Journal of Applied Biosciences 22: 1350 - 1358
ISSN 1997–5902

The influence of AC electromagnetic fields on the initial radicle growth rate of *Phaseolus vulgaris* L.

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Published online at www.biosciences.elewa.org on October 7, 2009

ABSTRACT
Objectives: To determine if AC electromagnetic fields can be used to improve growth of food crops. This would reduce and minimize contamination of yield that is associated with application of fertilizers to promote plant growth and chemicals to control pests and diseases.
Methodology and results: Alternating 50Hz electromagnetic fields generated by Helmholtz coil of 0, 5, 10, 30 and 60mT were applied to germinated Rosecoco bean (*Phaseolus vulgaris* L.) seedlings. For a given sample, seedlings were exposed to AC electromagnetic field for 3, 4.5 and 6h per day. The radical length of beans was measured after every 12h over a 4 days incubation period. Linear regression analysis showed that the incubation period significantly influenced bean radicle elongation with mean optimum rate of 0.088cm/hr after incubation for 66h. Exposure period and strength of electromagnetic field did not significantly influence the initial rate of radicle elongation of Rosecoco beans.
Conclusion and application of findings: Beans growing naturally have a more uniform increase in length than those exposed to AC electromagnetic fields. The growth regulators (hormones) are accelerated after exposure to magnetic field hence higher elongation of radicle. Further research on this need to be done especially if the pretreatment of seeds will give the same results so that it can be used in developing better quality and fast growing bean seed.

Key words: Bean, electromagnetic fields, plant growth, Helmholtz coil

INTRODUCTION
Bean (*Phaseolus vulgaris*) is a major source of protein in the world especially in developing countries (Onchabo, 2002) who may not afford the more expensive animal protein. The variety of common beans mainly grown in Kenya is the "Rosecoco" type (*Phaseolus vulgaris* L.), cultivated on about 700,000 hectares due to their adaptability to agroecology, attractive market prices, taste and good cooking properties (Onchabo, 2002). Intercropping and rotational agriculture (main methods of growing beans in Kenya) have led to low productivity of beans. Intercropping reduces bean yield because the plants compete for nutrients.

Chemical additives e.g. biological pesticides (Trichoderma, neem, neem cake, Neemroc and Neemros water extract (50g/l)), insecticides such as synthetic pyrethroids: are used to raise productivity of beans (DPI&F, 2007). The insecticides and pesticides control and kill

African bollworm (*Helicoverpa armigera*), legume pod borer (*Maruca testulalis*), black bean aphid (*Aphis fabae*), and bean stem maggots (Bean flies (Ophiomyia spp.), bean rust (Uromyces appendiculatus var. appendiculatus) and other bacterial, fungal and viral diseases However, their application may contaminate the produced beans with toxins that are dangerous to consumers' health (Faqenabi *et al.,* 2009; Martínez *et al.,* 2009).

A study on the effects of agro-chemicals in Mekong River Delta in southern Vietnam has shown that inorganic fertilizer use in agriculture, particularly if large quantities are applied or if they are applied incorrectly, will lead to its accumulation with adverse effects to human life. For instance; Nitrogen (N) and phosphorus (P) in run-off can contribute to eutrophication, with a risk of oxygen depletion and fish death. Ammonia (NH_3) gas can cause haze and contribute to the acidification of soils, nitrogen oxides (NO_X) can contribute to acid precipitation and reduced air quality and sulphur dioxide (SO_2) reacts with other gases and contributes to haze formation and also to acid precipitation (Nyuyen, 1999).

Rice farmers were poisoned through pesticide use through direct exposure during handling and application, and from uptake of pesticide residues in their food (e.g., vegetables, beans, root crops, frogs and fish).

Similar observations elsewhere have led many countries to come up with standards of application and encourage use of farm practices e.g. intercropping and rotational farming (CGAP, 1999). In Kenya, beans are by far the most important pulse crops cultivated mainly by small-scale farmers for domestic use. Beans are intercropped with other crops especially maize, potatoes and cassava (Onchabo, 2002). Large scale growing of beans is highly commercialized and a lot of inorganic fertilizers and chemicals are used. Kenya's capacity to monitor nitrate concentrations in soil, food, water, especially drinking water as part of environmental monitoring programs is weak. Therefore developing and implementing new methods to increase productivity and quality of beans in Kenya is necessary. Use of AC electromagnetic fields produced by a pair of Helmholtz coil to enhance elongation of bean radical is one possibility that would reduce use of inorganic fertilizers and chemicals to increase yield in farms.

