achieved maximum elongation of 143% in Helmholtz DC field, as well as a maximum of 66% of control in North Pole field. Furthermore the maximum percent of control for the length of radicle in South Pole was achieved at 300G. The best percent of control achieved at 50G DC field strength was 66% (3hrs exposure and 84hrs incubation time) at North Pole and Helmholtz DC field. Regardless of the field type and incubation / exposure time 100G DC field achieved radicle elongation of less than 20% of control in nearly all the recorded data. Radicle elongated by 40% at field strength of 100G Helmholtz DC field after 6hrs exposure and 96hrs incubation period.

A field strength of 600G did not support radicle elongation as compared to other field strengths, instead it inhibited radicle elongation, regardless of incubation / exposure time. Greatest inhibition to radicle elongation (29%) when exposed to DC fields occurred at field strength of 300G (North Pole field, 6hrs exposure and 84hrs incubation), followed by 600G, which inhibited it by 25% (South Pole field, 6hrs exposure and 96hrs incubation), and finally 600G by 24% (Helmholtz DC field, 6hrs exposure and 84hrs incubation). In all the DC fields, at least once in the three exposure periods 96hrs incubation time achieved maximum radicle elongation compared to the control in that field type. Incubation period of 84hrs achieved more than 50% radicle elongation compared to the control in Helmholtz DC field (3hrs exposure), and in North Pole field (3hrs exposure). At 72hrs incubation achieved more than 50% radicle elongation compared to the control only in a North Pole field (4.5hrs exposure). Inhibition of radicle elongation when exposed to DC field occurred at incubation period of 84hrs.

4.1.2 Length of radicle exposed to AC fields

4.1.2.1 Results

The length of the radicle versus the type of field within a given field exposed for a certain number of hours per day for the alternating current field is shown in table 4.2 and fig. 4.8, 4.9, 4.10 and 4.11.

Table 4.2: Radicle length of seeds exposed to varied AC field strengths at different incubation periods

AC strength	Field	Time of exposure																	
		3HRS						4.5HRS						6HRS					
		Incubation time (hrs)						Incubation time (hrs)						Incubation time (hrs)					
		36	48	60	72	84	96	36	48	60	72	84	96	36	48	60	72	84	96
50 G	HA	0.93	8.40	17.47	37.33	46.03	54.13	1.10	10.43	21.43	42.33	51.80	57.90	1.67	9.27	19.17	41.10	49.33	55.53
	FA	1.60	9.08	18.22	40.08	50.60	59.15	1.37	10.75	21.65	42.68	53.03	59.15	1.25	8.82	19.33	41.42	49.88	57.05
	CA	1.17	9.87	19.50	42.90	52.63	60.63	1.27	11.17	22.77	42.17	51.20	55.43	1.23	8.30	17.20	39.37	49.13	56.50
100G	HA	0.70	8.23	18.80	43.20	51.87	56.07	0.00	5.13	13.63	32.67	44.87	55.30	0.67	6.40	17.67	36.67	46.97	54.43
	FA	1.08	8.42	19.53	44.98	56.05	61.72	0.12	5.03	13.30	32.98	45.90	55.32	0.58	6.88	17.35	37.62	48.02	56.85
	CA	0.50	7.03	16.23	38.10	46.10	52.73	0.00	4.67	12.17	29.63	40.37	52.20	0.80	6.23	15.67	35.40	47.30	54.80
300G	HA	0.73	7.47	15.70	35.33	44.30	50.73	0.90	11.00	25.73	50.27	58.87	67.43	0.70	7.13	16.77	36.63	47.43	57.40
	FA	0.32	7.23	15.82	36.33	46.33	53.50	1.48	12.03	27.40	50.70	59.72	66.12	0.55	7.70	16.62	36.15	47.05	55.97
	CA	0.23	7.23	14.00	31.77	39.70	45.23	1.43	11.57	24.60	47.23	56.67	64.10	0.57	7.33	15.53	32.60	41.97	51.17
600G	HA	0.87	8.47	16.77	35.73	44.87	53.70	2.17	11.37	21.63	43.73	53.57	61.93	1.03	8.43	18.80	40.37	51.43	61.70
	FA	1.47	9.02	18.70	40.00	49.28	57.98	0.85	8.18	17.08	36.48	45.42	52.72	1.28	7.55	17.15	36.15	46.03	55.40
	CA	0.70	9.60	19.17	41.33	51.97	60.47	0.97	7.80	14.73	33.13	41.53	48.67	0.77	7.97	16.63	36.40	46.87	56.60

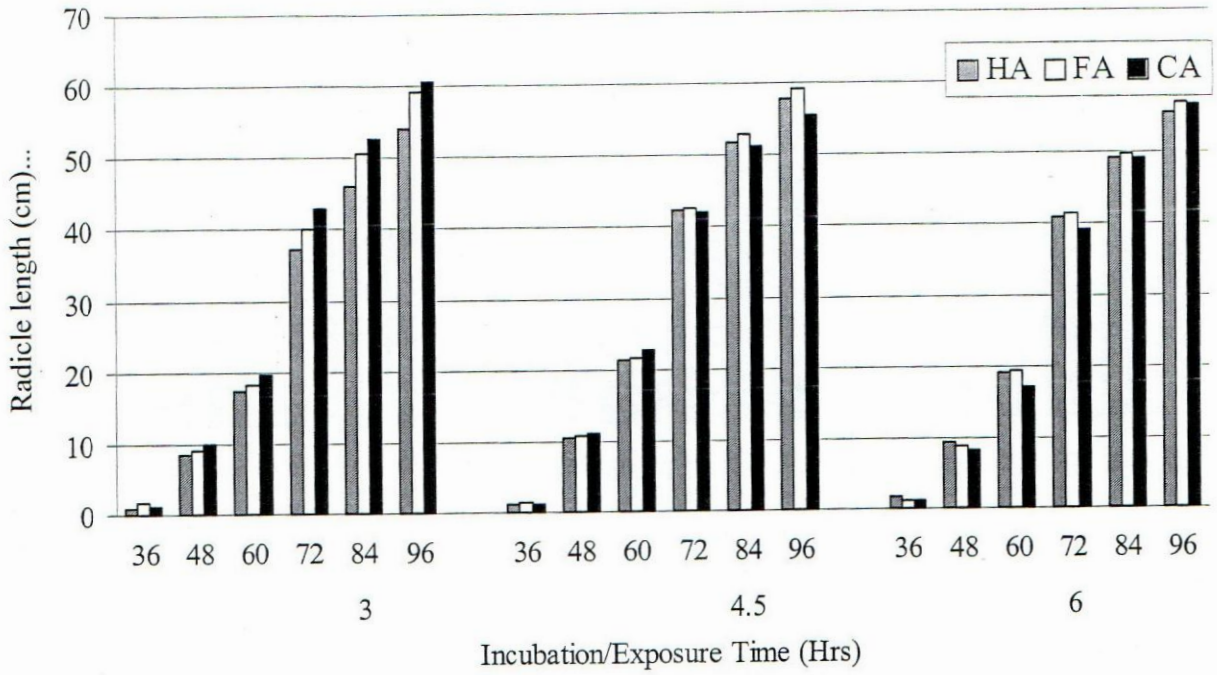


Fig 4.8: Radicle length at varying exposure and incubation time for 50G AC field

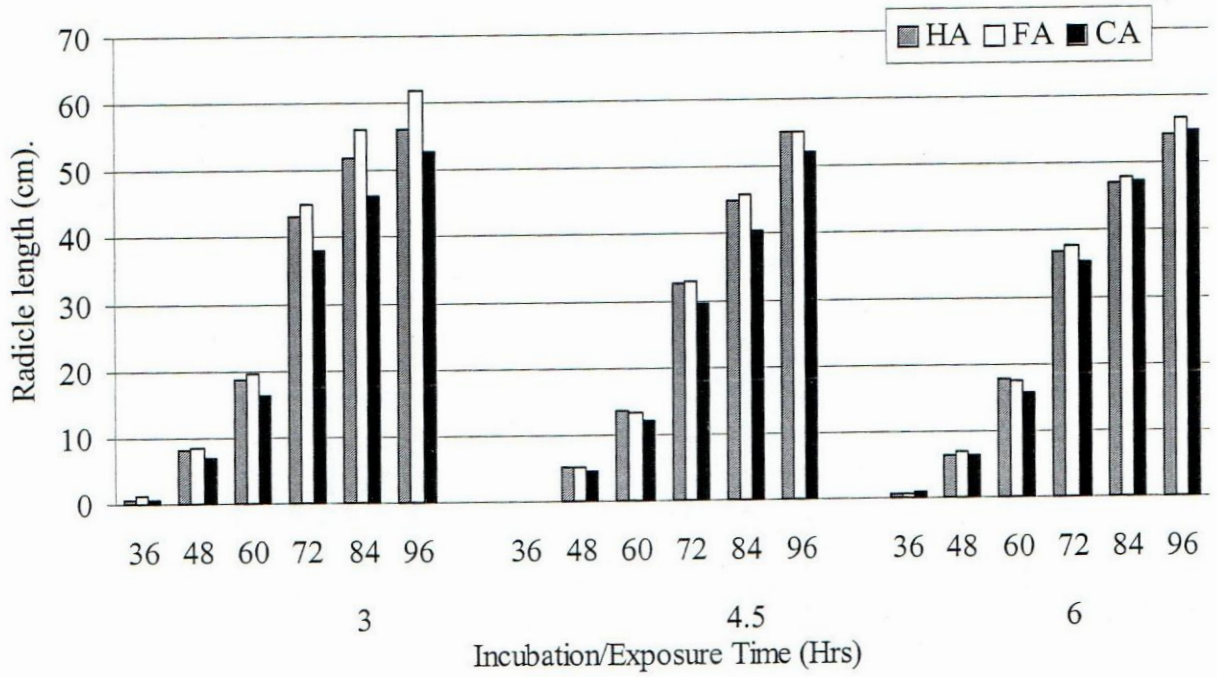


Fig 4.9: Radicle length at varying exposure and incubation time for 100G AC field

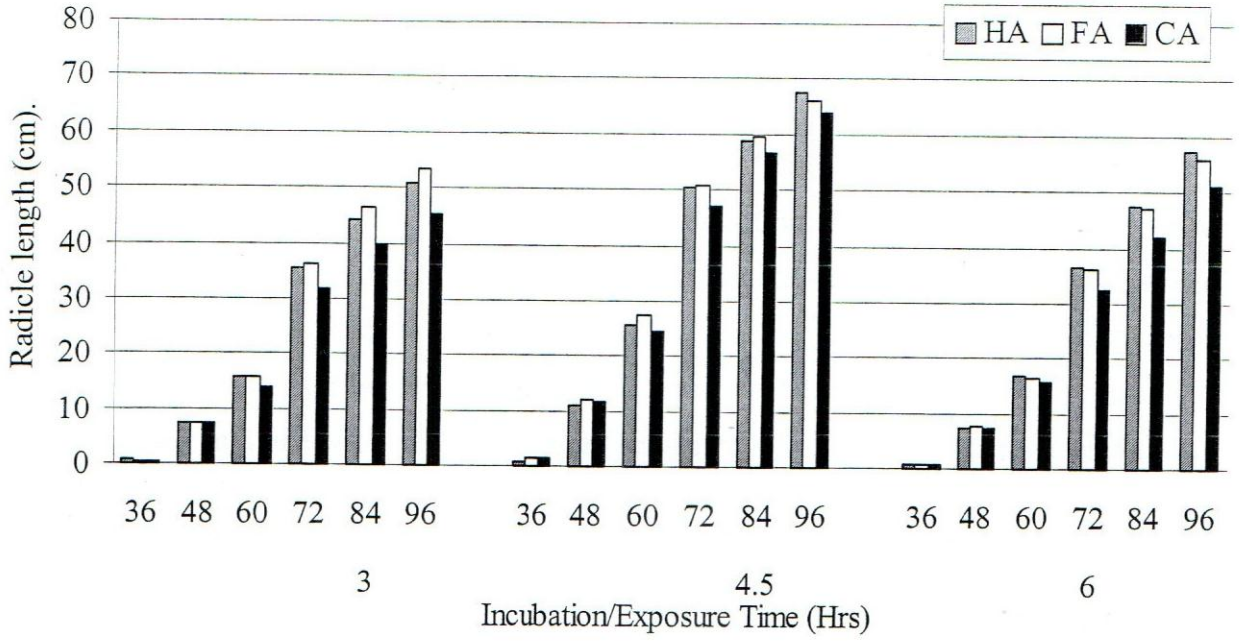


Fig 4.10: Radicle length at varying exposure and incubation time for 300G AC field

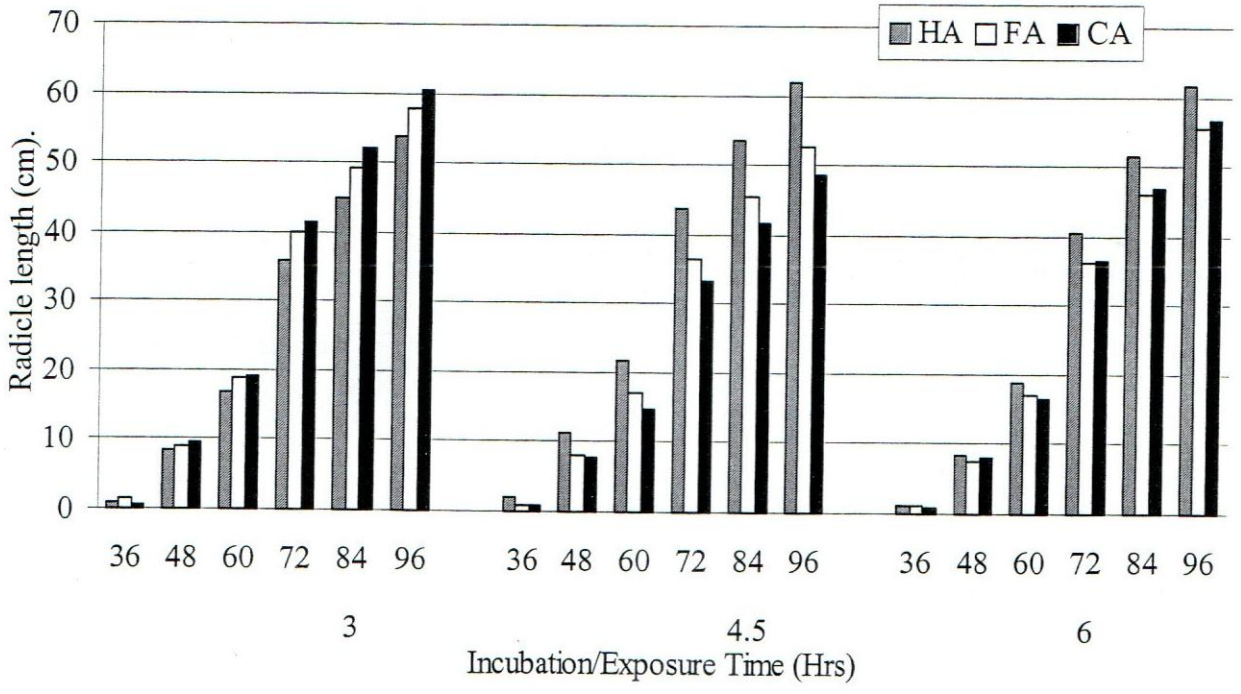


Fig 4.11: Radicle length at varying exposure and incubation time for 600G AC field

4.1.2.2 Data analysis

Radicle length of seeds exposed to the AC fields generated by Helmholtz coil

The descriptive analysis of radicle of bean seedlings exposed to the AC field generated by the Helmholtz coil gives the mean of 6.35cm, standard deviation of 6.75 and standard error mean of 0.65 as shown in appendix 2(a). The length of the radicle exposed to AC field generated by Helmholtz coil was not significantly different from that not exposed, $p>0.05$, t-test (appendix 2(b)). Fig. 4.12 shows the percent of radicle length as calculated from equation 4.1, as a function of incubation and exposure time for each constant AC field treatment generated by the Helmholtz coil. Seeds grown under the AC field achieved maximum percent radicle growth of 47% compared to the control when exposed for 4.5hrs per day at field strength of 600G measured after 60hrs (Fig. 4.12). Field strength of 600G exposed for 3hrs per day inhibited radicle growth by 14% compared to the control after 84hrs of incubation.

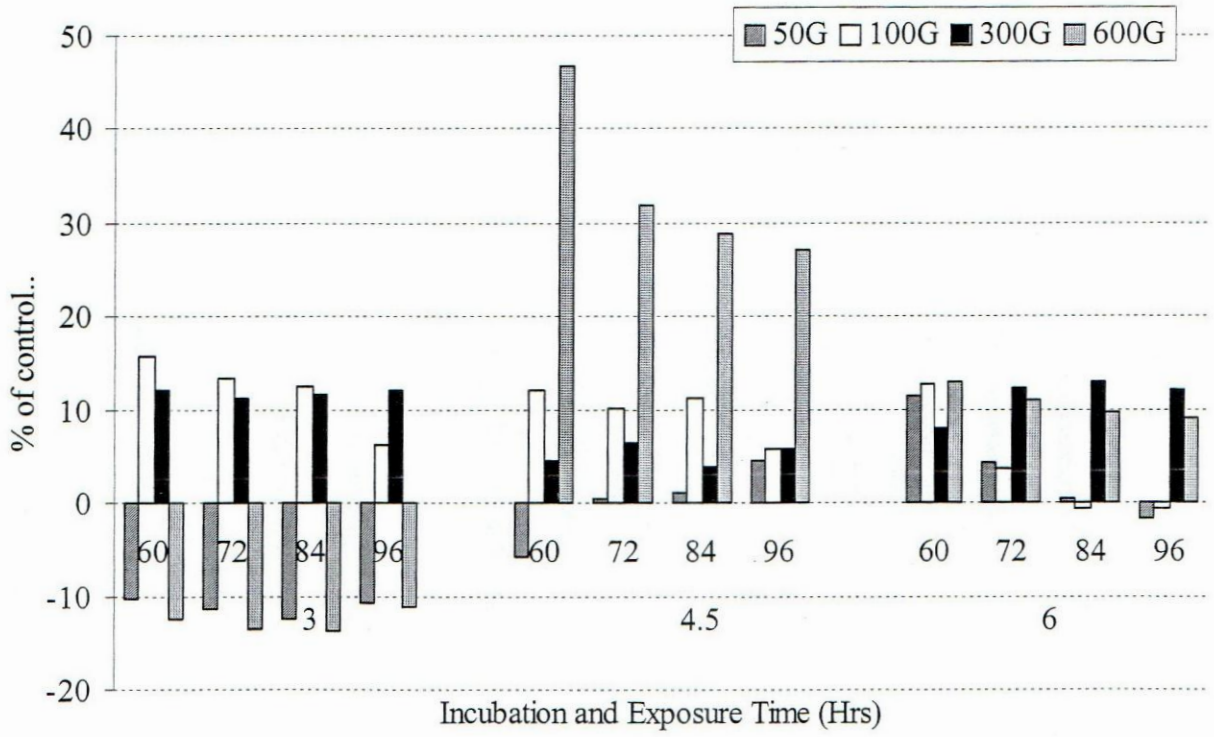


Fig 4.12: The Percentage of the increased radicle length as a function of incubation and exposure time for each constant AC Helmholtz field treatment

Radicle length of seeds exposed to the AC field generated by a solenoid

Seedlings exposed to the AC field generated by the solenoid (FA) had a mean radicle length of 6.40cm compared to the control (CA), standard deviation of 6.79 and standard error mean of 0.65 as shown in appendix 5(a). The length of the radicle exposed to the AC field generated by the solenoid was not significantly different ($p=0.74$) from that not exposed, $p>0.05$, t-test (appendix 5(b)). Fig. 4.13 shows the percentage of the increased radicle length as calculated from equation 4.1, as a function of incubation and exposure time for each constant AC field treatment generated by the solenoid. From Fig. 4.13, the field achieved maximum percent radicle growth of 22% with field strength of 100G exposed for 3hrs per day incubated for 84hrs. The AC field generated by the solenoid inhibited radicle elongation by 7% at field strength of 50G exposed for 3hrs per day when the seedlings were incubated for 72hrs.

