centrosur e-ISSN:2706-6800
INSTITUTO TECNOLÓGICO CORPORATIVO EDWARDS DEMING

Proposal of a mathematical model to evaluate the effects of magnetic radiation applied as growth stimulation of beet (*Beta vulgaris*) seeds

Propuesta de un modelo matemático para evaluar los efectos de la radiación magnética aplicada como estimulación de crecimiento de semillas de remolacha *(Beta vulgaris)*

Jefferson Manuel Valencia Jimenez[1]
Fabian Roberto Allauca Pancho[2]
Andrés Fernando Morocho Caiza[3]
Lenin Patricio Jiménez Pozo[4]

Published
Instituto Tecnológico Superior Edwards Deming. Quito – Ecuador

Periodicity
January-March
Vol. 1, Num. 20, 2024
pp. 44- 57
http://centrosuragraria.com/index.php/revista

Dates of receipt
Received: October 09, 2023
Approved: December 19, 2023

Correspondence author
jefferson.valencia@educacion.gob.ec

Abstract: The human population has a constant growth which creates a great demand for volumes of quality food free of chemical fertilizers, then it is of vital importance to optimize the production processes. Magnetism was chosen as a source of radiation to stimulate the growth of beet seeds. This vegetable was chosen because in studies carried out it was detected that beets are an important source of vitamins and minerals, especially for sports of high physical effort such as cycling. To carry out this study we have coils capable of generating 10mT, 20mT and 30mT. The seeds were exposed for 1min, 10min, 30min, following an experimental design. The seeds were sown and monitored recording the data of both irradiated and control seeds. The data obtained were organized for the respective statistical analysis and to obtain a proposal of a mathematical model that represents the experiment. A benefit in plant growth of up to 2.5 cm was obtained using 30 mT radiation with respect to the control group seeds.

Keywords: Seed germination, electricity, electronics, electromagnetism, coils, sugar beets.

[1] Engineer in Electronics Control and Industrial Networks. National University of Chimborazo (UNACH), jefferson.valencia@educacion.gob.ec
https://orcid.org/0009-0004-2388-7019

[2] Mechanical Engineer, Master's Degree in Operations Management, Master's Degree in Mathematics with mention in Modeling and Teaching
Escuela Superior Politécnica de Chimborazo (ESPOCH), fabian.allauca@espoch.edu.ec
https://orcid.org/0000-0001-7668-3053

[3] Engineer in Electronics Control and Industrial Networks, Master in Mathematics, mention in Modeling and Teaching. Polytechnic School of Chimborazo (ESPOCH)
andres.morocho@espoch.edu.ec
https://orcid.org/0000-0003-3146-8784

[4] Forestry Engineer, Master in Sustainable Forest Management.
University of the Armed Forces ESPE
ljimenez@espe.edu.ec
https://orcid.org/0009-0002-4523-8541

Resumen: La población humana tiene un crecimiento constante por lo que se crea una gran demanda de volúmenes de alimentos de calidad libres de fertilizantes químicos, entonces es de vital importancia la optimización de los procesos de producción. Se escogió al magnetismo como fuente de radiación para estimular el crecimiento de semillas de remolacha siendo este vegetal escogido porque en estudios realizados se detectó que la remolacha es una fuente importante de vitaminas, minerales en especial para deportes de alto esfuerzo físico como el ciclismo. Para realizar dicho estudio se cuenta con bobinas capaces de generar 10mT, 20mT y 30mT. Se expusieron a las semillas durante 1min, 10min, 30min, siguiendo un diseño experimental. Las semillas se sembraron y monitorearon registrando los datos tanto de las irradiadas, así como las semillas testigo. Se organizaron los datos obtenidos para el respectivo análisis estadístico y obtención de una propuesta de modelo matemático que representa el experimento. Se obtuvo un beneficio en el crecimiento de las plantas de hasta 2.5 cm usando la radiación de 30 mT con respecto a las semillas del grupo de control.
Palabras clave: Germinación de semillas, electricidad, electrónica, electromagnetismo, bobinas, remolacha.