Effects of magnetic fields on biological material have been studied extensively (Tenuzzo *et al.*, 2006; Chou, 2007; Trebbi *et al.,* 2007). A 60Hz AC field has been shown to adversely affect growth of *Pisum sativum* L. root while increased growth of radish seedlings was observed when tuned to the ion cyclotron resonance for calcium (Inoue *et al*., 1985; Davies, 1996). An electromagnetic field consists of an electrical part and a magnetic part. The electrical part is produced by a voltage gradient whereas the magnetic part is generated by any flow of current. The alternating currents (AC) produce fields varying over time (alternating fields). Every ion is known to vibrate at a certain frequency. If the electromagnetic field vibrate at the frequency of a certain ion, the electromagnetic field is said to resonate at the frequency of that ion i.e. ion cyclotron resonance for that ion (Yates, 2007).

Vegetative growth and life span of duckweed was reduced when grown near a 160MHz radio frequency electromagnetic field (Magone, 1996). Magnetic water has been noted to increase crop production and drastically decrease plant disease incidence, and in some cases to improve the taste of agricultural products (Magnetic Technologies, 2004). Sait (2003) was able to relate plant sap pH to frequency emitted by the same plant for various plants, and also related both measurements to the plant's resistance to diseases and pests. Ruzic *et al*. (1998) noted that germination and growth of spruce seedlings (*Picea abies* (L.) Karsten) depended on the created pH when exposed to magnetic fields. At very low pH, there was inhibitory effect on germination and growth whereas at higher pH there was a stimulatory effect when spruce seedlings were exposed to magnetic field of 26mT and frequency of 50Hz. This effect increased as the strength of the magnetic field was increased.

Magnetically treated water used for crop irrigation resulted into better germination percentages, larger growth and better yields of tomatoes, wheat, cucumbers and carrots (Namba *et al*., 1995; Nargis & Thiagarajan, 1996; Hilal & Hilal, 2000). It has been reported that magnetizing causes physical and chemical changes of natural water parameters, resulting in improvement of filtration and dissolving properties of water (Magnetic Technologies, 2004). According to experiments done by Henkenius and

Retseck (1992), magnetic treated water also stimulates the growth of seedlings through increased height, weight and number of leaves.

This study was carried out to determine whether AC 50Hz electromagnetic field can positively affect the elongation of radicle in Rosecoco beans, which would accelerate germination and growth, thus contributing to bean productivity in Kenya.

MATERIALS AND METHODS

Instruments: Magnetic flux was measured using the magnetic flux density unit (model Unilab 612.002) connected to Multi-meter (model ALDA AVD830B). 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 and 2A, radius 7cm. The radical length was measured using a string and straightened along a ruler.

Calibration of magnetic flux density unit and Teslameter: The magnetic flux density unit was calibrated using Group 3 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. Digital teslameter (mT) recording showed a direct linear relationship against the potential difference (mV) generated by the magnetic flux density unit when the probes of the two were inserted in a magnetic field and measured at the same time.

Preparation of bean seeds: Two kilograms of viable Rosecoco GLP-2 seeds were purchased from Kenya Seed Company. The seeds were assumed to have the same moisture level. Bean seeds of nearly the same size and coloration were selected and grouped in twenties. Each group of 20 seeds was soaked for 2h before being transferred to a Petri dish lined with two sheets of absorbent paper (serviette). A single 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, two Petri dishes were prepared and labeled either as H for use in the field produced by Helmholtz coil or C which served as control. The seeds were allowed to germinate (Moon and Chung, 2000) within 24h after incubation. Ten germinated seeds were selected before exposure to the different field strengths for varied periods of time.