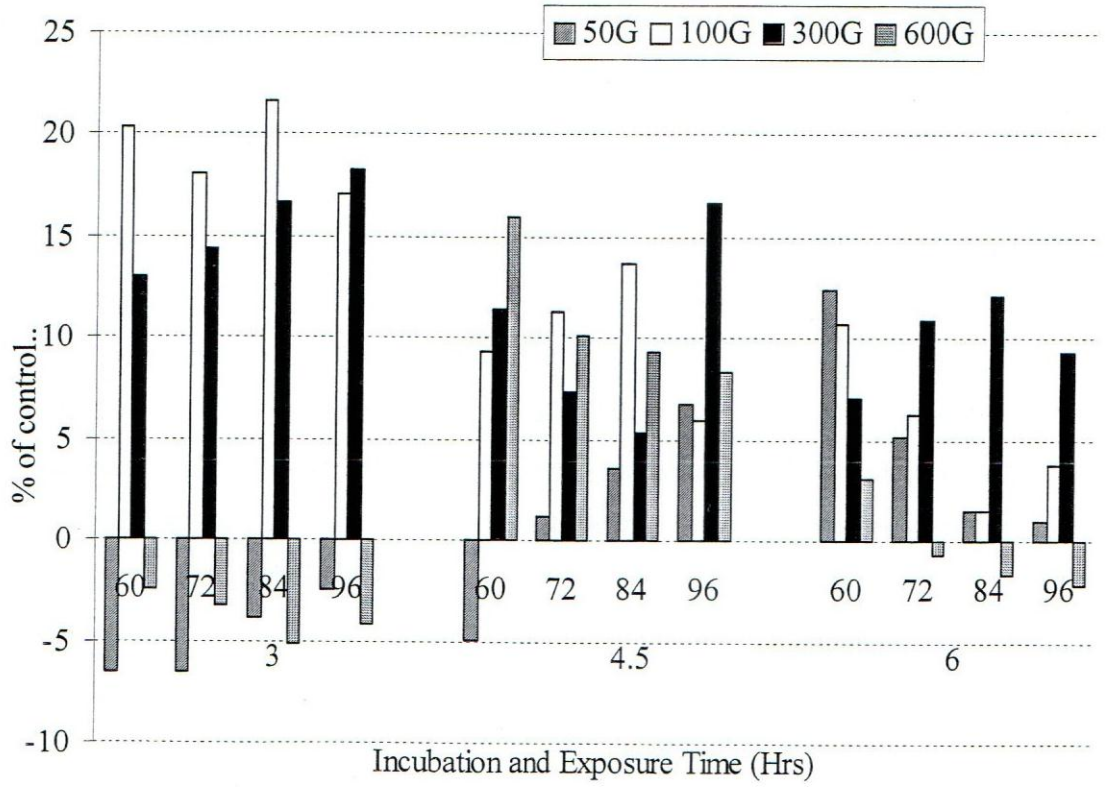


Fig. 4.13: The Percentage of the increased radicle length as a function of incubation and exposure time for each constant AC field generated by a solenoid treatment

4.1.2.3 Discussion

Radicle length of bean seeds exposed to AC fields

There was no significant difference between radicle length of seeds exposed to magnetic field and the control, $p>0.05$, t-test. Field strengths of 50G and 600G exposed for 3hrs inhibited radicle growth. Radicle elongation was stimulated at strength of 600G Helmholtz AC fields exposed for 4.5hrs and 6hrs but was inhibited when exposed for 3hrs throughout the incubation period ranging from 36hrs to 96hrs. AC field's strength of 300G encouraged elongation of the radicle. Remarkable growth was detected when the seedlings were exposed for 4.5hrs per day for the 96hrs incubation period. Cumulative radicle length was highest at 96hrs incubation; 4.5hrs exposure achieved 68cm long. AC field strength of 100G encouraged elongation of radicle at exposure time of 3hrs, with maximum radicle length achieved at 96hrs incubation period. Whereas radicle elongation was inhibited at 50G and 600G AC fields when exposed for 3hrs, the same exposure time realised remarkable change at 100G and 300G. Effects of magnetic or electromagnetic fields in stimulating root and shoot growth was also observed by Phitke *et al.* (1996), whereas O'Kiely and O'Riordan (1998) observed that magnetically treated water did affect grass growth.

Maximum radicle elongation of 47% was observed at 600G when exposed for 4.5hrs. Field strength of 600G inhibited radicle length elongation compared to the control when the seedlings were exposed to the AC field for 3hrs per day. Radicle elongation at this AC field strength occurred at 60hrs incubation period, exposure time of 4.5hrs and 6hrs. This AC field strength achieved maximum percentage radicle elongation at 60hrs incubation, 4.5hrs exposure to Helmholtz coil and subsequently decreased bit by bit as the incubation time increased in each field type. Percent radicle elongation decreased gradually as the incubation time increased progressively at AC field strength of 100G at exposure time of 6hrs in field generated by solenoid and in 3hrs, 4.5hrs and 6hrs exposure for Helmholtz field.

Radicle elongation was inhibited at 50G in case of Helmholtz AC field. At this field strength and 3hrs exposure, as incubation period increased from 60hrs onwards, maximum inhibition of approximately 13% of control was achieved after 84hrs. This inhibition decreased as incubation time reached 96hrs. A further decrease in inhibition was noted when exposure time was increased to 4.5hrs incubated for 60hrs. As incubation time increased from 60hrs to 96hrs,

inhibition effect of 50G AC Helmholtz field diminished and a steady positive elongation in comparison to the control was noted. This steady increase was observed through the increasing incubation time and achieved its maximum percent elongation of approximately 11% at 6hrs exposure, incubated for 60hrs. As incubation time increased from its peak at 60hrs, radicle elongation decreased steadily such that at an incubation period of 96hrs, radicle elongation was inhibited at 6hrs exposure. The same trend was noted for 50G AC field generated by the solenoid achieving maximum percent inhibition of 7% compared to the control at 3hrs exposure, 72hrs incubation period, while achieving maximum elongation of approximately 13% compared to the control at 6hrs exposure, 60hrs incubation.

In comparing Helmholtz AC field to the AC field generated by the solenoid based on how they stimulated radicle elongation as compared to the control, Helmholtz AC field achieved the first four highest percentages of 47%, 32%, 28% and 27%. AC field generated by the solenoid achieved highest percent of 22% followed by 20% of the control of the radicle length. The incubation time that achieved maximum radicle elongation was 60hrs. As the incubation period increased, the percent compared to control decreased. This trend was observed at all exposure times of AC Helmholtz field. It was not easy to identify the exposure time that encouraged faster radicle elongation probably due to using large intervals for the measured parameters i.e. time and field strength. Helmholtz AC field achieved highest peak at 4.5hrs exposure followed by 6hrs exposure, whereas 3hrs exposure achieved both positive and negative percentages. Maximum positive percent change of 22% and maximum inhibition of 7% occurred at 3hrs exposure in case of AC field generated by a solenoid. Jones *et al.*, (1986) noted a significant increase in plant growth hormone indicators Phenylalanine Ammonia-lyase (PAL) in beans and potatoes, whereas Krizaj and Valencic (1989) noted that water cress (*Lepidium sativum*) roots elongated when exposed to magnetically treated water. The plant growth hormone indicators Phenylalanine Ammonia-lyase stimulates faster cell elongation and consequently may account for the observed difference in length of radicle of bean seeds exposed to magnetic fields and the control.

4.2 Bean Seed Germination

4.2.1 Germination of bean seeds exposed to DC fields

4.2.1.1 Results

The percent germination has been considered between 24 and 48 hrs incubation period because this marks the onset of germination and beyond this period 100% germination. The number of germinated seeds for the different fields; strength and exposure time is shown in table 4.3 and figures 4.14, 4.15, 4.16 and 4.17.

Table 4.3: Percent germinated bean seeds exposed to varied DC field strengths at different incubation and exposure time

	3HRS EXPOSURE				4.5HRS EXPOSURE				6HRS EXPOSURE			
	Field	Incubation (hrs)			Field	Incubation (hrs)			Field	Incubation (hrs)		
Strength		24	36	48		24	36	48		24	36	48
50G	HA	46.67	90.00	96.67	HA	26.67	93.33	96.67	HA	60.00	100.00	100.00
	NA	53.33	86.67	96.67	NA	20.00	96.67	96.67	NA	46.67	96.67	100.00
	SA	56.67	100.00	100.00	SA	16.67	86.67	100.00	SA	50.00	90.00	100.00
	CA	56.67	96.67	96.67	CA	23.33	96.67	96.67	CA	40.00	100.00	100.00
100G	HA	0.00	20.00	70.00	HA	70.00	100.00	100.00	HA	3.33	43.33	86.67
	NA	3.33	43.33	86.67	NA	66.67	96.67	96.67	NA	6.67	53.33	80.00
	SA	0.00	26.67	76.67	SA	76.67	100.00	100.00	SA	6.67	50.00	90.00
	CA	0.00	6.67	70.00	CA	63.33	100.00	100.00	CA	10.00	50.00	80.00
300G	HA	30.00	93.33	96.67	HA	73.33	100.00	100.00	HA	23.33	80.00	100.00
	NA	30.00	76.67	100.00	NA	70.00	100.00	100.00	NA	30.00	60.00	96.67
	SA	26.67	73.33	100.00	SA	76.67	100.00	100.00	SA	10.00	76.67	100.00
	CA	43.33	93.33	100.00	CA	76.67	93.33	100.00	CA	6.67	36.67	100.00
600G	HA	56.67	90.00	100.00	HA	63.33	86.67	96.67	HA	20.00	96.67	100.00
	NA	56.67	90.00	96.67	NA	53.33	90.00	96.67	NA	36.67	96.67	100.00
	SA	53.33	80.00	93.33	SA	56.67	96.67	100.00	SA	33.33	93.33	96.67
	CA	43.33	90.00	93.33	CA	60.00	96.67	100.00	CA	20.00	96.67	100.00

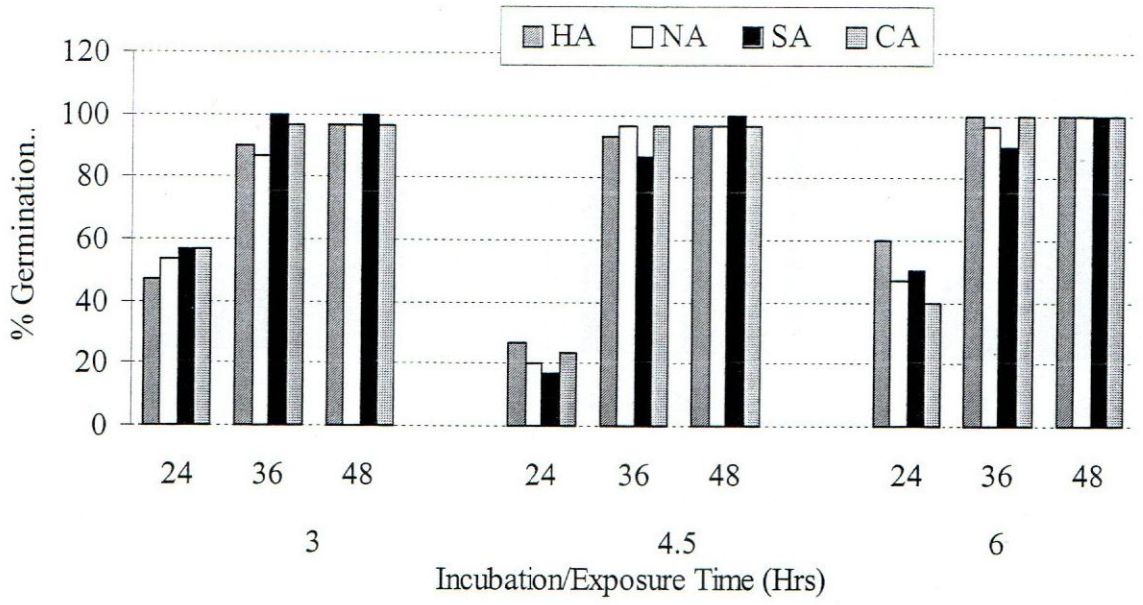


Fig 4.14: The Percentage of the increased germinated seeds at varying incubation and exposure times for 50G DC field

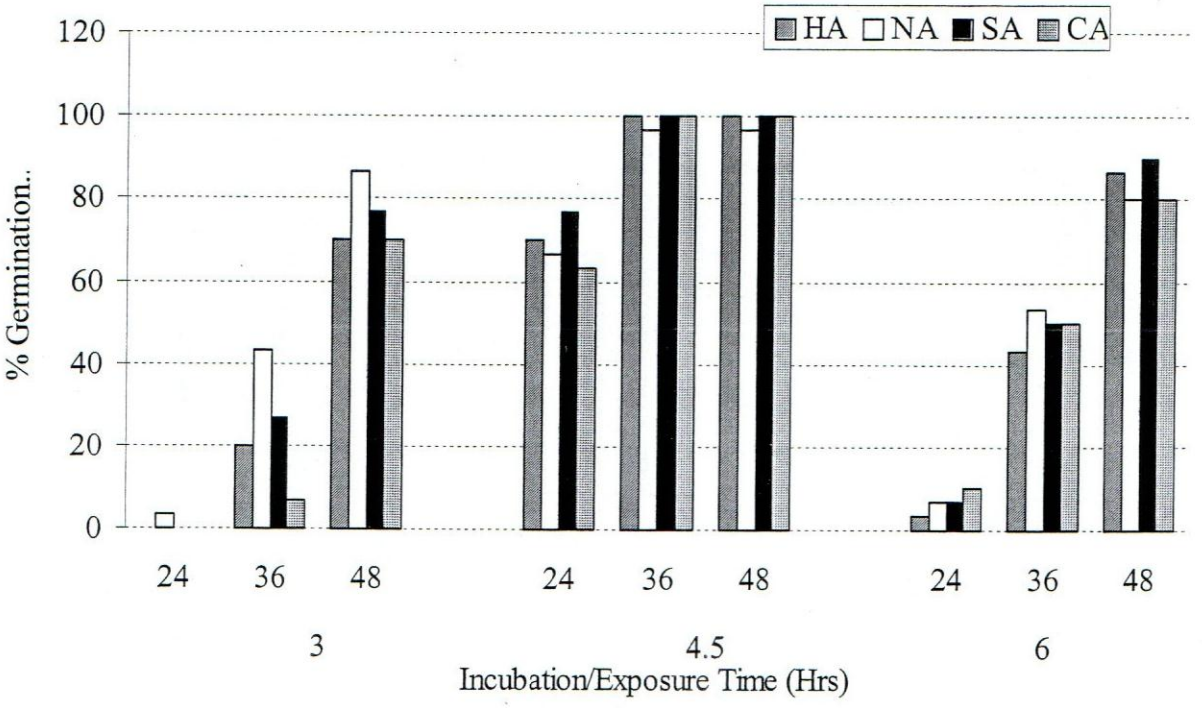


Fig 4.15: The Percentage of the increased germinated seeds at varying incubation and exposure times for 100G DC field

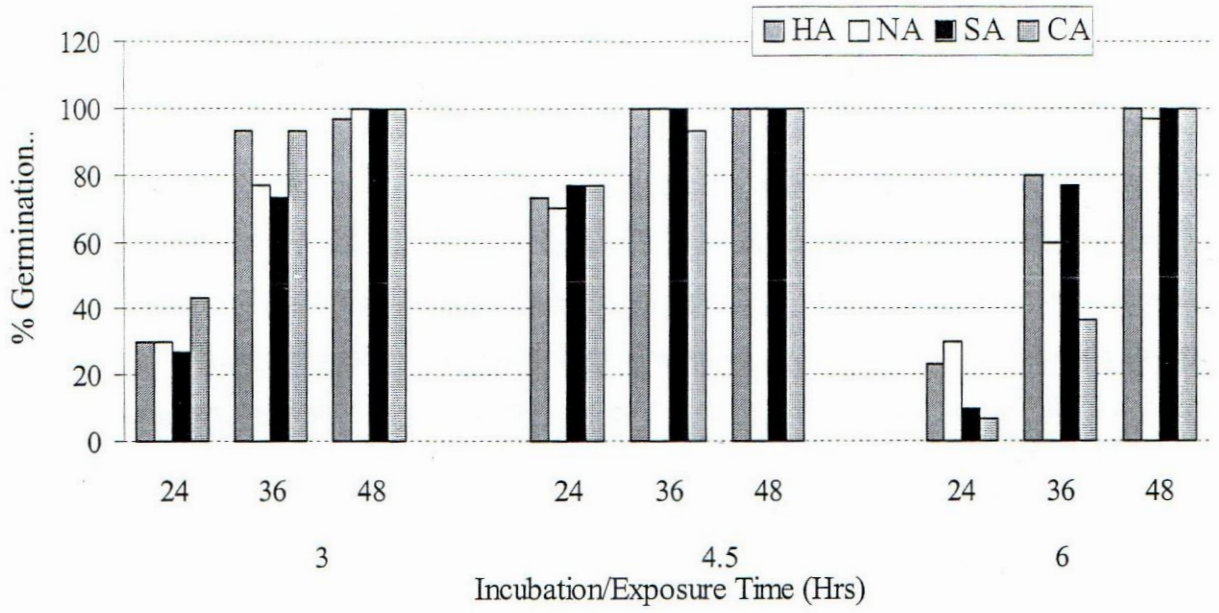


Fig 4.16: The Percentage of the increased germinated seeds at varying incubation and exposure times for 300G DC field

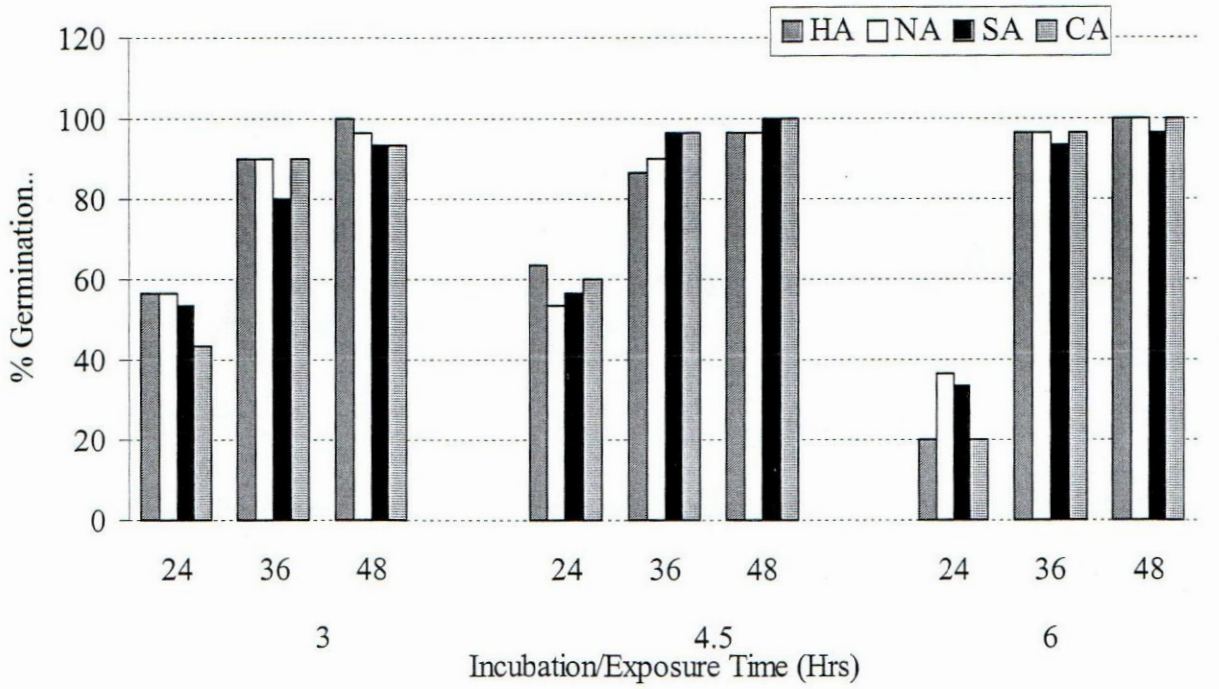


Fig 4.17: The Percentage of the increased germinated seeds at varying incubation and exposure times for 600G DC field

4.2.1.2 Data analysis

Germination of bean seeds exposed to DC fields generated by Helmholtz coil

The descriptive analysis of the germination rate of seeds exposed to the DC field had a mean of 68.48cm, standard deviation of 42.75 and standard error mean of 4.11 as shown in appendix 6(a). Germination rate of the exposed seeds was not significantly different from the control, $p>0.05$, t-test (appendix 6(b)). Fig. 4.18 shows the percent of germination rate of seeds as calculated based on equation 4.1, as a function of incubation and exposure time for each constant DC field treatment generated by the Helmholtz coil. Seeds grown under the DC field achieved maximum percent germination of 243% compared to the control when exposed for 6hrs per day at field strength of 300G measured after 24hrs incubation period (Fig 4.18). Exposure of seeds to field strength of 100G for 6hrs per day inhibited germination by 67% when incubated for 24hrs.

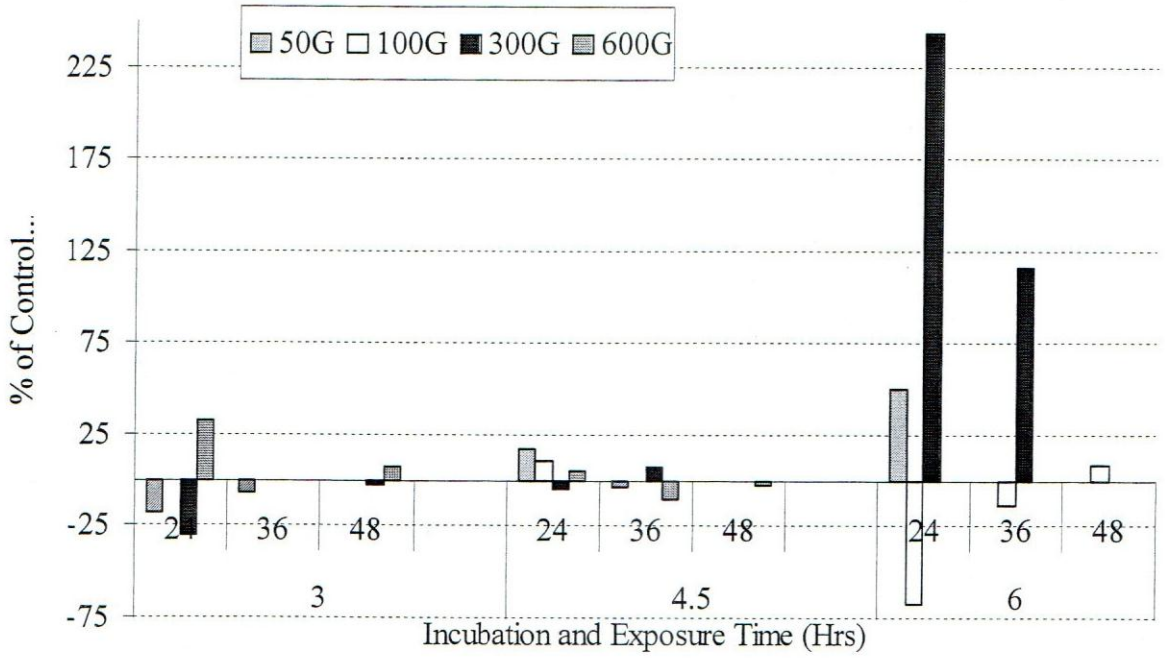


Fig. 4.18: The Percentage of the increased germinated bean seeds as a function of incubation and exposure time for each constant DC field generated by a Helmholtz coil

Germination of bean seeds exposed to the North Pole field

The North Pole field (NA) had the following descriptive statistics compared to the control (CA); mean of 68.24cm, standard deviation of 42.04 and standard error mean of 4.05 as shown in appendix 8(a). The germination rate of seeds exposed to the North Pole field was not

significantly different (p=0.92) from that not exposed, p>0.05, t-test (appendix 8(b)). Fig. 4.19 shows the percent of germinating seeds as calculated from equation 4.1, as a function of incubation and exposure time for each constant North Pole field. Seeds exposed achieved maximum percent germination of 348% compared to the control at field strength of 300G exposed for 6hrs per day when incubated for 24hrs. Germination was inhibited by 33% at field strength of 100G exposed for 6hrs per day when incubated for 24hrs.