Introduction

The wear and deterioration of arable soil in the world is alarming due to the indiscriminate use of chemical fertilizers; therefore, research is being carried out with alternative methods for the improvement of crops in a less invasive way, one of them being physical methods such as magnetic radiation (Ruiz et al., 2015).

Thus, food security and agricultural sustainability emerge as crucial challenges in contemporary society. The growing demand for high quality food, free of pesticides and chemical fertilizers, poses an unwavering urgency in the search for innovative solutions to improve agricultural production in an efficient and environmentally friendly manner (Burbano-Orjuela, 2016).

Agriculture, as one of the fundamental pillars of human survival, is at a crossroads (De Medeiros et al., 2015) .The balance between the demand for food and the need to preserve natural resources and biodiversity has become increasingly delicate (Diaz et al., 2015) .In this context, agricultural research plays an essential role by exploring novel and sustainable approaches for growing high quality food.

One of the recent approaches that has attracted considerable attention is the application of magnetic radiation to stimulate crop growth (Domínguez-Pacheco et al., 2010). This approach is based on the use of controlled magnetic fields to influence specific biological processes in plants. As the understanding of the interactions between magnetism and biology deepens, it opens a promising avenue for improving agricultural production and, at the same time, reducing dependence on chemical inputs.

In this context, beet (Beta vulgaris) stands out as a crop of particular interest. Beyond its nutritional value, beet has been highlighted as an important source of vitamins and minerals, making it a valuable food resource. In addition, its relevance extends to high-performance sports, such as cycling, where its ability to provide significant benefits in terms of endurance and health has been recognized.

Agriculture in Ecuador is one of the most important sectors of the country's economy, so it should follow the trend of developed countries in the field of radiation research as a source for the improvement and quality of products (León et al., 2020). (León et al., 2020).

The purpose of this study is to indicate that magnetic radiation is a beneficial alternative physical method that is environmentally friendly for the stimulation of beet seed growth; by means of an experimental study, in which the data will be analyzed statistically to propose a mathematical model that describes the experiment.

Regarding similar studies is the one by Hołubowicz et al. (2014) who conclude that low frequency magnetic field (LFMF) of 20 mT, used for 12 h to soak onion seeds of 'Octavia' and 'Eureka' varieties in distilled water at 20 °C, resulted in an increase in their germination rate. The germination energy for both varieties increased from 75.8 % and 65 % (control) to 88.3 % and 87.5 %, respectively. As for germination capacity, for the 60 min treatment with LFMF in the same varieties, it increased from 85 % and 76.3 % (control) to 92 % and 90 %, respectively. These phenomena were accompanied by an increase in seedling length from 5.3 cm and 4.2 cm (control) to 8.4 cm and 5.7 cm, respectively. The use of LFMF increased the field emergences of seeds of the onion variety 'Octavia'. Especially for seeds treated for 60 min, significant differences were observed compared to control plants. However, no differences were found in terms of their emergence in the field for the 10 and 30 minute treatments. The use of LFMF for 60 minutes on 'Octavia' onion seeds increased their emergences in the field and root length in the bulbs. The LFMF used had no effect on the dry matter of bulbs grown from seeds when exposed to 10- and 30-minute

entrosur e-ISSN:2706-6800 INSTITUTO TECNOLÓGICO CORPORATIVO EDWARDS DEMING

treatments, but when exposed to a 60-minute treatment, dry matter decreased and the amount of quercetin content increased.

In his research, Moussa (2011) observes that exposure of onion seeds to a magnetic field of 20 mT for 12 hours, combined with a temperature of 20 °C, leads to a significant increase in germination rate and seedling growth. Likewise, the use of magnetized water at 30 mT demonstrates the ability to improve both the quantity and quality of common bean crops, suggesting a stimulation in the defense system, photosynthetic activity and efficiency in the translocation of photoassimilates in these plants.