Experimental set up: Magnetic field strength for the Helmholtz coil was set at 5mT with the aid of a magnetic flux density unit (PHWE 612.002) and by varying current in the coil. A Petri dish labeled H was placed in between the two pairs of Helmholtz coils. The exposure time for magnetic field intensity was varied from 3, 4.5 and 6h per day of incubation. The Petri dish labeled C served as a control and it was subjected to the same conditions but not exposed to magnetic field. The length of radical was measured and recorded starting at 36h after incubation, and then after every 12h for the next 96h after inception of the experiment. The magnetic field strength was increased from 5mT to 10mT then to 30mT and finally to 60mT and the above procedure repeated for each case. The experiments were repeated three times.

RESULTS AND DISCUSSION

There was a significant ($p<0.01$) strong positive correlation (0.8) between the strength of magnetic field and radicle of beans (Table 1). In this case the beans seedlings exposed to AC electromagnetic field exhibited radicle length different from those not exposed. The radicle elongation was insignificantly ($p>0.05$) and slightly negatively correlated (- 0.015) to increase in the strength of the field and increase in exposure period. The radicle elongation was significantly ($p<0.05$) and strongly positively correlated to incubation period.

There was a significant difference between the effect of different strengths of field applied to the growing bean seedling ($p<0.05$), the period beans were exposed to a given field strength and the incubation period of the seedling ($P<0.01$) (Table 2).

Table 1: Pearson's correlation relating length of radicle subjected to magnetic field in comparison to the strength of the field, exposure period and incubation period.

Parameter	Statistic	Strength of field	Exposure period	Incubation period
Exposure / non exposure	Pearson Correlation	0.845(**)	0.866(**)	0.000
	Sig. (2-tailed)	0.000	.0000	1.000
	N	648	648	648
Length of radicle (cm)	Pearson Correlation	-0.015	-0.015	0.946(**)
	Sig. (2-tailed)	0.703	0.695	0.000
	N	648	648	648

** Correlation is significant at the 0.01 level (2-tailed).

Table 2: Test of significance within and between subject effects with length of radicle as dependent variable.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Exposure / non exposure	.000	0	.	.	.
Strength	211.143	3	70.381	2.784	0.040
Exposure period	468.580	2	234.290	9.267	0.000
Incubation period	222309.064	8	27788.633	1099.192	0.000
Strength of field * Exposure period	1125.176	6	187.529	7.418	0.000
Strength of field * Incubation period	161.755	24	6.740	.267	1.000
Exposure period * Incubation period	346.235	16	21.640	.856	0.621

R Squared = .954 (Adjusted R Squared = .943)

A multiple regression analysis was done on length as a dependent variable against the strength of field, exposure period and incubation period (Table 3). The average applied strength of field (b = - 0.114) did not significantly affect (p=0.670) length of the bean radicle, and the coefficient was negative which indicates that as the strength of the field decreases, the bean radicle elongates (which was not expected). The effect of exposure period (b = -0.176, p=0.607) on the length of radicle was insignificant and its coefficient negative indicating that as the exposure period decreases, the bean radicle elongates. As incubation period increased the length of bean radicle also increased. The R-squared was 0.896 which means that approximately 89.6% of the variance of length of bean's radicle is accounted for by the model.

From the results (Table 3), exposure of beans to a magnetic field did not statistically influence the elongation of radicle. While attempting to reproduce the studies of Smith *et al*. (1993) and Davies (1996), Potts *et al*. (1997) also noted an insignificant difference in growth when radish (*Raphanus sativus* L.) seedlings were exposed to 60Hz electromagnetic field tuned to ion cyclotron.

Table 3: Multiple regression model relating dependent variable (length of radicle, cm) to strength of field, exposure period and incubation period.

Parameter	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
Constant	-15.678	0.945		-16.584	0.000
Strength of field	-0.114	0.267	-0.008	-0.426	0.670
Exposure period	-0.176	0.342	-0.010	-0.514	0.607
Incubation period	7.736	0.104	0.946	74.298	0.000