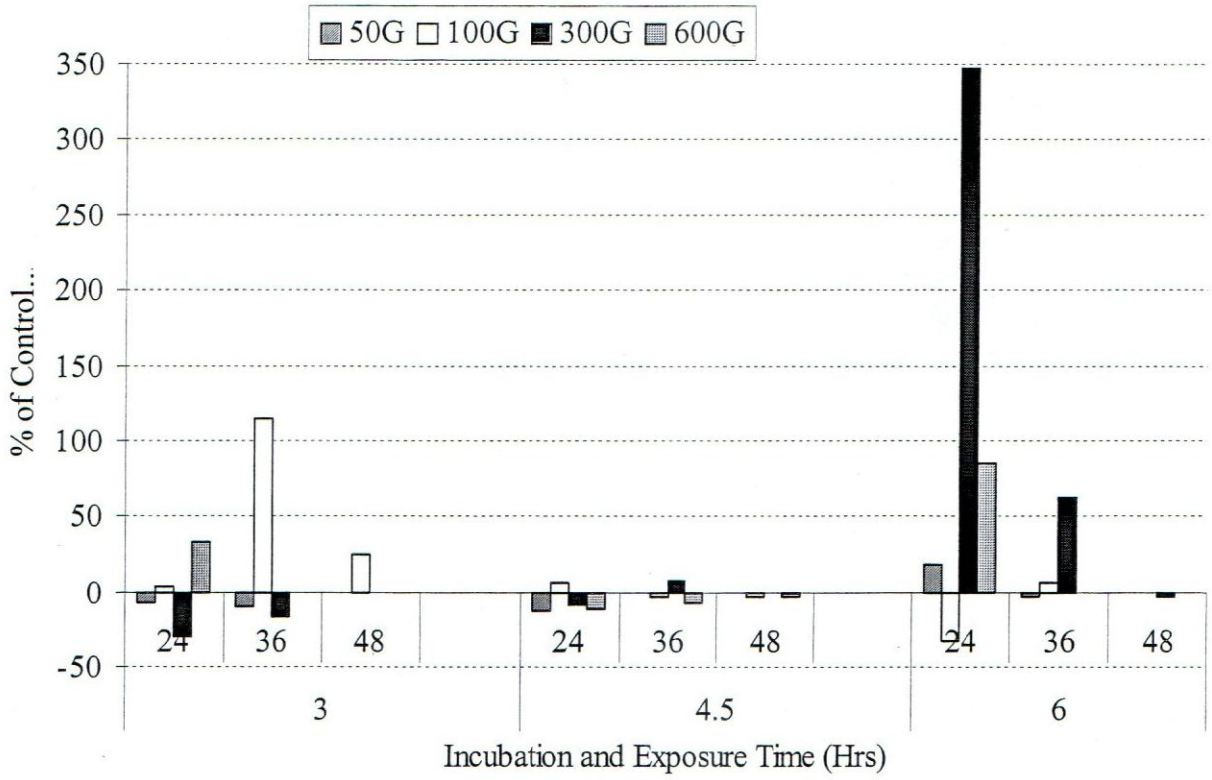


Fig 4.19: The Percentage of the increased germinated bean seeds as a function of incubation and exposure time for each constant North Pole field

Germination of bean seeds exposed to the South Pole fields

The germination rate of seeds exposed to the South Pole field (SA) compared to the control (CA), had a mean of 68.42, standard deviation of 42.75 and standard error mean of 4.11 as shown in appendix 9(a). The germination rate of seeds exposed to the North Pole field was not significantly different (p=0.90) from that not exposed, p>0.05, t-test (appendix 9(b)). Fig. 4.20 shows the percent of germinating seeds as calculated based on equation 4.1, as a function of

incubation and exposure time for each constant South Pole field. Seeds exposed to this field achieved maximum percent germination of 108% compared to the control at field strength of 300G exposed for 6hrs per day when incubated for 36hrs. Germination was inhibited by 37% at field strength of 300G exposed for 3hrs per day when incubated for 24hrs.

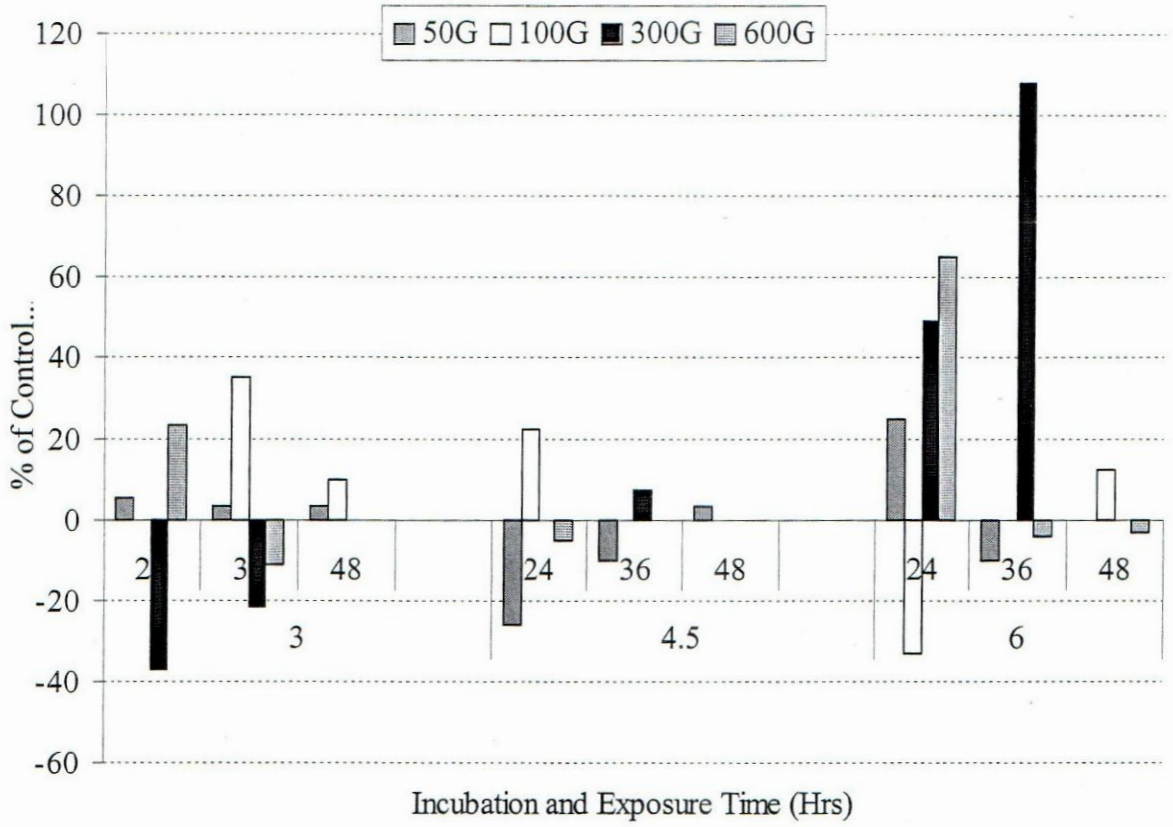


Fig. 4.20: Percent of germinating bean seeds as a function of incubation and exposure time for each constant South pole field treatment

4.2.1.3 Discussion

Germination of bean seeds exposed to DC fields

At 3hrs exposure, Helmholtz DC field, North Pole and South Pole fields all inhibited germination. O'Kiely and O'Riordan (1998) made similar observation when they noted that magnetically activated water did not affect germination of grass seed. As exposure time increased to 4.5hrs, inhibition reduced and when exposure was increased to 6hrs all the fields stimulated faster germination of seeds when incubated for 24hrs. Field strength of 100G stimulated faster seed germination when exposed for 3hrs and 4.5hrs. A further increase of the

exposure time to 6hrs inhibited seed germination when incubated for 24 and 36 hours, except for North Pole field incubated for 36hrs.

As incubation time increased from 36hrs to 48hrs for the case of 6hrs exposure, there was faster germination as compared to control for Helmholtz DC field and South Pole field. When the DC field was increased to 300G, germination inhibition was noted at 3hrs and 4.5hrs exposure incubated for 24hrs. However, at 6hrs exposure incubated for 24hrs, faster germination as compared to the control was noted in all the fields. An increase of the DC field to 600G at an incubation period of 24hrs and exposure time of 3hrs for the three fields (i.e. North Pole, South Pole and Helmholtz DC field) stimulated faster seed germination at the same incubation period. Phitke *et al.* (1996) made similar observations, when they noted that as the strength of magnetic field was increased, germination of grass seed was accelerated. At an exposure time of 6hrs, North Pole and South Pole fields encouraged faster germination whereas Helmholtz DC had no effect on the germination. Exposure to Helmholtz coil for 4.5hrs and 24hrs incubation supported faster germination whereas the North Pole and South Pole fields inhibited germination. Carbonell *et al.* (2000) had a contradictory observation in that a stimulatory effect was noted when seeds were exposed to the South Pole and North Pole magnetic fields in comparison to the control. In DC fields, the trend showed that when seeds were exposed for a long period (in this case 6hrs) at field strength of 300G, regardless of incubation time, maximum seed germination is achieved. Considering the case of seeds exposed to DC field generated by the Helmholtz coil, North Pole field and South Pole field, seeds achieved maximum germination percent of 243%, 348% and 108% when incubated for 24, 24 and 36hrs respectively. Maximum percent germination occurred at incubation period of 24hrs for the case of DC fields. Other incubation periods achieved less than 120% germination compared to the control.

In comparing the type of field that stimulate faster seed germination, North pole field achieved maximum seed germination of 348% compared to control followed by Helmholtz DC field achieving 243%, 115% by North Pole and 108% of control by South Pole. Comparing the strength of DC fields in order of how fast bean seeds germinated; 300G stimulated germination of bean seeds more than other strengths of DC fields. The highest percent germination of 348% occurred at 300G of North Pole field whereas 243% and 115% were induced by 300G of Helmholtz and 100G of North Pole fields respectively. The fastest germination for DC field (whether Helmholtz DC, North or South Pole field) occurred at field strength of 300G. In terms

of exposure time it was noted that maximum germination of bean seeds occurred at 6hrs exposure time. Apart from North Pole field with 115% germination (100G, 3hrs exposure, 36hrs incubation), the rest of the exposures at 3hrs and 4.5hrs did not achieve more than 50% germination compared to the control and this did not depend on the type of field.

4.2.2 Germination of bean seeds exposed to AC fields

4.2.2.1 Results

The percent germination was considered between 24 and 48 hrs incubation times because this marks the onset of germination and beyond this period 100% germination. The number of germinated seeds versus the type of field within a given field exposed for a certain number of hours per day for the alternating current field is shown in table 4.4 and figures 4.21, 4.22, 4.23 and 4.24.

Table 4.4: The Percentage of the increased germinated seeds after exposure to AC field of varying strengths

Strength	Field Type	Time of exposure (hrs)								
		3			4.5			6		
		Incubation time (hrs)			Incubation time (hrs)			Incubation time (hrs)		
		24	36	48	24	36	48	24	36	48
50G	HA	26.7	96.7	100.0	33.3	93.3	100.0	46.7	93.3	96.7
	FA	46.7	100.0	100.0	43.3	100.0	100.0	40.0	100.0	100.0
	CA	36.7	100.0	100.0	40.0	100.0	100.0	33.3	96.7	100.0
100G	HA	26.7	100.0	100.0	0.0	96.7	100.0	20.0	90.0	96.7
	FA	33.3	96.7	100.0	6.7	100.0	100.0	23.3	100.0	100.0
	CA	13.3	83.3	96.7	0.0	93.3	96.7	23.3	96.7	100.0
300G	HA	26.7	100.0	100.0	26.7	96.7	100.0	20.0	96.7	70.0
	FA	13.3	100.0	100.0	40.0	100.0	100.0	20.0	96.7	100.0
	CA	10.0	100.0	100.0	30.0	93.3	96.7	13.3	93.3	100.0
600G	HA	20.0	90.0	93.3	53.3	93.3	96.7	30.0	100.0	100.0
	FA	33.3	93.3	100.0	26.7	96.7	100.0	36.7	93.3	100.0
	CA	20.0	100.0	100.0	20.0	93.3	93.3	33.3	100.0	100.0

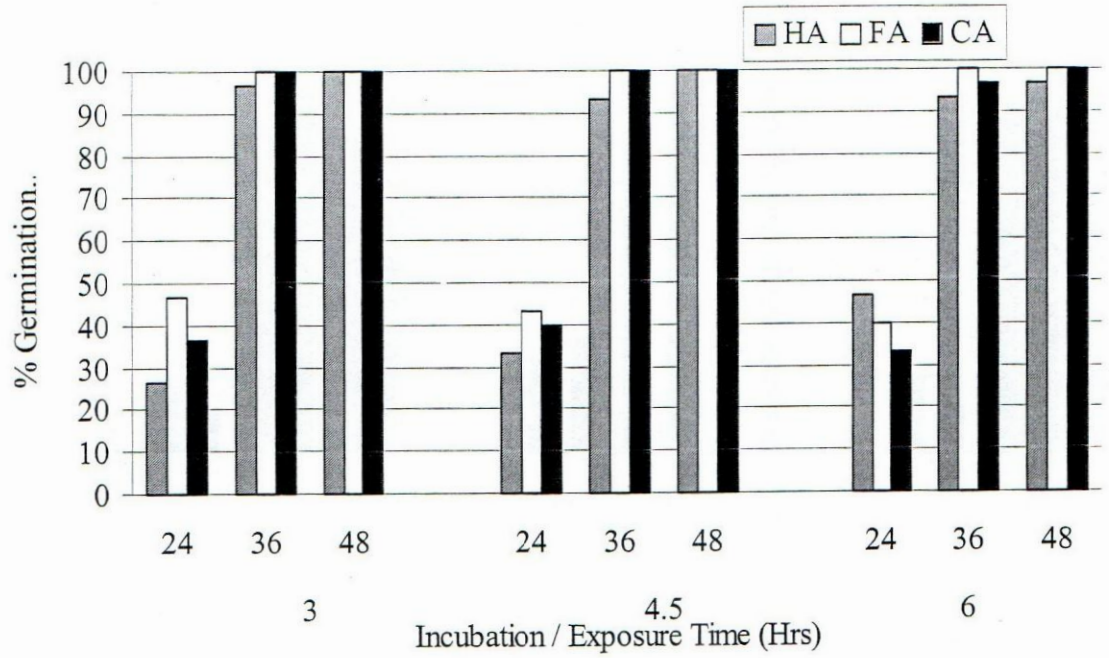


Fig 4.21: The Percentage of the increased germination at varying incubation and exposure time for 50G AC field

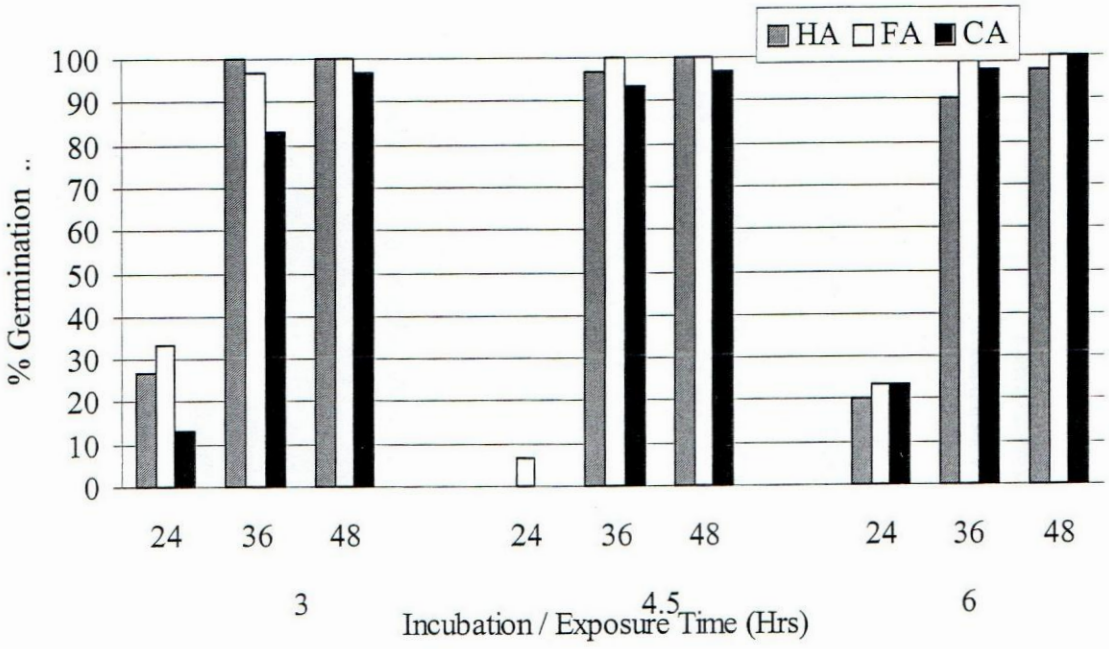


Fig 4.22: The Percentage of the increased germination at varying incubation and exposure time for 100G AC field

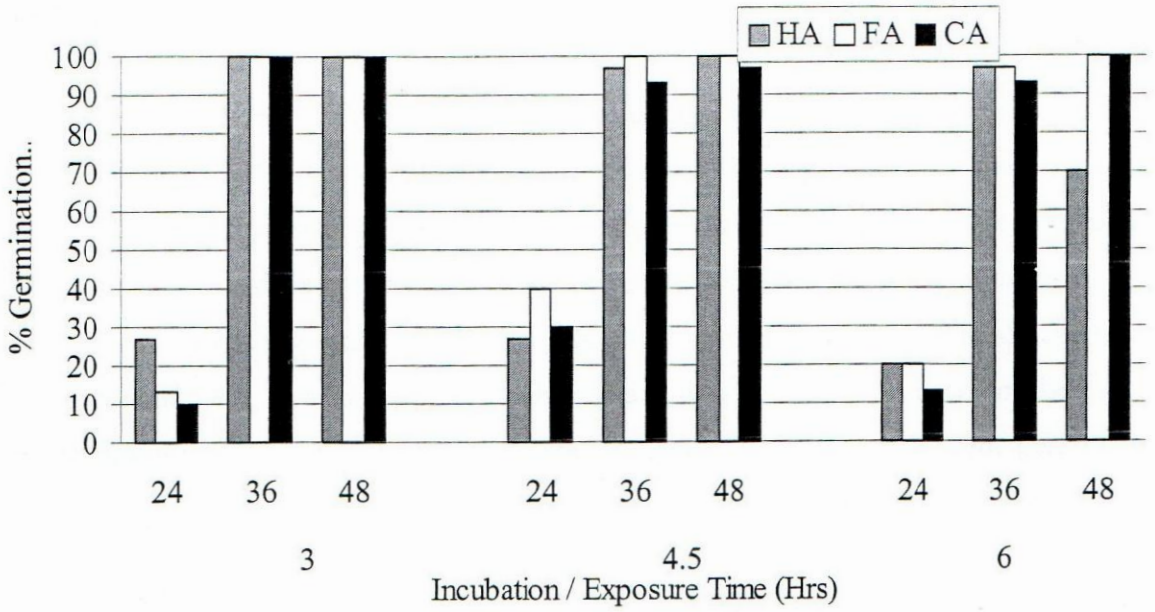


Fig 4.23: The Percentage of the increased germination at varying incubation and exposure time for 300G AC field

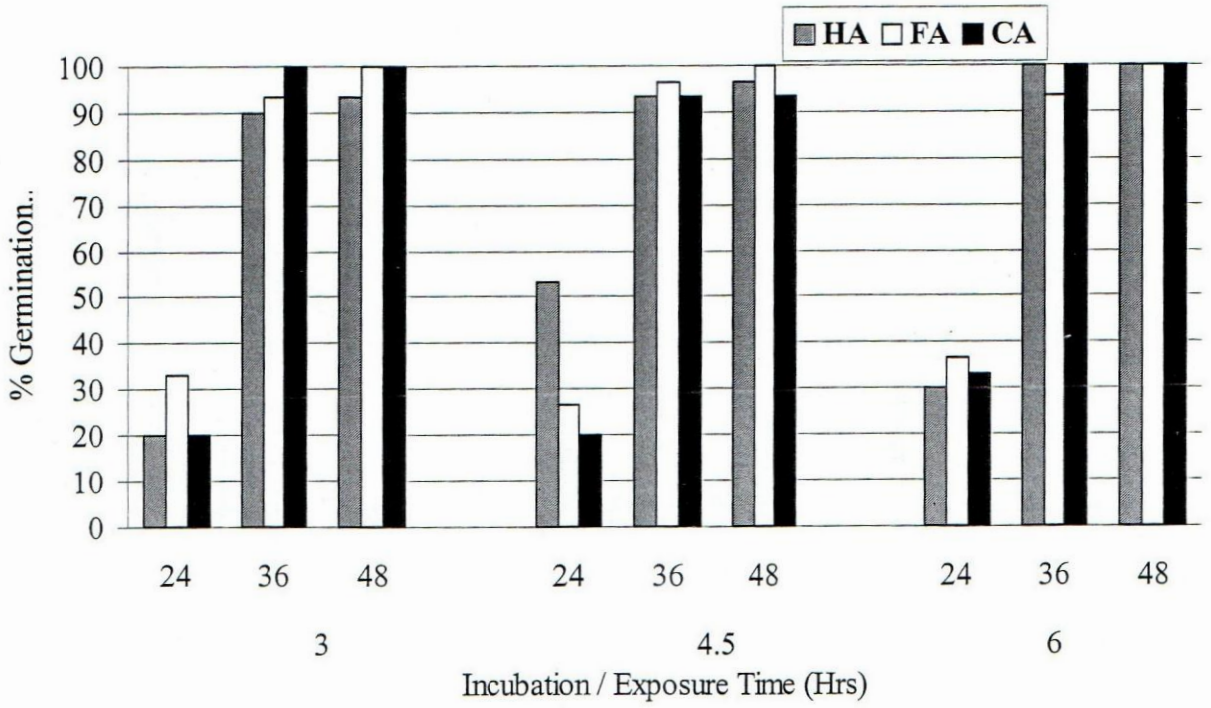


Fig 4.24: The Percentage of the increased germination at varying incubation and exposure time for 600G AC field

4.2.2.2 Data analysis

Germination of bean seeds exposed to AC fields generated by Helmholtz coil

A total of 108 bean seeds were considered for the control and an equal number exposed to the AC field generated by the Helmholtz coil. The mean of 69.01% germination, standard deviation of 43.42 and standard error mean of 4.18 as shown in appendix 7(a) were obtained. The germination rate of seeds was not significantly different ($p=0.93$) from that not exposed, $p>0.05$, t-test (appendix 7(b)). Fig. 4.25 shows the percent of germination rate of seeds as calculated basing on equation 4.1, as a function of incubation and exposure time for each constant AC field treatment. Seeds grown under the magnetic fields achieved maximum percent germination of 167% when exposed for 4.5hrs per day at field strength of 600G measured after 24hrs incubation period. Likewise the same percent change was also achieved at field strength of 300G when exposed for 3hrs and incubated for 24hrs (Fig. 4.25). A field strength of 50G exposed for 3hrs per day inhibited seed germination by 27% when incubated for 24hrs.