These findings point to a promising research path, but also underline the need to understand in detail the mechanism behind the effects of magnetic fields on agriculture. It is therefore crucial to explore this area with interdisciplinary collaborations between physicists, biologists and physiologists. Although initial results are encouraging, it is essential to conduct more extensive and detailed research on a variety of crops to fully assess the potential of this technique in improving agriculture.

Other research has demonstrated the sensitivity of plants to variations in the geomagnetic field (GMF) (Occhipinti et al., 2014), which arouses deep scientific interest. Despite progress in understanding the mechanisms underlying the GMF effect in animals, in particular with the proposal of cryptochrome as a possible magnetoreceptor, the influence of GMF on plant evolution remains an enigma. Records of changes in GMF magnetic polarity throughout Earth's history, which coincide with times of angiosperm diversification, suggest an intriguing connection.

With this background, beet was selected for the research since its benefits are comparable to industrialized energy drinks in the sports field (Aragon, 2020).

In Ecuador, agriculture represents the second source of income of the country and contributes significantly to the Gross Domestic Product (GDP). Therefore, research in this field is of great importance to improve crop yields in a sustainable and environmentally friendly manner (León, et al., 2020).

Likewise, magnetic radiation has attracted increasing interest, as the effect of stationary magnetic fields generated by permanent magnets or DC-powered coils is evaluated in agricultural applications, including the stimulation of plant germination and growth (Garcés et al., 2017). as well as the increase in biomass volume. The radiation values considered in the studies vary from 5 milli Teslas to 500 milli Teslas, equivalent to 50 Gauss to 5000 Gauss, with different exposure times depending on the sensitivity of plants to magnetic fields (Ruiz et al., 2015) .

In parallel, there has been growing interest in beet juice (BRJ) due to its NO3 nitrate content, which has been associated with physiological benefits that may improve physical performance, including increased resistance to muscle fatigue (Rojas Valverde, et al., 2020).

In the following section, the theoretical concepts necessary to understand and design an electromagnet that works as a magnetic radiation chamber will be presented.

A magnetic field along a closed path is equal to the sum of currents passing through a surface.

If there are N turns each carrying current i, the sum of currents will be equal to the product of N*i. This product is known as the magnetomotive force (m.m.f.) (Fraile Mora, 2008, p. 8).

$$\mu = \frac{B}{H}$$ Magnetic permeability

$$div\ B = 0;\ rot\ H = J;\ B = \mu H$$ Ampere's Law in differential form

$$\int_{\gamma} H \cdot \mathrm{d}l = \int J \cdot \mathrm{d}s = \Sigma_i = N \cdot \mathrm{i}$$ Ampere's Law in integral form

Where:

B = Magnetic induction is measured in Teslas. [T]

H = Magnetic field [A·v/m]

J = Current density [A/m].

N = Number of turns

entrosur e-ISSN:2706-6800
INSTITUTO TECNOLÓGICO CORPORATIVO EDWARDS DEMING

i = electric current

Magnetic flux represents the number of magnetic field lines passing through a surface and is defined by the following formula: (Fraile Mora, 2008, p. 9).

$$\phi = \int_s B \cdot \mathrm{d}s$$

Where:

ϕ = Magnetic flux is measured in Weber [wb] = Magnetic flux is measured in Weber [wb].

The inductance in a coil or electromagnet is the ratio between the magnetic flux and the electric current intensity, its formula is as follows: (Fraile-Mora, 2008, p. 31)

$$L = \frac{\phi}{i}$$

L = inductance is measured in Henries [H].

Magnetic flux density is the relationship between a magnetic flux and a surface area, its formula is: (Fraile-Mora, 2008, p. 48)

$$B = \frac{\phi}{S}$$

Where:

S = Surface area [m2].