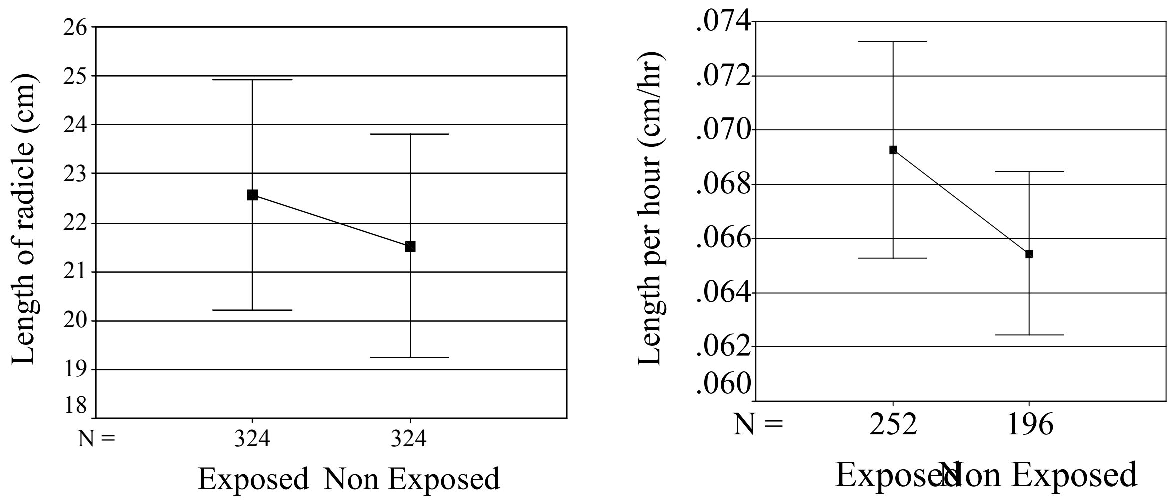


Figure 1: A & B: Mean radicle length of beans exposed to magnetic field in comparison to those not exposed (Bars indicate standard error).

The mean radicle length of beans exposed to magnetic field was 22.5 cm as compared to 21.5 cm for the control (Fig. 1A). The standard error for the control is equal to that of radicles exposed to magnetic field (Fig. 1A). Fig. 1B shows that beans exposed to magnetic field elongate faster (0.069cm/h) than those kept under natural conditions (0.065cm/h). Variation in the rate of radicle elongation as shown by standard error is slightly higher for beans exposed to magnetic field (Fig. 1B). Beans growing naturally have a more uniform increase in length than those exposed to AC electromagnetic fields. This may be due to growth regulators (hormones) being accelerated upon exposure to magnetic field. The growth of the radicle and fresh weight of spruce (*Picea abies* L.) seedlings were inhibited (Ruzic *et al.,* 1996), when exposed to 25µT and 100µT for 12h/day under drought stress.

Exposure period: The exposure period (b = -0.176, p=0.607) had insignificant effects and its coefficient was negative indicating that as the exposure period decreases the bean radicle elongates (Table 3). Contrary to this finding, Alexander and Doijode (1995) found that onion and rice seeds exposed to a weak electromagnetic field for 12 h had significantly increased shoot and root lengths. De Souza *et al.* (2006) noted a significant increase in root relative growth rates when tomato (cv Campbell-28) was exposed to an electromagnet field for 10 min at 100 mT (rms) and for 3 min at 170 mT (rms). The weak negative correlation between bean radicle elongation and exposure period is shown in fig. 3A and B.

From fig. 2(a) it can be seen that the mean radicle elongation for the control (0h of exposure) and 3h exposure period is approximately the same. As exposure period is increased from 3 to 4.5h there is a steady increase in mean radicle length until it reaches optimum and then decreases steadily as exposure period increases to 6h. The standard error for the control is less than that of radicles exposed to magnetic field (Fig. 2A), suggesting that exposure to magnetic field stimulates growth regulators. However, this effect could not be seen clearly in Fig. 1A as the standard errors appeared nearly equal. The optimum rate of radicle elongation (0.073cm/h) is achieved after 4.5h exposure, and then decreases steadily as exposure period is increased towards 6h. Variation in the rate of radicle elongation as shown by standard error is more for beans exposed to magnetic field than the control for all exposure periods (Fig. 2B).

Strength of the field: The average applied strength of field (b = - 0.114) had no significant effect (p=0.670) on the elongation of the radicle, and the coefficient was negative which indicated that as the strength of the field decreases, the bean radicle elongates (Table 3, Fig. 4A and B). This was not aligned to our expectation and was also contrary to the significant effects observed when one-year-old scions rooting of 'Uslu' grapevine cuttings were exposed to 0.15 mT ELF at 50 Hz (Dardenýz *et al*., 2006).