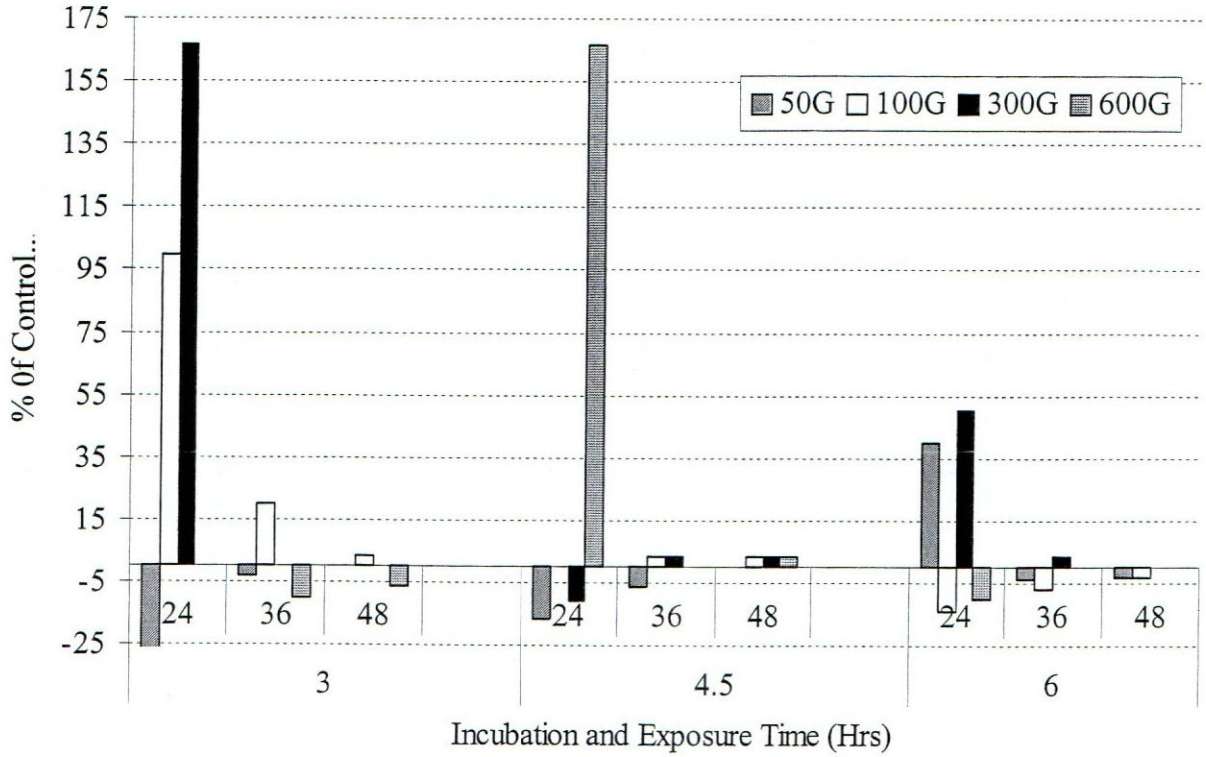


Fig. 4.25: The Percentage of the increased germinated bean seeds as a function of incubation and exposure time for each constant AC field generated by Helmholtz coil

Germination of bean seeds exposed to the AC field generated by the solenoid

The descriptive analysis of the germination rate of seeds exposed to the AC field generated by the solenoid (FA) had a mean of 69.81%, standard deviation of 43.43 and standard error mean of 4.18 as shown in appendix 10(a). The germination rate of seeds exposed to the AC field was not significantly different ($p=0.82$) from that not exposed, $p>0.05$, t-test (appendix 10(b)). Figure 4.26 shows the percent of germinating seeds as calculated basing on equation 4.1, as a function of incubation and exposure time for each constant AC field treatment. From this figure, the AC field achieved maximum percent germination of 150% with field strength of 100G exposed for 3hrs per day when incubated for 24hrs. The AC field inhibited germination by 7% at field strength of 600G exposed for 3hrs per day when the seedlings were incubated for 36hrs.

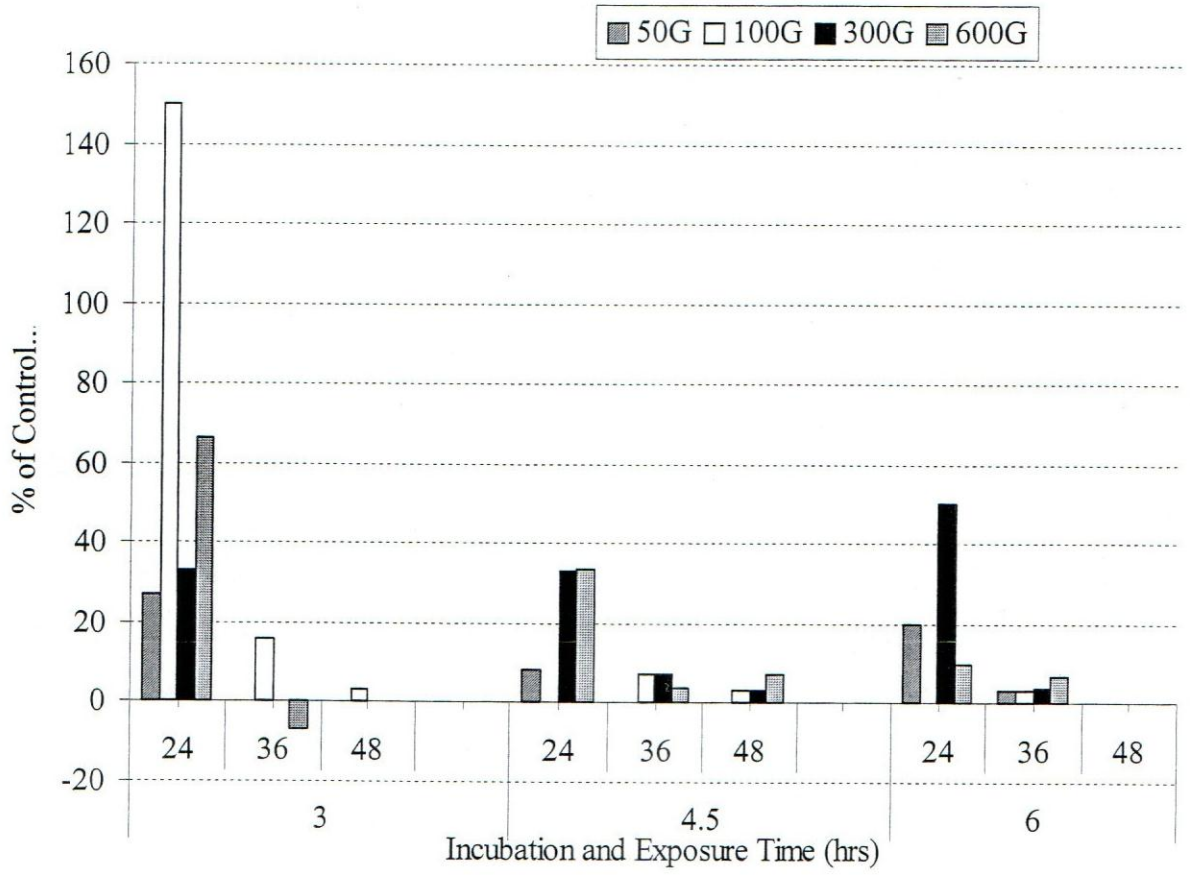


Fig. 4.26: The Percentage of the increased germinated bean seeds as a function of incubation and exposure time for each constant AC field generated by the solenoid treatment

4.2.2.3 Discussion

The rate of germination was compared at incubation period ranging from 24hrs and 48hrs. This period marks the onset of germination and beyond this period marks 100% germination of the beans hence comparing them at this range gives a fair comparison.

Germination of bean seeds exposed to AC fields

At 50G, the field produced by solenoid (FA) encouraged germination when seeds were exposed for 3hrs and 4.5hrs at an incubation period of 24hrs after inception of the experiment. At the same field strength and incubation period, Helmholtz AC field inhibited germination. At higher exposure period i.e. 6hrs per day, both AC fields (i.e. Helmholtz and solenoid) induced a higher percent germination as compared to control incubated for 24hrs. A remarkable change in germination was noted at 100G AC field, 4.5hrs exposure incubated for 24hrs. In this case seeds not exposed to any field and those exposed to field generated by Helmholtz coil had not started germinating whereas the field generated by solenoid recorded a noted increase in germination of approximately 7%. In this case, 3hrs and 4.5hrs exposure encouraged germination of seeds whereas 6hrs exposure inhibited germination at 100G Helmholtz AC field at 24hrs incubation period. When the bean seeds were exposed to 300G AC field, Helmholtz fields stimulated germination of bean seedlings at 3hrs and 6hrs exposure whereas at 4.5hrs exposure it inhibited germination when incubated for 24hrs.

Maximum germination of more than 40% was achieved when seeds were incubated for 24hrs after exposure to 300G AC field generated by the solenoid for 4.5hrs. Phitke *et al.* (1996) made contrary observations, when they noted that as the strength of magnetic field increased, the germination of grass seed was accelerated. It was realized that seeds incubated for 24hrs, achieved maximum percent germination of approximately 58% when exposed to Helmholtz AC field for 4.5hrs. At 3hrs exposure a field produced by solenoid achieved a higher percent germination than the control. For 6hrs exposure, it is clear that a field generated by Helmholtz coil inhibited germination when incubated for 24hrs. Seeds germinated under AC fields also achieved highest percent germination of 167% and 150% when incubated for 24hrs after exposure for 3 and 4.5hrs respectively. As the incubation time increased from 24hrs to 36hrs and finally 48hrs, the percent germination decreased as compared to control. The exposure time that

induced maximum germination for the AC field as compared to control was 3hrs and 4.5hrs in case of Helmholtz AC fields whereas it was 3hrs in case of AC field generated by solenoid. Hence it can be concluded that maximum seed germination occurred at 3hrs exposure time when exposed to AC field as compared to 6hrs exposure for DC fields.

Helmholtz AC field supported faster percent germination achieving an optimum of 167% whereas AC field produced by the solenoid achieved a percent germination of 150% compared to control. In comparing the strength of the field, 300G and 600G Helmholtz AC field supported germination achieving 167% of control at 3hrs and 4.5hrs exposure respectively. At 50G AC Helmholtz field inhibited germination at 3hrs and 4.5hrs exposure before a positive germination percent at 6hrs exposure when incubated for 24hrs. In case of AC field generated by the solenoid, 100G field strength achieved maximum percent germination of 150% compared to other fields. The remaining field strengths achieved less than 70% of control germination regardless of incubation and exposure time.

4.3 Mass of Bean Seeds / Seedlings

4.3.1 Mass of seed / seedlings exposed to DC fields

4.3.1.1 Results

The mass of seeds versus the time for the alternating field is shown in table 4.5. The mass was measured using Ohaus beam balance, which recorded to one decimal point. Table 4.5 shows average of the three recordings hence approximated to two decimal places. Figures 4.27, 4.28, 4.29 and 4.30 show the mass of seeds at varying incubation and exposure time for different fields and magnetic strengths.

Table 4.5: Mass of seeds (g) exposed to varied DC field strengths at different incubation and exposure time

	(a) 50G										(b) 100G								
Time of exposure (hrs)	**Field**	**Incubation time (hrs)**									**Field**	**Incubation time (hrs)**								
		0	**12**	**24**	**36**	**48**	**60**	**72**	**84**	**96**		**0**	**12**	**24**	**36**	**48**	**60**	**72**	**84**	**96**
	HA	3.58	6.43	6.82	7.09	7.23	7.36	7.43	7.53	7.58	HA	3.51	4.24	5.34	6.00	6.46	6.68	6.87	7.03	7.20
	NA	3.62	6.20	6.81	7.06	7.22	7.36	7.45	7.59	7.62	NA	3.40	4.53	5.55	6.08	6.41	6.69	6.89	7.12	7.36
	SA	3.57	6.49	6.83	7.06	7.22	7.32	7.43	7.51	7.57	SA	3.55	4.23	5.57	6.25	6.61	6.89	7.08	7.28	7.46
3	CA	3.70	6.76	7.01	7.10	7.22	7.32	7.42	7.41	7.50	CA	3.74	4.46	5.73	6.47	6.89	7.14	7.34	7.52	7.71
	HA	3.40	6.73	6.95	7.06	7.15	7.27	7.39	7.31	7.41	HA	3.65	7.61	7.82	7.95	8.19	8.41	8.60	8.77	9.11
	NA	3.47	6.78	6.97	7.23	7.36	7.48	7.60	7.53	7.66	NA	3.65	7.57	7.78	7.97	8.26	8.50	8.74	8.90	9.16
	SA	3.51	6.81	7.04	7.14	7.24	7.28	7.36	7.38	7.45	SA	3.55	7.34	7.60	7.76	7.98	8.14	8.28	8.34	8.49
4.5	CA	3.38	6.69	6.84	6.83	6.97	6.98	7.09	7.11	7.18	CA	3.58	7.53	7.69	7.83	7.97	8.21	8.40	8.59	8.74
	HA	3.57	7.52	7.58	7.69	7.78	7.92	8.00	8.17	8.26	HA	3.76	4.92	6.10	6.85	7.12	7.37	7.50	7.70	7.84
	NA	3.63	7.45	7.52	7.63	7.79	7.95	7.99	8.10	8.19	NA	3.65	5.01	6.05	6.75	7.03	7.35	7.54	7.77	7.96
	SA	3.53	7.28	7.41	7.51	7.60	7.70	7.63	7.72	7.78	SA	3.41	4.65	5.78	6.38	6.62	6.90	7.05	7.26	7.46
6	CA	3.49	7.31	7.40	7.43	7.50	7.65	7.67	7.86	7.96	CA	3.58	4.78	5.76	6.49	6.72	7.01	7.19	7.37	7.56

Table 4.5 continued

	(c) 300G										(d) 600G									
Time of exposure (hrs)	**Field**	**Incubation time (hrs)**									**Field**	**Incubation time (hrs)**								
		0	**12**	**24**	**36**	**48**	**60**	**72**	**84**	**96**		**0**	**12**	**24**	**36**	**48**	**60**	**72**	**84**	**96**
	HA	3.52	5.56	6.42	6.88	7.13	7.41	7.57	7.82	8.02	HA	3.62	6.93	7.19	7.36	7.46	7.61	7.73	7.88	8.06
	NA	3.64	5.50	6.48	7.12	7.36	7.64	7.79	8.08	8.23	NA	3.53	6.37	6.96	7.09	7.20	7.36	7.45	7.55	7.73
	SA	3.51	5.37	6.23	6.75	7.02	7.35	7.55	7.87	8.07	SA	3.61	7.06	6.97	7.19	7.27	7.39	7.46	7.56	7.75
3	CA	3.47	5.80	6.65	7.10	7.47	7.80	7.98	8.26	8.50	CA	3.43	6.93	7.08	7.19	7.23	7.35	7.48	7.58	7.70
	HA	3.77	7.29	7.48	7.65	7.84	7.96	8.08	8.19	8.34	HA	3.81	7.85	7.96	8.04	8.07	8.19	8.23	8.29	8.38
	NA	3.73	7.97	8.01	8.17	8.29	8.36	8.51	8.72	8.91	NA	3.38	7.17	7.25	7.36	7.43	7.54	7.49	7.76	7.83
	SA	3.75	7.96	7.96	8.19	8.37	8.44	8.59	8.71	8.84	SA	3.37	7.13	7.19	7.29	7.37	7.43	7.61	7.58	7.64
4.5	CA	3.52	7.40	7.49	7.54	7.63	7.70	7.79	7.91	7.97	CA	3.44	7.14	7.29	7.41	7.52	7.67	7.74	7.84	7.90
	HA	3.54	5.33	6.37	6.78	7.18	7.39	7.61	7.84	8.12	HA	3.23	6.85	6.92	6.97	6.96	7.06	7.10	7.21	7.23
	NA	3.41	5.19	5.91	6.47	6.75	6.89	7.05	7.16	7.25	NA	3.52	7.35	7.41	7.45	7.49	7.57	7.67	7.79	7.83
	SA	3.45	5.50	6.31	6.87	7.11	7.21	7.39	7.55	7.69	SA	3.45	7.33	7.39	7.46	7.50	7.59	7.65	7.72	7.73
6	CA	3.34	5.02	5.58	6.42	6.76	6.97	7.13	7.31	7.36	CA	3.46	7.25	7.33	7.36	7.49	7.60	7.68	7.77	7.81

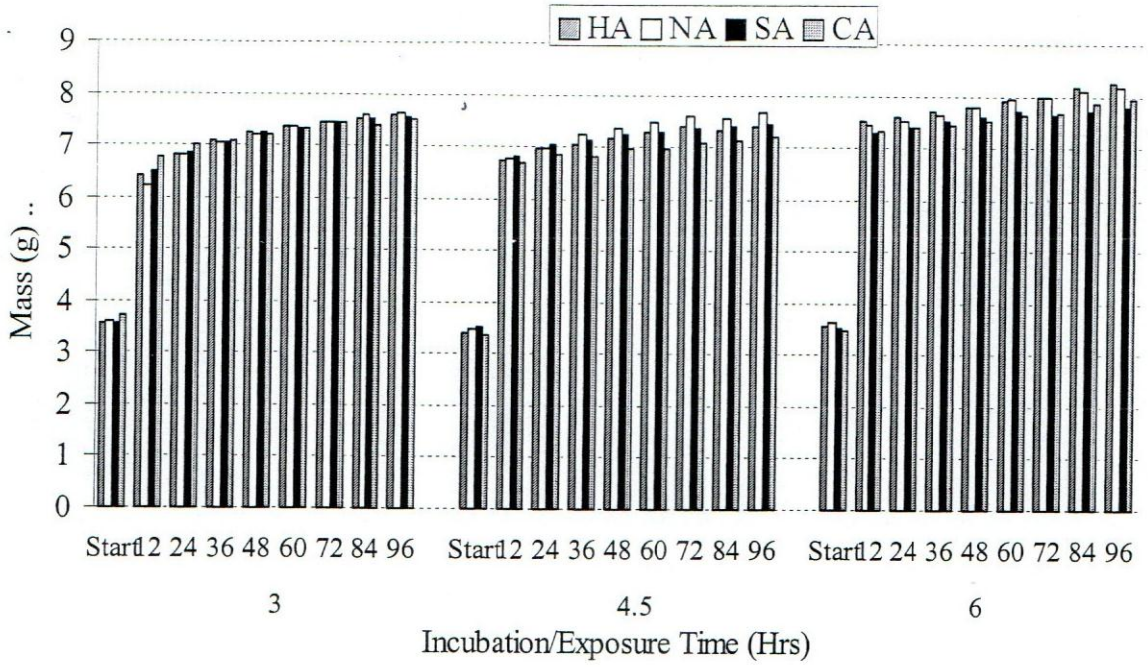


Fig 4.27: Mass of seeds (g) at varying incubation and exposure time for 50G DC field

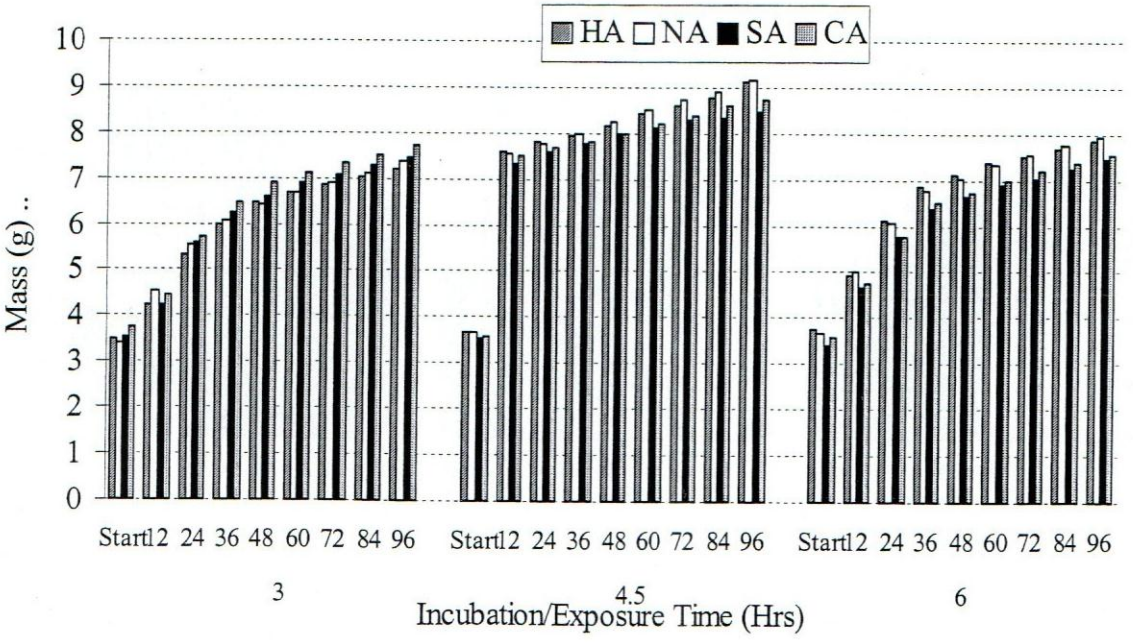


Fig 4.28: Mass of seeds (g) at varying incubation and exposure time for 100G DC field

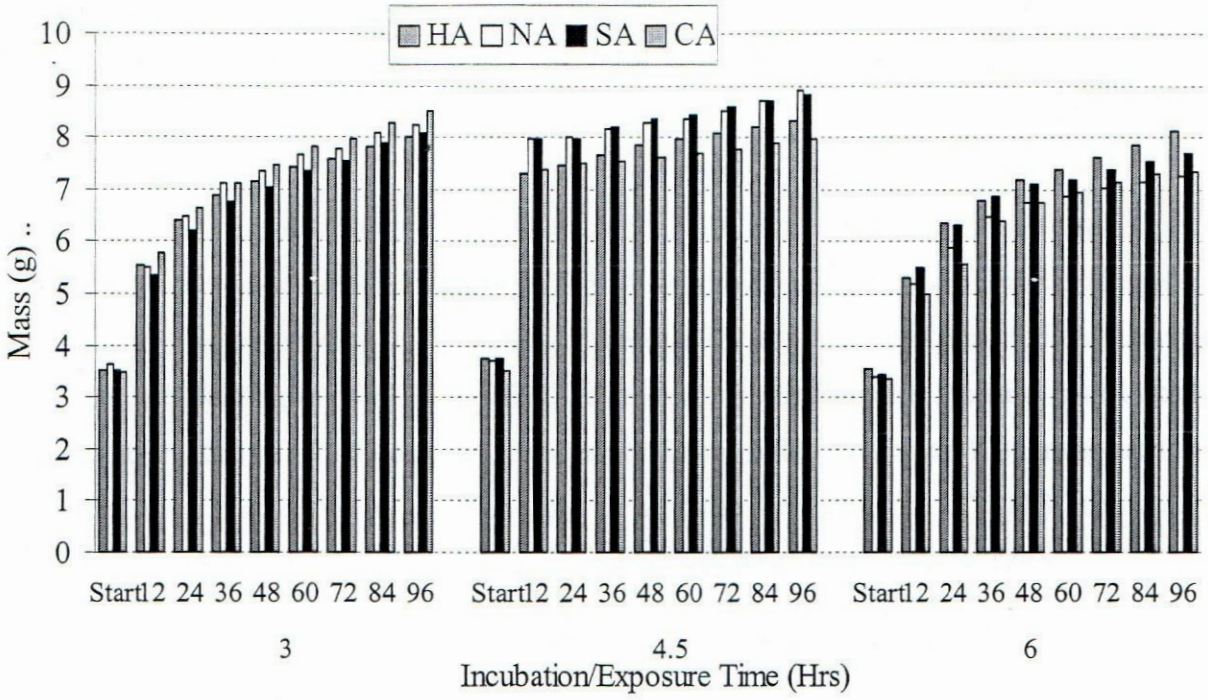


Fig 4.29: Mass of seeds (g) at varying incubation and exposure time for 300G DC field

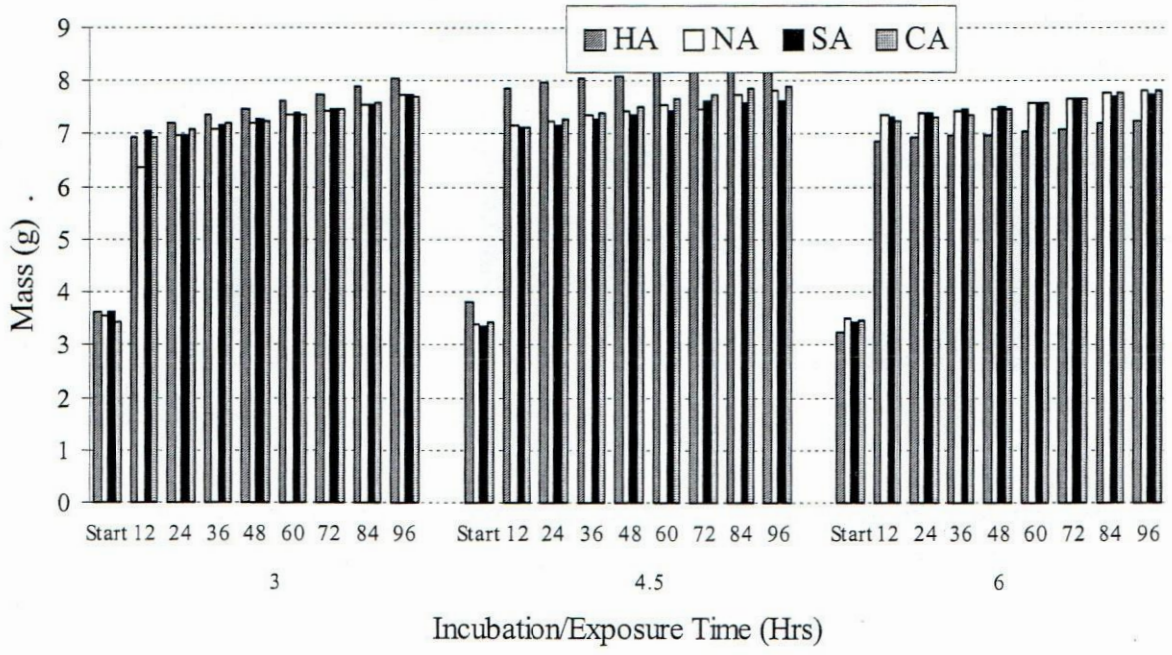


Fig 4.30: Mass of seeds (g) at varying incubation and exposure time for 600G DC field

4.3.1.2 Data analysis

Mass of seeds / seedlings exposed to the DC fields generated by Helmholtz coil

The mass of seeds exposed to the DC field generated by Helmholtz coil (HA) had a mean of 6.95g, standard deviation of 1.41 and standard error mean of 0.14 as shown in appendix 11(a). The mass of seeds exposed to the DC field was not significantly different ($p=0.63$) from that not exposed, $p>0.05$, t-test (appendix 11(b)). Fig. 4.31 shows the percent of mass of seeds as computed from equation 4.1, as a function of incubation and exposure time for each constant field treatment. Seeds grown under this field achieved maximum percent increase in mass of 8% compared to the control when exposed for 6hrs per day at field strength of 300G measured after 24hrs incubation period (Fig 4.31). Exposure of seeds to field strength of 100G generated by Helmholtz coil for 4.5hrs per day inhibited growth by 9% when incubated for 12hrs.

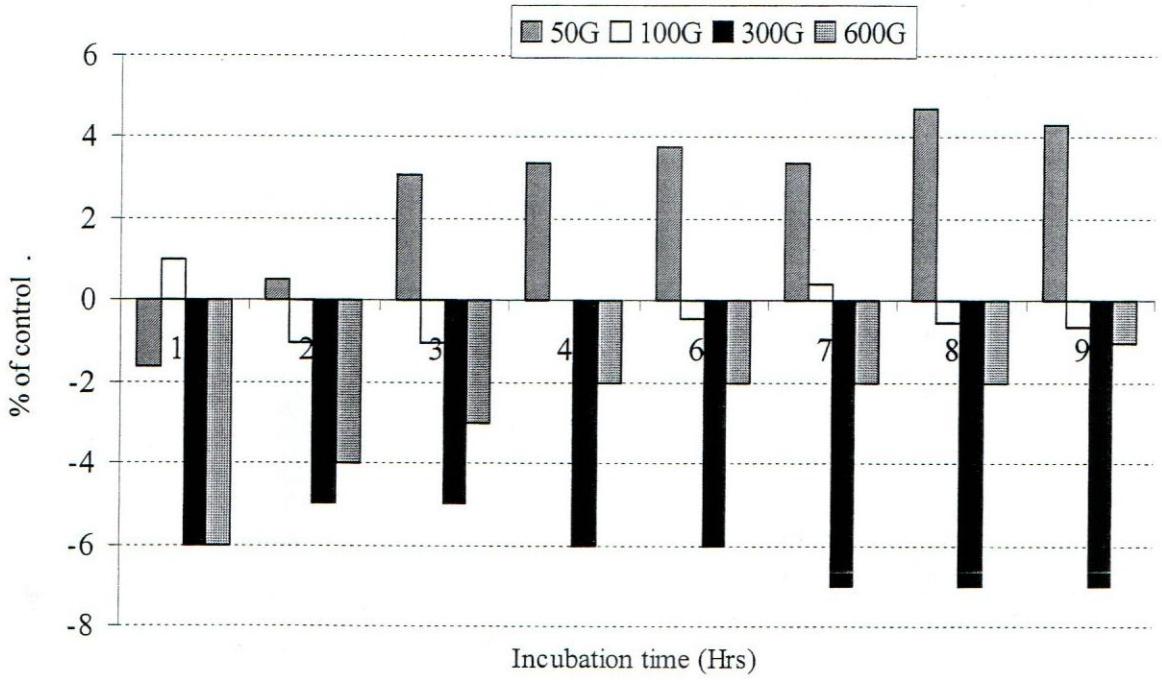


Fig. 4.31 (a): Percent mass of germinating bean seeds as a function of incubation period for 3hrs exposure time for each constant DC field generated by the Helmholtz coil

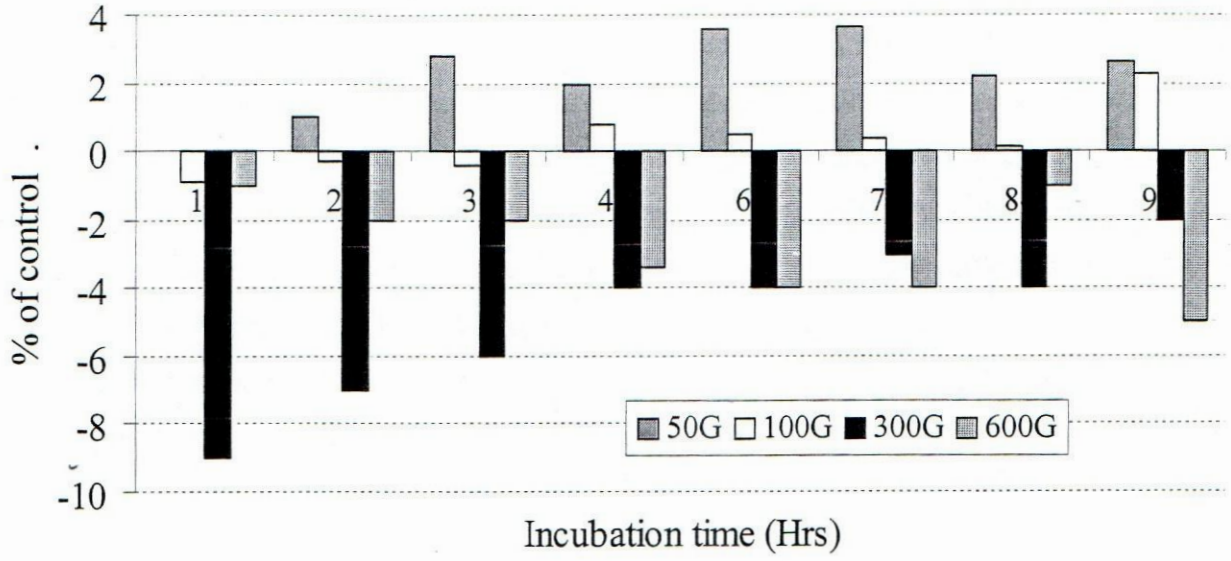


Fig. 4.31 (b): Percent mass of germinating bean seeds as a function of incubation period for 4.5hrs exposure time for each constant DC field generated by the Helmholtz coil

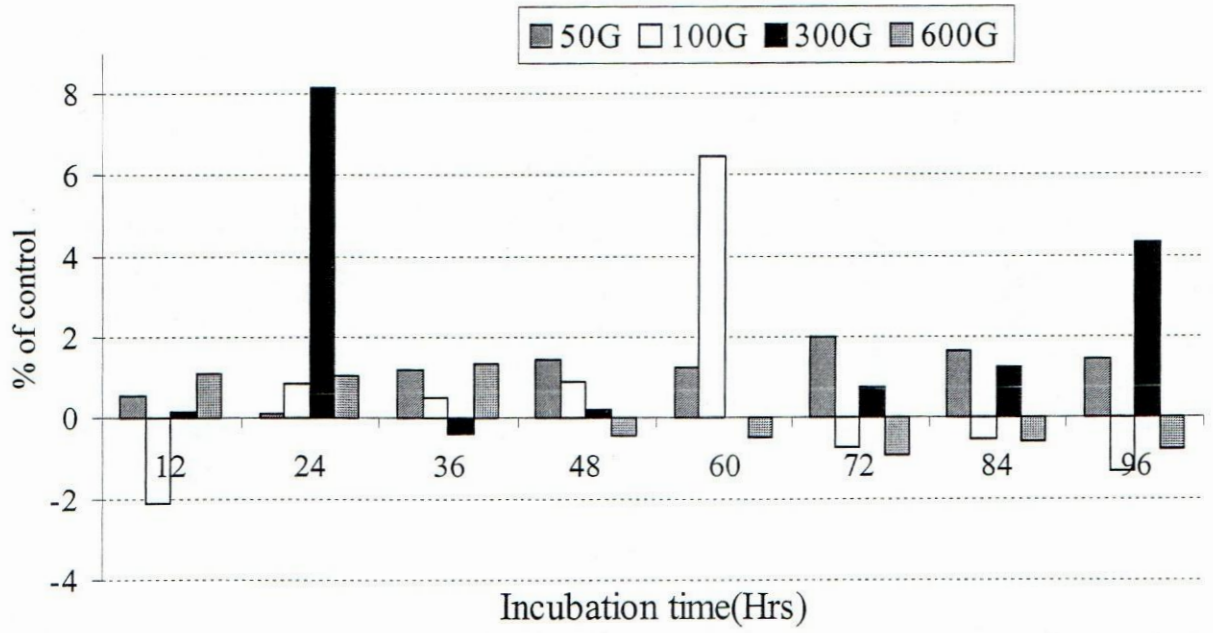


Fig. 4.31 (c): Percent mass of germinating bean seeds as a function of incubation period for 6hrs exposure time for each constant DC field generated by the Helmholtz coil

Mass of seeds / seedlings exposed to the North Pole fields

The descriptive analysis of the mass of seeds exposed to the North Pole field (NA) had a mean of 6.94g, standard deviation of 1.43 and standard error mean of 0.14 as shown in appendix 13(a). The mass of exposed seeds did not significantly differ ($p=0.64$) from that of control, $p>0.05$, t-test (appendix 13(b)). Fig. 4.32 shows the percent of mass of seeds as calculated from equation 4.1 as a function of incubation and exposure time for each constant North Pole field. Seeds exposed to the North Pole achieved maximum percent mass increase of 11% compared to the control at field strength of 100G exposed for 3hrs per day incubated for 12hrs. Increase in mass was inhibited by 11% at field strength of 600G exposed for 3hrs per day when incubated for 12hrs.

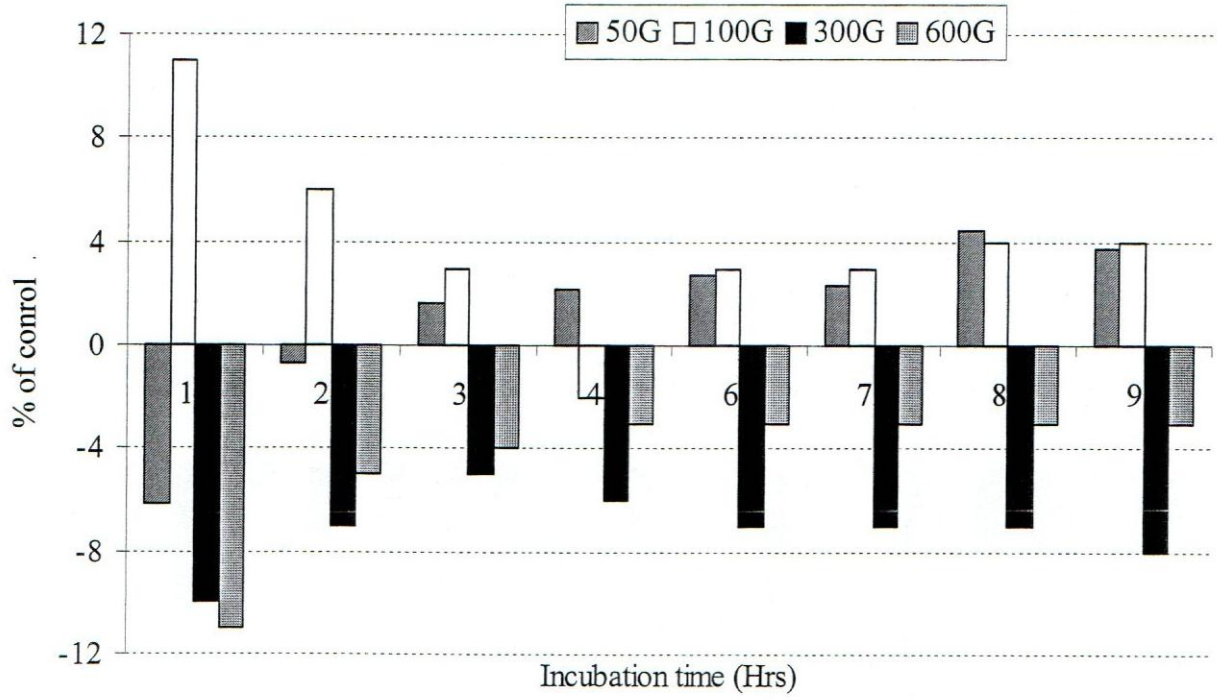


Fig. 4.32 (a): Percent mass of germinating bean seeds as a function of incubation time at 3hrs exposure for each constant North Pole field treatment

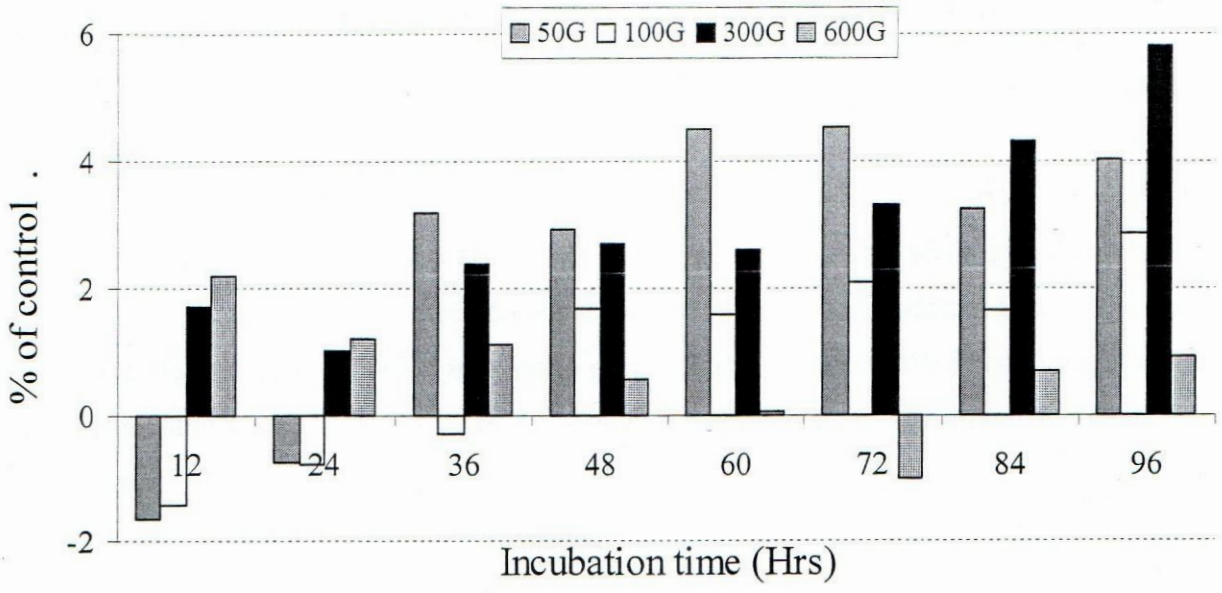


Fig. 4.32 (b): Percent mass of germinating bean seeds as a function of incubation time at 4.5hrs exposure for each constant North Pole field treatment

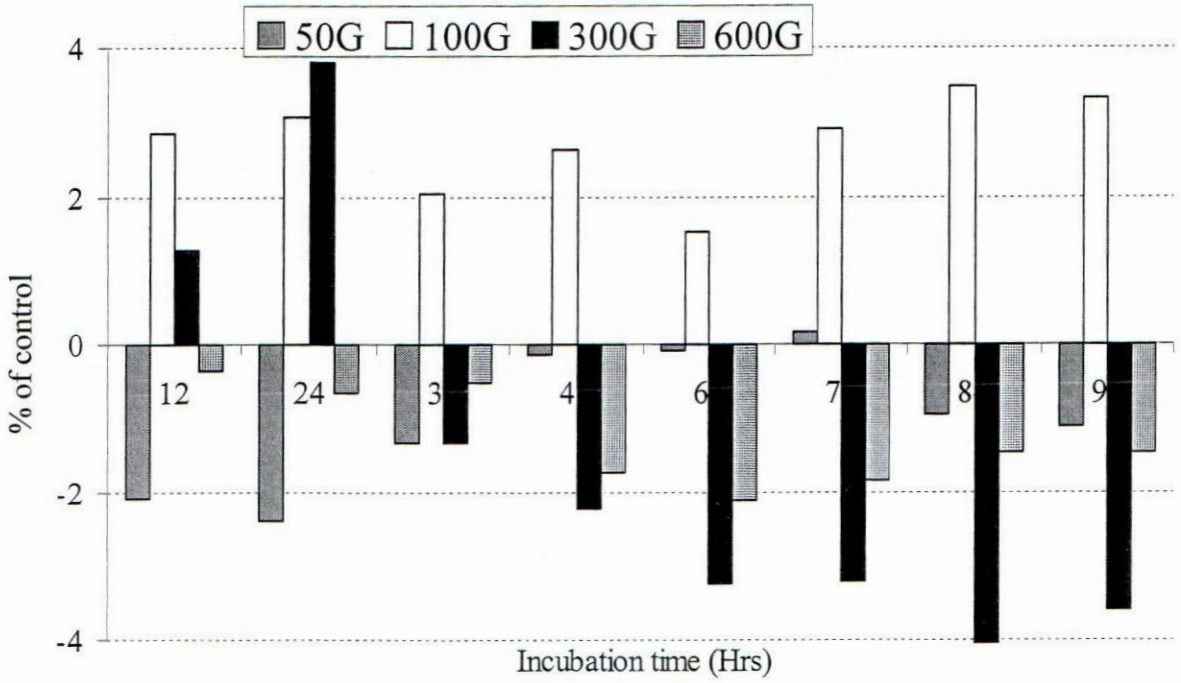


Fig. 4.32 (c): Percent mass of germinating bean seeds as a function of incubation time at 6hrs exposure for each constant North Pole field treatment

Mass of seeds/seedlings exposed to the South Pole fields

The mass of seeds exposed to the South Pole field had a mean of 6.88g, standard deviation of 1.39 and standard error mean of 0.13 as shown in appendix 14(a). The mass of seeds exposed to the South Pole field was not significantly different ($p=0.90$) from that of seeds not exposed, $p>0.05$, t-test (appendix 14(b)). Fig. 4.33 shows the percent of mass of seeds calculated basing on equation 4.1, as a function of incubation and exposure time for each constant South Pole field. Seeds exposed to this field achieved maximum percent mass increase of 9.8% compared to the control at field strength of 300G exposed for 6hrs per day incubated for 24hrs. The South Pole inhibited increase in mass by 9% compared to the control at field strength of 300G exposed for 3hrs per day and measured after 12hrs incubation.