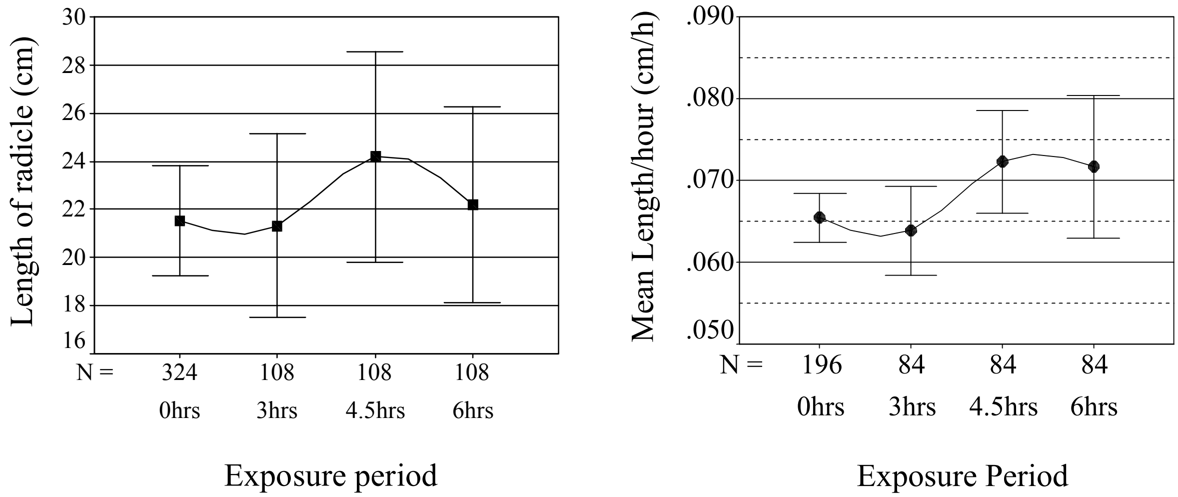


Figure 2 A & B: Mean length of bean radicles exposed to Helmholtz generated magnetic field for varying Exposure period.

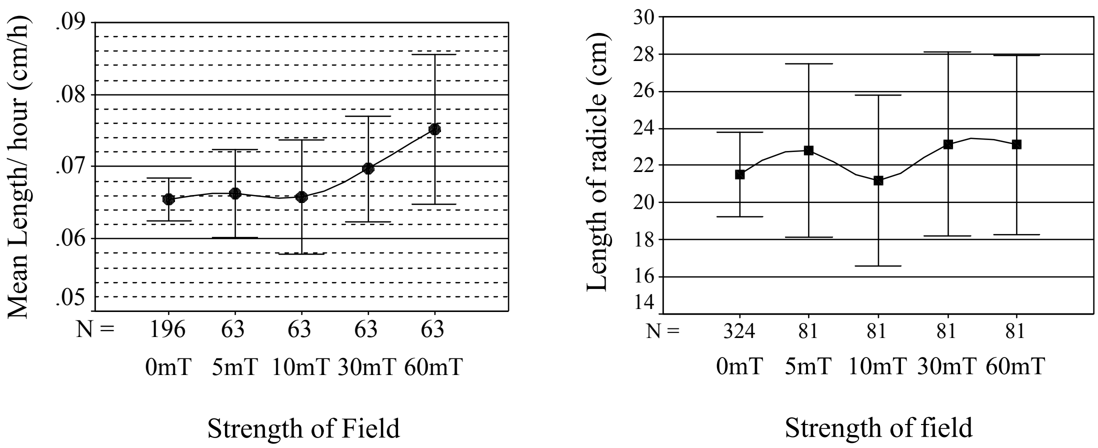
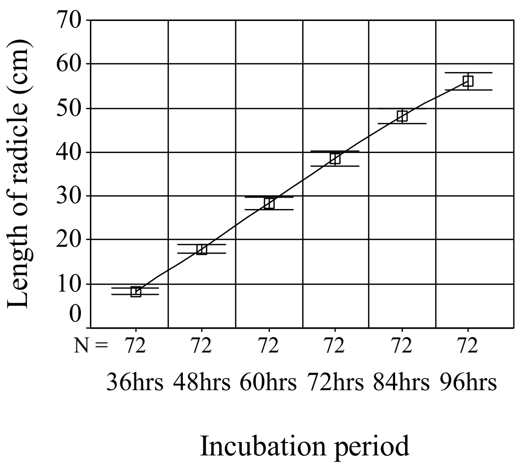


Figure 3A and B: Mean bean radicle length after exposure to Helmholtz generated magnetic field of varying strength of fields. Bars indicate standard error.