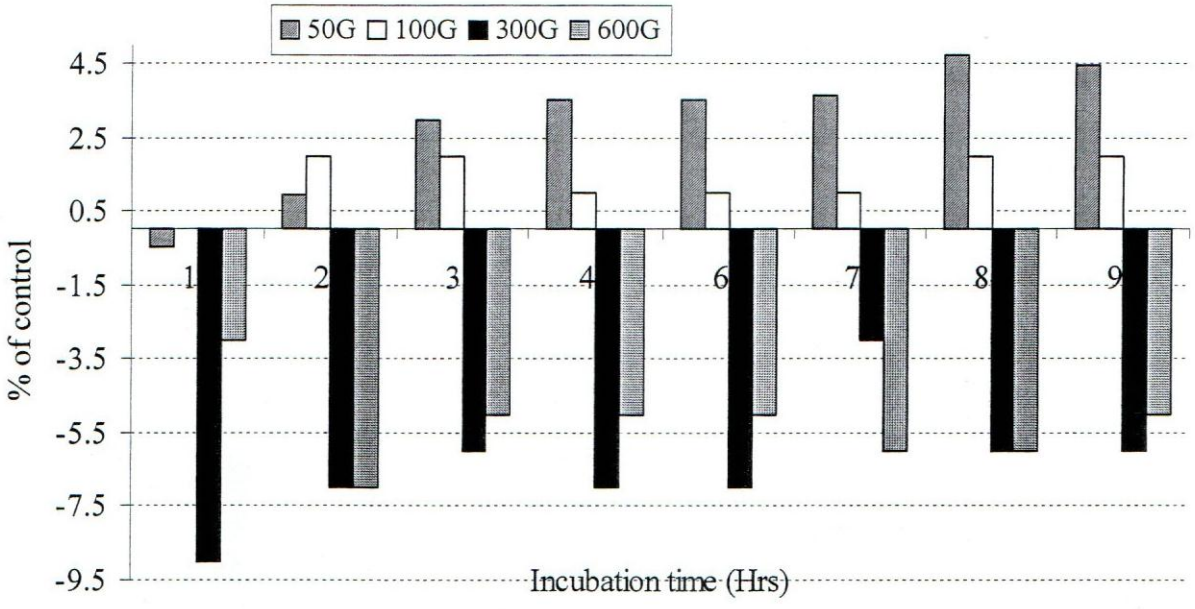


Fig. 4.33 (a): Percent mass of germinating bean seeds as a function of incubation at 3hrs exposure for each constant DC field generated by the Helmholtz coil

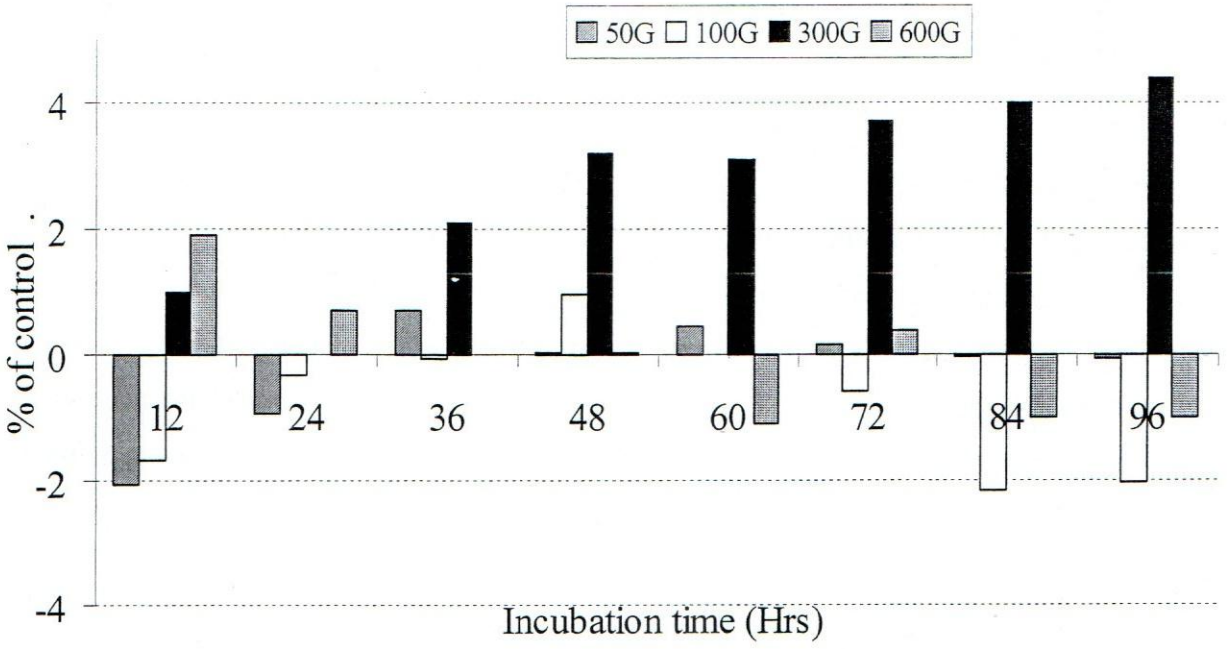


Fig. 4.33 (b): Percent mass of germinating bean seeds as a function of incubation at 4.5hrs exposure for each constant DC field generated by the Helmholtz coil

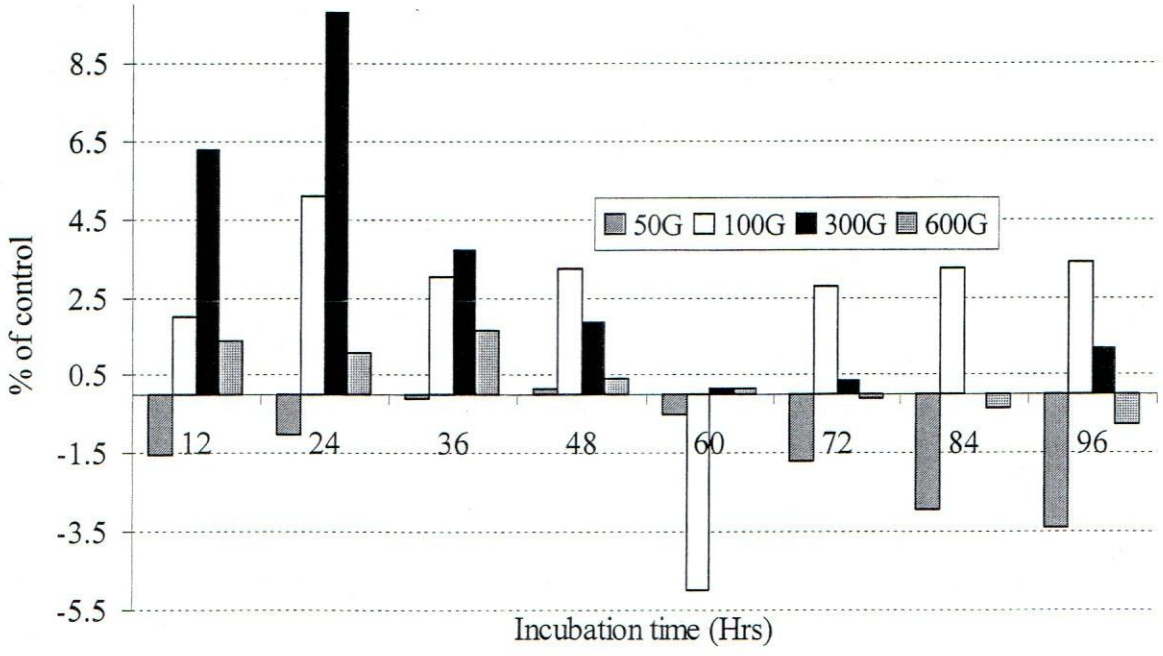


Fig. 4.33 (c): Percent mass of germinating bean seeds as a function of incubation at 6hrs exposure for each constant DC field generated by the Helmholtz coil

4.3.1.3 Discussion

Effect of DC field on mass of bean seeds / seedlings

The mass of bean seeds at the start (0hrs incubation) was half or slightly more than half the mass of the seeds incubated for 12hrs at 50G and 600G. This is probably due to the seeds absorbing water through imbibition consequently doubling their mass. The mass of seeds increased by not more than +2 gram, regardless of whether incubation period was varied from 12hrs to 96hrs at field intensity of 50G and 600G. The case of 100G and 300G DC fields was slightly different from the other observed trends, whereby for 3hrs and 6hrs exposure, the mass of seeds increased steadily between start (0hrs incubation) and 48hrs incubation. Voica *et al.*, (2003) observed a similar stimulatory effect on the 7th day of the experiment on photosynthesis and assimilatory pigments content from the bean leaves when they varied magnetic fluid concentrations before exposing the beans. All the concentrations of magnetic fluid (i.e. 0.25, 0.50 and 1%) increased the total biomass and the dry matter from each organ although 1% concentration achieved the highest increase of dry matter for the roots.

Between 48hrs and 96hrs incubation another steady increase in mass with a less sharp gradient was observed. Exposure for 4.5hrs for both 100G and 300G DC field exhibited a similar trend to that of 50G and 600G DC fields. Direct current field strength of 300G and 600G whether produced by Helmholtz coil, North Pole or South Pole, inhibited increase in mass of the germinating seeds when exposed for 3hrs. Exposure of seeds for 4.5hrs to DC field produced by Helmholtz coil further inhibited mass increase at a field strength of 300G and 600G, whereas North Pole field of strength 300G exposed for 4.5hrs increased mass of seeds compared to the control. A maximum of 6% was reached at 96hrs incubation time before starting to decrease at 6hrs exposure as incubation time increased. Direct current field strength of 100G generated by the Helmholtz coil induced mass changes of between –2% and +1% except for 4.5hrs exposure, 96hrs incubation and 6hrs exposure, 60hrs incubation. Field strength of 300G incubated for 24hrs and exposed for 4.5hrs increased seed mass steadily achieving maximum percent change of 9% at 6hrs exposure, 24hrs incubation period, before decreasing gradually to zero as incubation time increased to 60hrs at 6hrs exposure. There was no significant difference between exposed and control bean seeds in terms of change in mass between 60 and 84 hrs incubation period for field strength of 300G exposed for 6hrs in case of South Pole field. Field strength of 100G achieved a maximum percent change of 11% (North pole field, 3hrs exposure and 12hrs

incubation), followed by 300G at 9.8% (south pole field, 6hrs exposure and 24hrs incubation) and finally 300G at 8.2% (Helmholtz coil, 6hrs exposure and 24hrs incubation).

A field strength of 600G inhibited mass increase by 11% (North Pole and 12hrs incubation), followed by 300G (10% and 9% respectively). The type of field that achieved maximum percent change of mass compared to control was North Pole (11%), followed by South Pole (9.8%), and finally a DC field generated by Helmholtz coil (8.2%); maximum inhibition was noted from North Pole (11% and 10%). Maximum percent increase in mass occurred at incubation time of 12hrs (11%), 24hrs (9.8%) and 24hrs (8.2%), in the North Pole, South Pole and DC field generated by Helmholtz coil respectively. In comparing exposure time; 3hrs, 6hrs and 6hrs achieved 11%, 9.8% and 8% increase in mass respectively. In comparing exposure time, 3hrs per day exposure time achieved 11% increase in mass followed by 6hrs and 6hrs per day with 9.8% and 8.2% respectively. Maximum inhibition to the increase in mass was experienced at exposure time of 3hrs per day by 11%, 10% and 9%. Exposure time of 4.5hrs per day was also noted to inhibit mass increase by 9%.

4.3.2 Mass of seed / seedlings exposed to AC fields

4.3.2.1 Results

The mass of seeds after varying incubation and exposure time for the alternating field is as shown in table 4.6 and figures 4.34 (a), (b) and (c).

Table 4.6: Mass of seeds (g) after varying incubation and exposure time for various intensities of AC field

(a) 50G

Time of exposure (hrs)	Field	Incubation time (hrs)								
		0	12	24	36	48	60	72	84	96
3	HA	3.52	7.48	7.53	7.63	7.63	7.71	7.81	7.89	7.97
	FA	3.43	7.30	7.35	7.47	7.50	7.57	7.63	7.73	7.79
	CA	3.42	7.15	7.21	7.31	7.31	7.43	7.51	7.62	7.66
4.5	HA	3.47	7.16	7.23	7.24	7.30	7.42	7.46	7.52	7.54
	FA	3.28	6.96	7.01	7.08	7.12	7.23	7.25	7.34	7.37
	CA	3.50	7.31	7.36	7.43	7.50	7.51	7.53	7.63	7.57
6	HA	3.27	6.66	6.78	6.89	6.92	7.00	7.08	7.12	7.16
	FA	3.46	7.06	7.22	7.33	7.41	7.51	7.56	7.68	7.73
	CA	3.32	6.93	7.00	7.09	7.10	7.18	7.20	7.30	7.32

(b) 100G

Field	Incubation time (hrs)								
	0	12	24	36	48	60	72	84	96
HA	3.43	7.09	7.12	7.21	7.24	7.34	7.40	7.64	7.57
FA	3.71	7.71	7.75	7.82	7.88	7.98	8.05	8.17	8.23
CA	3.59	7.58	7.64	7.62	7.75	7.84	7.83	7.93	7.96
HA	3.66	7.64	7.71	7.80	7.85	7.95	8.00	8.12	8.21
FA	3.54	7.41	7.46	7.56	7.58	7.66	7.74	7.84	7.91
CA	3.46	7.27	7.33	7.44	7.46	7.51	7.53	7.66	7.72
HA	3.74	7.87	7.89	7.97	8.04	8.14	8.25	8.36	8.41
FA	3.58	7.53	7.57	7.66	7.72	7.82	7.91	8.03	8.12
CA	3.52	7.42	7.50	7.59	7.60	7.68	7.73	7.85	7.90

(C) 300G

Time of expos	Field	Incubation time (hrs)								
		0	12	24	36	48	60	72	84	96
3	HA	3.48	7.34	7.41	7.49	7.56	7.67	7.72	7.83	7.88
	FA	3.54	7.45	7.53	7.65	7.77	7.85	7.91	8.04	8.12
	CA	3.59	7.60	7.60	7.82	7.87	7.93	7.95	8.03	8.08
4.5	HA	3.62	7.23	7.40	7.50	7.59	7.71	7.84	7.92	8.06
	FA	3.68	7.47	7.57	7.67	7.74	7.82	7.88	7.93	8.03
	CA	3.73	7.59	7.69	7.78	7.78	7.88	8.08	8.05	8.09
6	HA	3.64	7.60	7.65	7.74	7.83	7.96	8.04	8.15	8.31
	FA	3.57	7.50	7.54	7.60	7.68	7.79	7.85	7.92	8.03
	CA	3.56	7.43	7.49	7.59	7.65	7.79	7.85	7.98	8.04

(d) 600G

Field	Incubation time (hrs)								
	0	12	24	36	48	60	72	84	96
HA	3.41	7.08	7.13	7.21	7.27	7.33	7.38	7.51	7.65
FA	3.60	7.21	7.32	7.41	7.43	7.51	7.54	7.68	7.78
CA	3.78	7.57	7.70	7.81	7.81	7.90	7.92	8.05	8.15
HA	3.74	7.36	7.51	7.63	7.70	7.83	7.92	8.03	8.14
FA	3.61	7.55	7.57	7.65	7.64	7.72	7.74	7.82	7.82
CA	3.63	7.49	7.58	7.67	7.69	7.78	7.79	7.89	7.90
HA	3.52	7.28	7.38	7.44	7.47	7.56	7.64	7.78	7.92
FA	3.63	7.48	7.49	7.58	7.63	7.73	7.77	7.92	8.00
CA	3.41	7.16	7.22	7.26	7.28	7.37	7.38	7.52	7.61

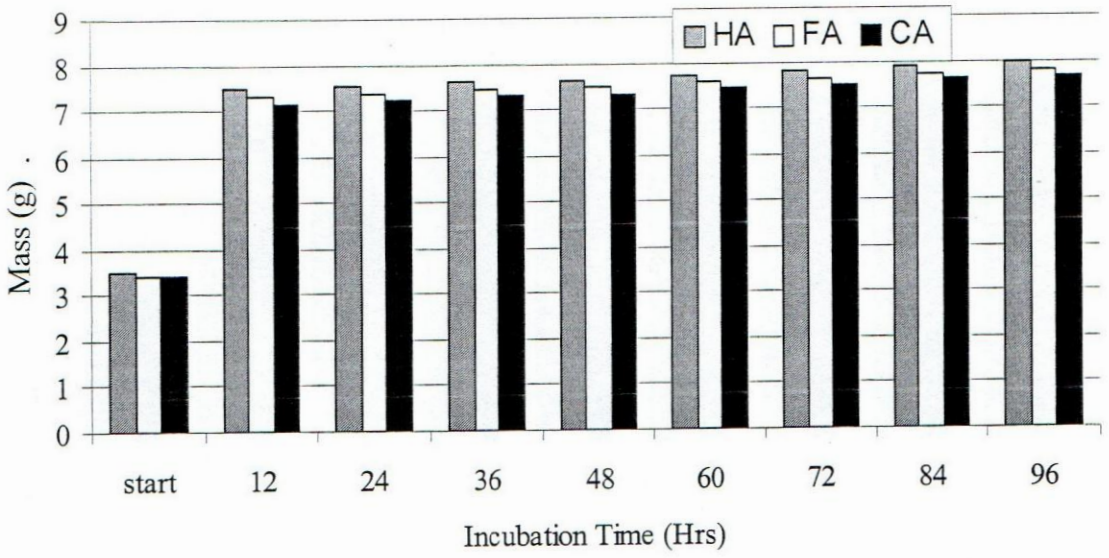


Fig 4.34 (a) Mass of bean seeds (g) exposed to 50G for 3hrs for various fields after varying incubation time for AC field

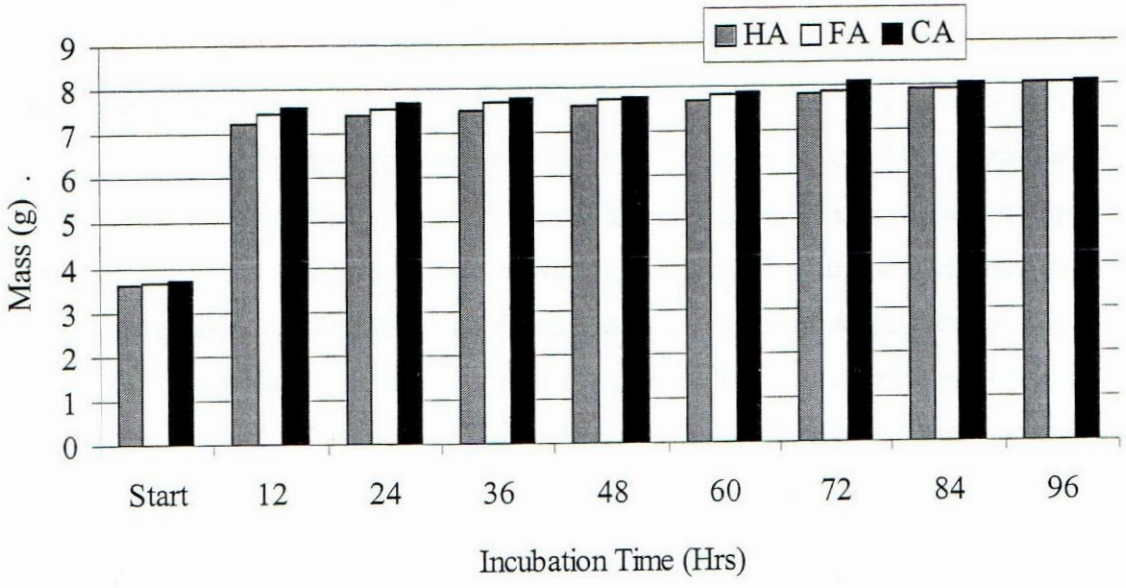


Fig 4.34 (b) Mass of bean seeds (g) exposed to 300G for 4.5hrs for various fields after varying incubation time for AC field

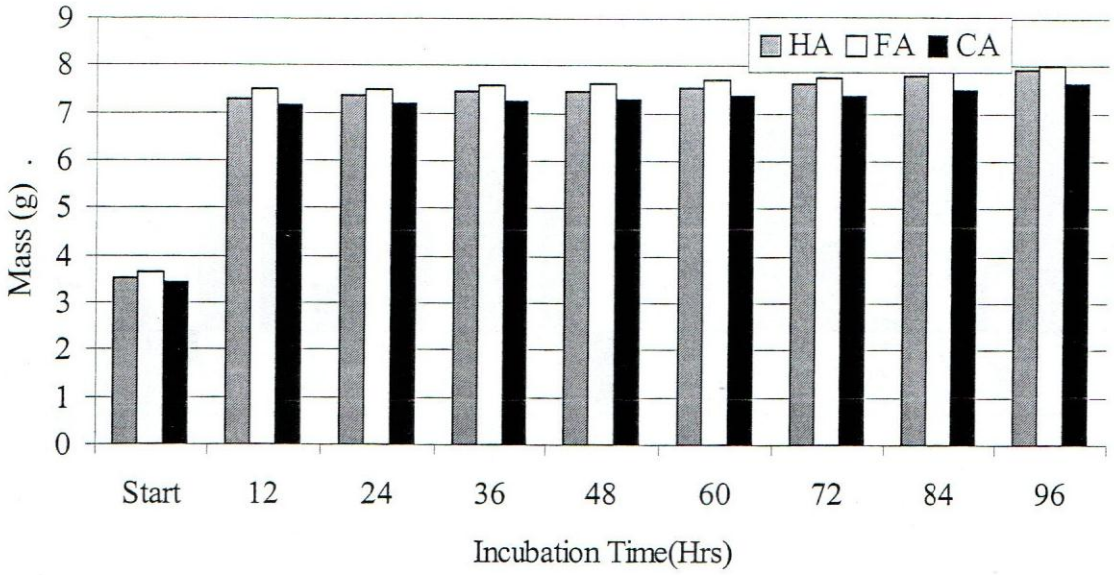


Fig 4.34 (c) Mass of bean seeds (g) exposed to 600G for 6hrs for various fields after varying incubation time for AC field

4.3.2.2 Data analysis

Mass of seeds exposed to the AC fields generated by Helmholtz coil

Seeds exposed to the AC field generated by the Helmholtz coil had a mean mass of 7.15g, standard deviation of 1.33 and standard error mean of 0.13 as shown in appendix 12(a). The mass of seeds exposed to the field was not significantly different ($p=0.95$) from that of control, $p>0.05$, t-test (appendix 12(b)). Fig. 4.35 shows the percent of mass of seeds as computed basing on equation 4.1, as a function of incubation and exposure time for each constant AC field treatment. Alternating current field achieved maximum percent mass increase of 3.7% when exposed for 3hrs per day at field strength of 600G after 96hrs incubation period (Fig. 4.35). At 600G AC field strength exposed for 4.5hrs per day inhibited increase in mass of seeds by 4.8% when incubated for 12hrs.

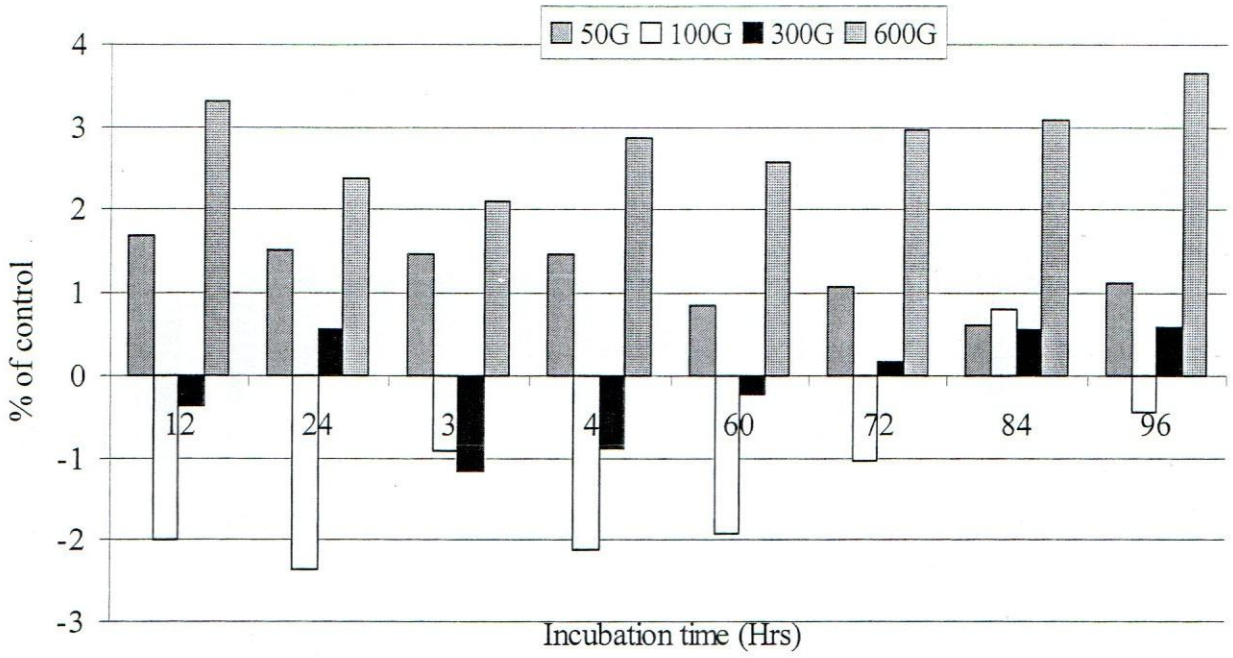


Fig 4.35 (a): Percent mass of germinating bean seeds as a function of incubation and exposure time at 3hrs incubation for each constant AC field generated by the Helmholtz coil

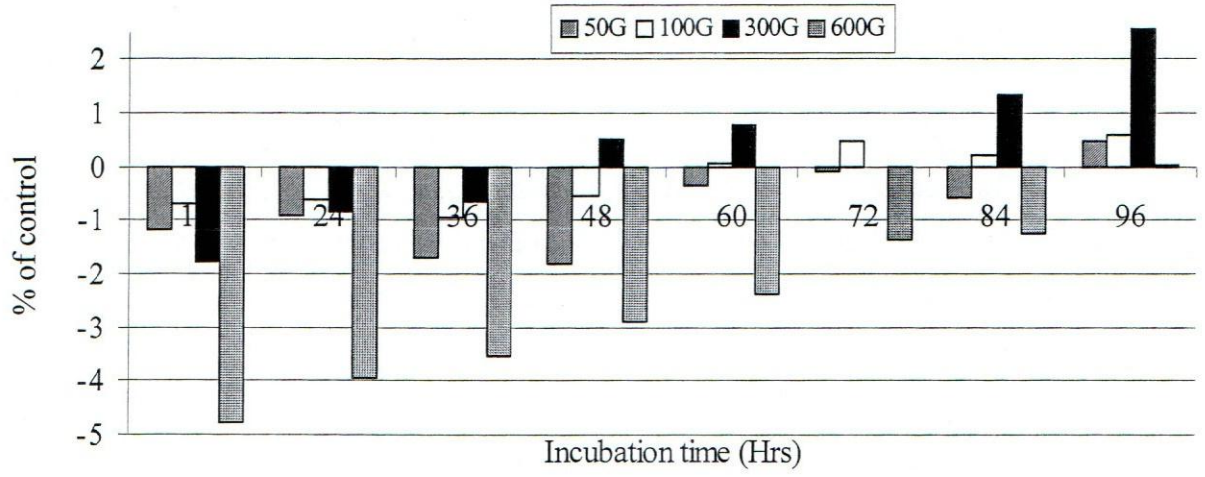


Fig 4.35 (b): Percent mass of germinating bean seeds as a function of incubation and exposure time at 4.5hrs incubation for each constant AC field generated by the Helmholtz coil

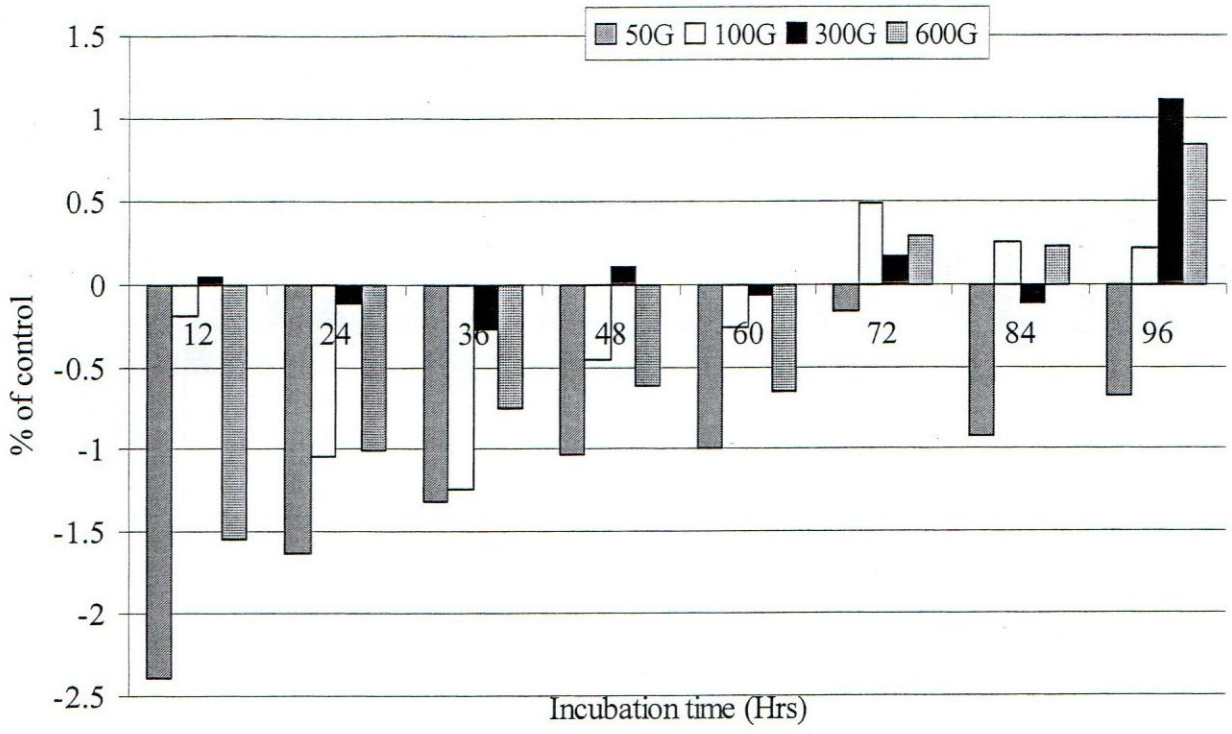


Fig 4.35 (c): Percent mass of germinating bean seeds as a function of incubation and exposure time at 6hrs incubation for each constant AC field generated by the Helmholtz coil

Mass of seeds / seedlings exposed to the AC field generated by a solenoid

The mass of seeds exposed to AC field generated by the solenoid had a mean of 7.19g, standard deviation of 1.32 and standard error mean of 0.13 as shown in appendix 15(a). There was no significant difference ($p>0.5$) between mass of exposed seeds and that of the non exposed seeds (appendix 15(b)). Fig. 4.36 shows the percent of mass of seeds calculated from equation 4.1 as a function of incubation and exposure time for each constant AC field treatment. Maximum percent increase in mass of 3.7% was achieved under this field as compared to the control when exposed for 4.5hrs per day at field strength of 50G measured after 96hrs incubation period (Fig. 4.36). Field strength of 600G exposed for 4.5hrs per day inhibited mass of seeds by 4.5% when incubated for 72hrs.

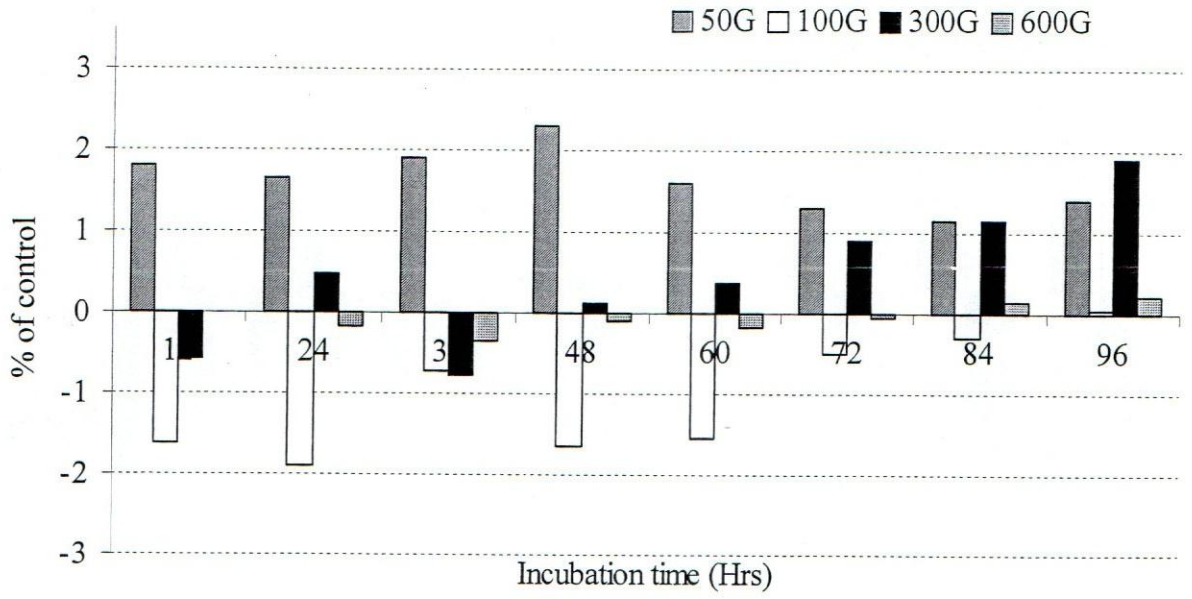


Fig. 4.36 (a): Percent mass of germinating bean seeds as a function of incubation at 3hrs exposure time for each constant AC field generated by the solenoid

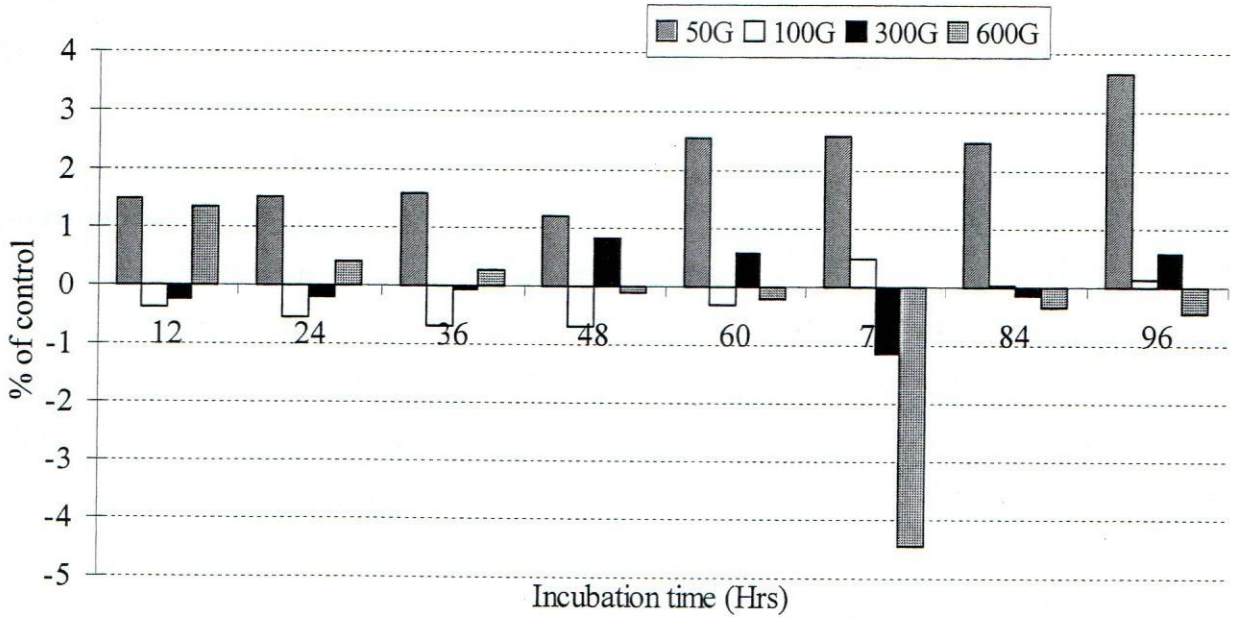


Fig. 4.36 (b): Percent mass of germinating bean seeds as a function of incubation at 4.5hrs exposure time for each constant AC field generated by the solenoid

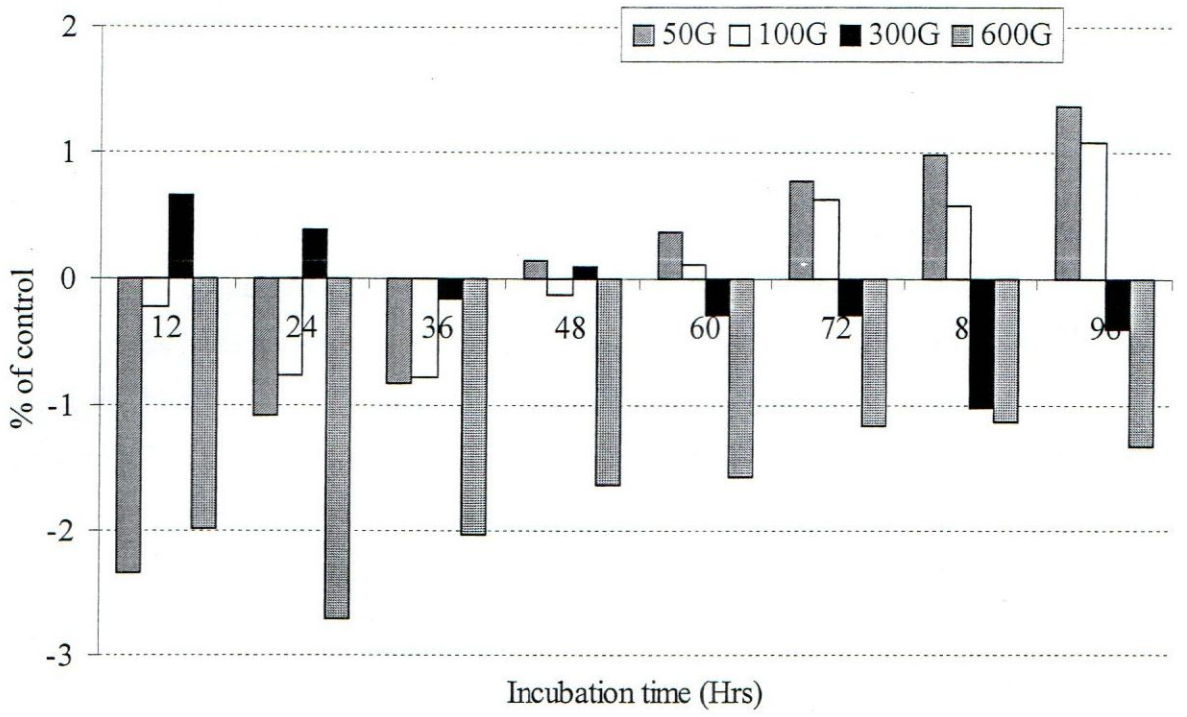


Fig. 4.36 (c): Percent mass of germinating bean seeds as a function of incubation at 6hrs exposure time for each constant AC field generated by the solenoid

4.3.2.3 Discussion

Effects of AC field on mass of bean seeds

The mass of seeds increased by less than +1 gram, regardless of whether intensity of the field varied or incubation period varied from 12hrs to 96hrs. Regardless of the AC field type, 100G and 300G inhibited increase in mass of germinating seed at incubation period less than 84hrs. There was no or very little change (above or below 0.5% of control) at and above 84hrs incubation time. 50G and 600G when exposed for 3hrs to the AC field generated by the Helmholtz field stimulated an increase in mass regardless of the incubation time. Seeds exposed to 600G increased in mass faster than the ones exposed to 50G. When the seeds were exposed for 4.5 or 6hrs, increase in mass was inhibited between onset of germination and 48hrs incubation beyond which this change was either positive or negative. AC field strength of 600G achieved the highest percent change in mass of 3.7%, 3.3% and 3.0% whereas 50G achieved 3.6% change in mass.