From Fig. 3 (b), it appears that there are alternate optimum at 5mT and 30mT, and minimum at 0mT and 10mT field strengths that affect radicle elongation. The pre-sowing magnetic treatments on growth of tomato (cv Campbell-28) exposed to an electromagnet at 100 mT (rms) for 10 min and at 170 mT (rms) for 3 min caused a significant increase in the root relative growth rates (De Souza *et al*., 2006). Based on our results (Table 4 (b)) we recommend 5mT to be used in the field when growing beans. This is because producing 5mT requires very little current hence less costly. Further more 5mT is less than 30mT; the higher the strength of the field the more dangerous it is to human health. The conclusions of the International Commission on Non Ionising Radiation (ICNIRP, 1998), the European Union Council Scientific Committees (1999), and the World Health Organization's – International Agency for Research on Cancer (IARC, 2001), the USA National Research Council (1997), the USA National Institute of Environmental Health Sciences (1999) and the UK National Radiation Protection Board (2001) have all agreed that the exposure to extremely low frequency magnetic fields is statistically associated with a small risk of childhood leukemia. Two-pooled analysis of epidemiological studies provided insight into the epidemiological evidence that played a pivotal role in the IARC (2001) evaluation. These studies suggested that, in a population exposed to average magnetic fields in excess of 0.3 to 0.4 μT, twice as many children might develop leukemia compared to a population with lower exposures. Though not proved, extremely low frequency electromagnetic fields (ELF-EMF) have been shown to cause carcinogenic diseases.

Incubation period: From Pearson's correlation (Table 1) it was noted that the incubation period is strongly positively correlated to the elongation of radicle (Fig. 4A). A simple linear regression analysis showed that the F-test was statistically significant, which means that the model was statistically significant. The R-squared was 0.895 meaning that approximately 89.5% of the variance of length of radicle was accounted for in the incubation period investigation. This is further demonstrated in fig. 4. A further probe of this linear relationship shows that the rate of radicle elongation forms a bow shaped curve with mean optimum rate of 0.086cm/h at incubation period of 54h (Fig. 4B).



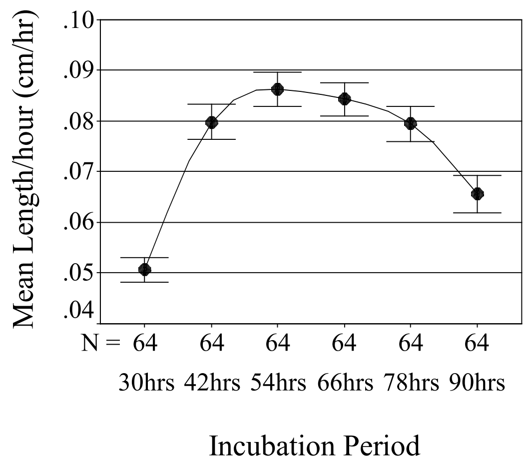


Fig. 4A and B: Mean bean radicle length after incubation for varying periods of time following exposure to Helmholtz generated magnetic field. Bars indicate standard error.

CONCLUSION

This study met the initial goal of adding knowledge to the already existing pool of knowledge in this field. The experiment allowed us to gain invaluable knowledge of the bio-effect of AC electromagnetic fields on plant growth. Much research in this field has dealt with the effect of electromagnetic fields on the growth of cash crops e.g. tea, pyrethrum and flowers whereas this study deals with beans, which are a major pulse crop among the poor farmers in Kenya.

Beans growing naturally have a more uniform increase in length than those exposed to AC electromagnetic fields. We hypothesize that production of growth regulators (hormones) is accelerated upon exposure of seedlings to magnetic field, hence faster elongation of radicle. Further research on this need to be done especially if the pretreatment of seeds will give the same results so that it can be used in developing better quality bean seed.

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