When germinating seeds were exposed to 100G AC fields generated by the solenoid; apart from 3hrs exposure, which inhibited the increase in mass, the 4.5hrs, and 6hrs exposure did not influence change in mass hence it concentrated around +1 and –1% of the control. It is clear that at 50, 300 and 600G AC field generated by the solenoid; as the exposure time increased from 3hrs towards 6hrs the percent change in mass decreased from positive to zero and finally towards negative side. AC field strength of 600G inhibited increase in mass by 4.8%, 4.0% and 3.5%, whereas 50G caused an inhibition of 4.5%. Comparing exposure time, 3hrs per day induced the highest percent change in mass of 3.7%, 3.3% and 3.0% of the control whereas exposure for 4.5hrs per day achieved 3.6%. The highest inhibition in mass increase occurred at exposure time of 4.5hrs per day. Comparing incubation time, 96hrs achieved the highest increase with values of 3.7% and 3.6%. Incubation period of 12hrs and 72hrs stimulated faster increase in mass by 3.3% and 3.0% respectively.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Effects of DC fields on the radicle length of bean seeds

There was no significant difference in the length of radicle between bean seeds exposed to DC fields and those not exposed. However, exposure to DC field for 3hrs slightly stimulated faster radicle growth whereas 6hrs exposure inhibited radicle growth. High radicle elongation was achieved with exposure to 300G of a pair of Helmholtz coil (143%), followed by North Pole (66%) and finally by the South Pole (43%).

Effects of AC fields on the radicle length of bean seeds

Exposure of bean seeds to AC fields had no statistical significance on the length of radicle. However a maximum of 47% elongation was achieved when seeds were exposed to 600G of Helmholtz field for 4.5hrs and incubated for 60hrs. Exposure to 50G Helmholtz AC field for 3hrs caused approximately 13% inhibition of radicle elongation at incubation period of more than 60hrs. Helmholtz AC field generally stimulated faster radicle elongation as compared to the solenoid.

Effects of DC fields on germination of bean seeds

Maximum seed germination was achieved when seeds were exposed for long periods i.e. 6hrs regardless of incubation time. At 3hrs exposure all DC fields inhibited germination. Maximum percent germination of 348% compared to the control occurred at incubation period of 24hrs for the case of DC fields. Other incubation periods achieved less than 120% germination compared to the control. Exposure to North Pole field induced the highest seed germination of 348%, followed by Helmholtz DC field achieving 243%, 115% by North Pole and 108% by South Pole. A DC field at strength of 300G induces faster bean seed germination than other strengths of DC fields.

Effects of AC fields on germination of bean seeds

At lower exposure period of 3hrs per day, both AC fields (i.e. Helmholtz and solenoid) recorded a higher percent seed germination as opposed to DC fields which recorded the highest

percent germination at 6hrs exposure. Seeds exposed to AC fields also achieved highest percent increase in germination of 167% at 24hrs incubation period. As the incubation time increased from 24hrs to 36hrs and finally 48hrs, the percent germination decreased. Helmholtz AC field supported faster percent germination achieving an optimum of 167% whereas AC field produced by the solenoid achieved a percent germination of 150%. 300G and 600G of Helmholtz AC field promotes germination to 167%. However this increase in germination is not statistically significant.

Effects of DC fields on mass of bean seedlings

Exposing bean seeds to DC fields has no significant effect on their mass. However exposure to 100G of North Pole field induced 11% increase in mass followed by 9.8% induced by 300G of South Pole field and by 8.2% induced by 300G of Helmholtz coil when seeds were incubated for 24hrs.

Effect of AC fields on mass of bean seeds

Exposure of bean seeds to AC fields had no significant effect on their mass. However, AC field strength of 600G induced 3.7% increase in mass of exposed bean seeds whereas exposure to 100G inhibited increase in mass by 4.6%.

5.2 Recommendations

1) This study revealed that when seeds are exposed to DC fields for a long time i.e. 6hrs regardless of incubation time maximum seed germination is achieved. The longest time of exposure was 6hrs. Increasing the exposure time to determine if the above trend will continue should be tested.
2) At 3hrs exposure all DC fields inhibit germination. Three hours was the shortest period to be considered in this study. Reducing exposure time to a set of values less than 3hrs to investigate if the same trend is observed and maybe determine the optimum inhibition point should be further experimented.
3) Maximum percent germination occurred at incubation period of 24hrs for the case of DC fields. It should be noted that incubation time measurement was recorded at interval of

12hrs. Further research should be done for a set of incubation periods ranging from 18hrs to 30hrs to determine the exact optimum incubation period.

4) This study investigated the effect of four strengths of the field i.e. 50G, 100G, 300G and 600G. A further investigation at intervals of 5 and 20G before and after the identified optimum field strength should be done to identify the actual optimum field strength.
5) The research noted several statistical insignificance in increase / changes in seed mass, germination and length of radicle when seeds were exposed to magnetic fields. Further study should be done to determine the real cause of statistical insignificance.
6) A further study whereby the strengths of the fields are exposed to the specimen horizontally should be done for comparison.
7) Further experiments to confirm the results of this study should be done under controlled uniform humidity and temperature.

REFERENCES

Acland D. J., (1971), "East Africa crops," Longman Publishers, London. Pg: 20-25.

Al-Akhras M. A., Elbetieha A., Hasan M. K., Al-Omari I., Darmani H. and Albiss B. (2001), "Effects of extremely low frequency magnetic field on fertility of adult male and female rats," *Bioelectromagnetics*. **22(5)**: 340-4.

Anonymous (2004), Healing of magnets and History, Healing of magnets introduction: http//www.healing-magnet.com.html. Assessed on 4th January 2006.

Bezrukov SM, Vodyanoy I (1997), Stochastic resonance in non-dynamical systems without response and thresholds. ***Nature*** **385**:319–321.

Blum R. and Roller E D., (1982), "Electricity, magnetism and light," Holden Day Publishers, San Francisco. **2nd Edition**: 48-126.

Brook J. A, (1964), "The living plant," Edinburgh University Press, Edinburgh. Pgs: 2-54.

Carbonell V. M., Martinez E. and Amaya M. J. (2000); "Stimulation of germination in rice (*Oryza sativa* L.) by a static magnetic field," *Journal of Electromagnetic Biology and Medicine,* **19(1)**: 121-128.

Cecconi S., Gualtieri G., Di Bantolomeo A., Troiani G., Cifone G. M. and Canipari R. (2000), "Evaluation of the effects of extremely low frequency electromagnetic fields on mammalian follicle development," *Human Reproduction*, **15(11)**: 2319-2325.

Chabay R and Sherwood B, (1995), "Electric and magnetic Interaction," John Wiles & Sons Inc., New York. Pgs: 441-454, 460-462.

Cook N. P., (1977), "Practical Electricity," Prentice hall Inc. New Jersey. Pgs: 80-89.

Davies M. I (1996), "Effects of 60Hz electromagnetic field on early growth in three plant species and a replication of previous results." *BioElectromagnetic* **17**:154-161.

Duffin W. J, (1990), "Electricity and Magnetism." McGraw Hill Book Company, London. **4**:171-172.

Evans, G.C. (1972), "The Quantitative Analysis of Plant Growth", U.C. Press, Berkeley, London.

Freeman C. D., Graham H. J., Tracy M., Emlen M. J. and Alados L. C. (1999), "Developmental instability as a means of assessing stress in plants: a case study using electromagnetic fields and soybeans." *International journal of plant science*, **160 (6 suppl)**: 157-166.

Galvanovskis J. and Sandblom J. (1997) Amplification of electromagnetic signals by ion channels. *Journal of Biophysics* **73:** 3056–3065.

Gutzeit H.O (2001), "Biological effects of ELF-EMF enhanced stress response: new insights and new questions." *Electro magneto-biol.* **20(1)**: 15-26

Hasenstein, H. K, (2004), "Discussion forum- Plant Rooting Hormones," Plant Propagation: http // www. Rooting - hormones. Com (discuss. Html); Assessed on 4th January 2006.

Inoue M., Miller M. W., Cox C. and Bryman A. A. (1985), "Absence of an electrolytic contaminant effect from a 60Hz electric field exposure sufficient to reduce root growth rate of *Pisum sativum* L." *Environ Exp bot* **25**: 89-97.

Jerman I., Berden M., Ruzic R and Skarja M., (1998), "Biological effects of TV SET EMF's on the growth of Spruce seedlings." *Electro. Magneto-biol.* **17 (1)**: 31-42.

Jones, D.B., Bolwell, G.P. and Gilliatt, 0. J. (1986), Amplification by pulsed electromagnetic fields of plant growth regulator induced phenylalaninc amonia-lyase during differentiation in suspension cultured plant cells. *Journal of Bioelectricity,* **5(1):** 1-2.

Krizaj, D. and Valencic. V. (1989), The effect of ELF magnetic fields and temperature on differential plant growth. *Journal of Bioelectricity* **8(2):** 159-165.

Kruglikov IL, H Dertinger (1994), Stochastic resonance as a possible mechanism of amplification of weak electric signals in living cells. *Bioelectromagnetics* **15**:539–547.

Lawlor H. and Leahy J. J. (1998), "Vi-Aqua Activated Water on Seed Germination and Subsequent Growth," Report on, "The innovation center on "vi-aqua" vitalized water and the aqua-fertilizer system, National technology park, Limerick, Grange Research Centre, Dunsany, Ireland. Accessed on 5th march 2005

Magnetic technologies, (2004), "Magnetic technologies in plant- growing": http // www. Magneticeast. com / agriculture / plant. Html. Assessed on 4th January 2006.

Magone I. (1996), "The effect of electromagnetic radiation from the skrunda radiolocation station on *Spirodela polyrhiza* schleiden culture." *Science Total Environment,* **180**:75-80.

Mc' Graw Hills, (1982), "Encyclopedia of science and technology," Mc' Graw company, New York**, M27**, 31-37.

Moon J. and Chung H. (2000), "Acceleration of germination of tomato seeds by applying AC electric and magnetic fields." *Journal of electrostatics,* **48**: 103-114

O'Kiely P. and O'Riordan E. (1998), 'Quantitative and Qualitative effects of vi-aqua activated water on the germination and growth of *Lolium perenne'*, Report on, "The Innovation center on "vi-aqua" vitalized water and the aqua-fertilizer system," National technology park, Limerick, Grange Research Centre, Dunsany, Ireland. Accessed on 5th march 2005

Onchabo M. O. (2002), "The effect of Lime, Phosphorous and Rhizobium inoculation on beans (*Phaseolus vulgaris* L.) Growth and yield in an acid mollic andesol." MSc. Thesis Egerton University: pp 98.

Phitke P. S., Kubde A. B. and Umbarkar, S. P. (1996), The influence of magnetic fields on plant growth, *Journal of Seed Science & Technology*. **24**: 375-392.

Roberts M. B. V. (1982), Biology: A functional Approach, Thomas Nelson and Sons Ltd, Edinburgh. 3rd Edition, Pg: 423-425.

Ruzic R, and Jerman I. (2002), "Weak magnetic field decreases heat stress in cress seedlings." *Electromagnetic Biology and Medicine* **21(1):** 45-53.

Ruzic R, Vodnik D and Jerman I. (2000), "Influence of aluminium in biologic effects of ELF magnetic field stimulation." *Electro magneto-biol.* **19(1)**: 57-68.

Ruzic R., Jerman I and Gogala N. (1998(b)), "Water stress reveals effects of ELF magnetic fields on the growth of seedlings." *Electro- Magnetobiol.* 17(1): 17-30.

Ruzic R., Jerman I. and Gogala N. (1998(a)), "Effects of weak low-frequency magnetic fields on spruce seed germination under acid conditions." *Canadian Journal of Forest Research* **28:** 609-616.

Ruzic R., Jerman I., Fefer D. and Jeglic A. (1993), "Various effects of pulsed and static magnetic fields on the development of castanea sativa mill. in tissue culture." *Electro and Magneto-biol.* **12 (2):** 165-177.

Segal S, (2004), "Discussion forum- Plant rooting hormones," plant propagation: http//www.rooting-hormones.com (discuss. Html). Assessed on 4th January 2006.

Sengbusch V. P. (2005), "Impressum", http://www.biologie.uni-hamburg.de/b-online/d00/copyrig.htm; Assessed on 4th January 2006.

Voica C., Polescu L. and Lazăr D. (2003), The influence of the magnetic fluids on some physiological processes in *Phaseolus vulgaris, Journal of Biological Vegetation* **48,1–2:** 9–15

White E. H, (1987), "Modern college physics," CBS Publishers, Delhi. Pgs: 89-101.

Zemansky S., (1970), "University Physics," Addison Wesley Publishing Company Inc., Canada: 134-156.

APPENDICES

Levene's test for equality was used to test the validity of the t-test. If the significance $p<0.1$ Levene's test when equal variance was assumed then the t-test is valid, whereas if $p>0.1$ equal variance assumed then the t-test is not valid. If the significance $p>0.1$ Levene's test, validity of the analysed data is observed when equal variance is not assumed.

APPENDIX 1 (a) and (b): Descriptive and statistical analysis for length of the radicle under DC Helmholtz field (HA) and the control (CA).

(a) Group Statistics (DC field)

Field	N	Mean	Std. Deviation	Std. Error Mean
HA	108	27.43	25.96	2.50
CA	108	25.00	23.40	2.25

(b) Independent Samples Test

HA/CA length	Levene's Test		t-test for Equality of Means		
	F	Sig.	t	df	Sig.(2-tailed)
Equal variances assumed	1.67	0.20	0.72	214.00	0.47
Equal variances not assumed			0.72	211.74	0.47

APPENDIX 2 (a) and (b): Descriptive and statistical analysis for Length of the radicle under AC Helmholtz field (HA) and the control (CA).

(a) Group Statistics (AC field)

Field	N	Mean	Std. Deviation	Std. Error Mean
HA	108	6.35	6.75	0.65
CA	108	6.10	6.51	0.63

(b) Independent Samples Test

HA/CA length	Levene's Test		t-test for Equality of Means		
	F	Sig.	T	df	Sig. (2-tailed)
Equal variances assumed	0.14	0.71	0.28	214.00	0.78
Equal variances not assumed			0.28	213.72	0.78

APPENDIX 3 (a) and (b): Descriptive and statistical analysis for Length of the radicle under North Pole field (NA) and the control (CA).

(a) Group Statistics (DC field)

Field	N	Mean	Std. Deviation	Std. Error Mean
NA	108	26.54	25.03	2.41
CA	108	25.00	23.40	2.25

(b) Independent Samples Test

NA/CA Length	Levene's Test		t-test for Equality of Means		
	F	Sig.	t	df	Sig. (2-tailed)
Equal variances assumed	0.98	0.32	0.47	214.00	0.64
Equal variances not assumed			0.47	213.03	0.64

APPENDIX 4 (a) and (b): Descriptive and statistical analysis for Length of the radicle under South Pole field (SA) and the control (CA).

(a) Group Statistics (DC field)

Field	N	Mean	Std. Deviation	Std. Error Mean
SA	108	25.84	24.15	2.32
CA	108	25.00	23.40	2.25

(b) Independent Samples Test

SA/CA Length	Levene's Test		t-test for Equality of Means		
	F	Sig.	t	df	Sig. (2-tailed)
Equal variances assumed	0.16	0.69	0.26	214.00	0.80
Equal variances not assumed			0.26	213.79	0.80

APPENDIX 5 (a) and (b): Descriptive and statistical analysis for Length of the radicle under AC fields generated by the solenoid (FA) and the control (CA).

(a) Group Statistics (AC field)

Field	N	Mean	Std.	Std.
FA	108	6.40	6.79	0.65
CA	108	6.10	6.51	0.63

(b) Independent Samples Test

FA/CA Length	Levene's Test		t-test for Equality of Means		
	F	Sig.	t	df	Sig. (2-tailed)
Equal variances assumed	0.13	0.72	0.33	214.00	0.74
Equal variances not assumed			0.33	213.63	0.74

APPENDIX 6 (a) and (b): Descriptive and statistical analysis for germinated seeds under DC Helmholtz field (HA) and the control (CA).

(a) Group Statistics (DC field)

Field	N	Mean	Std. Deviation	Std. Error Mean
HA	108	68.48	42.75	4.11
CA	108	67.65	43.07	4.14

(b) Independent Samples Test

HA/CA % Germination	Levene's Test for		t-test for Equality of Means		
	F	Sig.	t	df	Sig. (2-tailed)
Equal variances assumed	0.09	0.77	0.14	214.00	0.89
Equal variances not assumed			0.14	213.99	0.89

APPENDIX 7 (a) and (b): Descriptive and statistical analysis for germinated seeds under AC Helmholtz field (HA) and the control (CA).

(a) Group Statistics (AC field)

Field	N	Mean	Std. Deviation	Std. Error Mean
HA	108	69.01	43.42	4.18
CA	108	68.48	43.96	4.23

(b) Independent Samples Test

HA/CA % Germination	Levene's Test		t-test for Equality of Means		
	F	Sig.	t	df	Sig. (2-tailed)
Equal variances assumed	0.11	0.74	0.09	214.00	0.93
Equal variances not assumed			0.09	213.97	0.93

APPENDIX 8 (a) and (b): Descriptive and statistical analysis for germinated seeds under North pole field (NA) and the control (CA).

(a) Group Statistics (DC field)

Field	N	Mean	Std. Deviation	Std. Error Mean
NA	108	68.24	42.04	4.05
CA	108	67.65	43.07	4.14

(b) Independent Samples Test

NA/CA % Germination	Levene's Test		t-test for Equality of Means		
	F	Sig.	t	df	Sig. (2-tailed)
Equal variances assumed	0.35	0.56	0.10	214.00	0.92
Equal variances not assumed			0.10	213.88	0.92

APPENDIX 9: (a) and (b): Descriptive and statistical analysis for germinated seeds under South Pole field (SA) and the control (CA).

(a) Group Statistics (DC current, % germination)

Field	N	Mean	Std. Deviation	Std. Error Mean
SA	108	68.42	42.75	4.11
CA	108	67.65	43.07	4.14

(b) Independent Samples Test

SA/CA % Germination	Levene's Test		t-test for Equality of Means		
	F	Sig.	t	df	Sig. (2-tailed)
Equal variances assumed	0.09	0.77	0.13	214.00	0.90
Equal variances not assumed			0.13	213.99	0.90

APPENDIX 10: (a) and (b): Descriptive and statistical analysis for germinated seeds under AC fields generated by the solenoid (FA) and the control (CA).

(a) Group Statistics (AC field)

Field	N	Mean	Std. Deviation	Std. Error Mean
FA	108	69.81	43.43	4.18
CA	108	68.48	43.96	4.23

(b) Independent Samples Test

FA/CA % Germination	Levene's Test		t-test for Equality of Means		
	F	Sig.	t	df	Sig. (2-tailed)
Equal variances assumed	0.12	0.73	0.22	214.00	0.82
Equal variances not assumed			0.22	213.97	0.82

APPENDIX 11: (a) and (b): Descriptive and statistical analysis for mass of seeds under DC field generated by the Helmholtz coil (HA) and the control (CA).

(a) Group Statistics (DC field)

Field	N	Mean	Std. Deviation	Std. Error Mean
HA	108	6.95	1.41	0.14
CA	108	6.85	1.37	0.13

(b) Independent Samples Test

HA/CA Mass (DC field)	Levene's Test		t-test for Equality of Means		
	F	Sig.	t	df	Sig. (2-tailed)
Equal variances assumed	0.07	0.80	0.48	214.00	0.63
Equal variances not assumed			0.48	213.80	0.63

APPENDIX 12 (a) and (b): Descriptive and statistical analysis for mass of seeds under AC field generated by the Helmholtz coil (HA) and the control (CA).

(a) Group Statistics (AC field)

Field	N	Mean	Std. Deviation	Std. Error Mean
HA	108	7.15	1.33	0.13
CA	108	7.16	1.31	0.13

(b) Independent Samples Test

HA/CA Mass	Levene's Test		t-test for Equality of Means		
	F	Sig.	t	df	Sig. (2-tailed)
Equal variances assumed	0.02	0.88	-0.06	214.00	0.95
Equal variances not assumed			-0.06	213.97	0.95

APPENDIX 13 (a) and (b): Descriptive and statistical analysis for mass of seeds under North Pole field (NA) and the control (CA).

(a) Group Statistics (DC field)

Field	N	Mean	Std. Deviation	Std. Error Mean
HA	108	6.94	1.43	0.14
CA	108	6.85	1.37	0.14

(b) Independent Samples Test

NA/CA Mass (DC field)	Levene's Test		t-test for Equality of Means		
	F	Sig.	t	df	Sig. (2-tailed)
Equal variances assumed	0.26	0.61	0.46	214.00	0.64
Equal variances not assumed			0.46	213.59	0.64

APPENDIX 14 (a) and (b): Descriptive and statistical analysis for mass of seeds under South Pole field (SA) and the control (CA).

(a) Group Statistics (DC field)

Field	N	Mean	Std. Deviation	Std. Error Mean
SA	108	6.88	1.39	0.13
CA	108	6.85	1.37	0.13

(b) Independent Samples Test

SA/CA Mass DC Field	Levene's Test		t-test for Equality of Means		
	F	Sig.	t	df	Sig. (2-tailed)
Equal variances assumed	0.02	0.88	0.13	214.00	0.90
Equal variances not assumed			0.13	213.95	0.90

APPENDIX 15 (a) and (b): Descriptive and statistical analysis for germinated seeds under AC fields generated by the solenoid (FA) and the control (CA).

(a) Group Statistics (AC field)

Field	N	Mean	Std. Deviation	Std. Error Mean
FA	108	7.19	1.32	0.13
CA	108	7.16	1.31	0.13

(b) Independent Samples Test

FA/CA; Mass; AC current	Levene's Test		t-test for Equality of Means		
	F	Sig.	t	df	Sig. (2-tailed)
Equal variances assumed	0.00	0.96	0.16	214.00	0.87
Equal variances not assumed			0.16	214.00	0.87

EGERTON UNIVERSITY LIBRARY