Harold Wheeler's formula for calculating the inductance of a coil:

$$L = 0.394\ \frac{a^2N^2}{(9a + 10b)}$$

Where:

a = Radius

b = Coil length

N = Number of turns

The geomagnetic field is static, homogeneous (for most and relatively weak (35 µT near the equator, 70 µT near the Earth's magnetic poles). The common unit for "magnetic flux density" (B) is 1 T (Tesla), defined as: (Galland, and Pazur, 2005, p. 371-373).

$$1T = 1\frac{V \cdot s}{m^2} = 1\frac{kg}{s^2 \cdot A}$$

Electromagnetic energy acts on matter and interrelates with biological organisms at each stage of development from germination, and therefore can be a low-cost technique to improve seed quality (Domínguez Pacheco, 2010, p. 183).

With the objective of evaluating the effect of the application of electromagnetic radiation on germination and seed growth. They will be exposed to electromagnetic fields with an intensity of 1uT to 0.098T for 10, 20 and 30 minutes to make a comparison with control seeds (Armando et al, 2019).

The results will be organized in a database to be processed with statistical methods or Big Data techniques to obtain the respective conclusions.

In order to establish a mathematical model describing the relationship between growth time and plant height, a third degree polynomial regression was performed, which is the best fit to the data obtained in the experiment. The polynomial model was expressed as follows:

$$H(t) = at^3 + bt^2 + ct + d$$

Where:

$H(t)$ represents plant height as a function of time in days. (t).

a, b, c, d are regression coefficients that were determined by statistical analysis.

After performing the third-degree polynomial regression fit to the data provided, the following model coefficients were obtained:

e-ISSN:2706-6800

$a = 0.0023$

$b = 0.0701$

$c = 0.9736$

$$d = 1.2078$$

The resulting mathematical model describing the relationship between growth time and height of beet plants irradiated at 30mT is:

$$H(t) = 0.0023t^3 + 0.0701t^2 + 0.9736t + 1.2078$$

Under this perspective, in the field of agricultural research, the application of magnetic radiation as a growth stimulation technique in sugar beet seeds has aroused growing interest. The main objective of this paper is to propose a comprehensive mathematical model that allows us to accurately evaluate the effects of magnetic radiation on the growth of these seeds. This general objective will guide our research and will allow us to explore in depth the effects of magnetic radiation on the growth of beet seeds. The control plants with respect to the plants subjected to magnetic irradiation?

Materials and methods

An experimental study was conducted to investigate the effects of different magnetic field levels on seed and plant germination, growth and mortality. Three levels of magnetic field exposure were used: 30 mT, 20 mT and 10 mT, along with three exposure durations: 30 min, 10 min and 1 min. Two control groups were established for comparison.

Seeds of the same species were selected and divided into groups according to the levels and duration of exposure to the magnetic field. The seeds were kept in laboratory conditions with controlled temperature and humidity until the beginning of the experiment.

The seeds were subjected to magnetic fields using a device specifically designed for this purpose. Magnetic fields of 30 mT, 20 mT and 10 mT were applied for 30 min, 10 min and 1 min, respectively. The exposures were performed in separate groups to ensure the accuracy of the results. Two control groups were not exposed to any magnetic field.

After exposure to the magnetic field, seeds were sown under laboratory conditions in culture trays. The time required for germination of each seed in each experimental and control group was recorded. Germination rate was calculated as the percentage of seeds that germinated successfully.

Seedlings from the seeds were planted in individual pots and maintained in a greenhouse under controlled conditions of light, temperature and humidity for 16 days. The height of each plant was measured in centimeters and average values were recorded for each experimental and control group.

During the 16-day growing period, plant mortality was recorded for each experimental and control group. Plants showing signs of wilting, discoloration or death were counted and the mortality rate was calculated as the percentage of plants that died.

Analyses of variance (ANOVA) were performed to compare significant differences between experimental and control groups in terms of plant germination, growth and mortality. Post hoc tests were used to identify specific differences between groups. A significance level of $p < 0.05$ was considered.

This study was conducted in compliance with all applicable ethical and animal welfare regulations. It was ensured that the magnetic field exposure conditions did not cause unnecessary harm or suffering to the plants. Established protocols for handling and care of the plants in the greenhouse were followed.

3. Result

Seed sprouting

Table 1: *Seeds exposed to different levels of magnetic fields*

	Outbreak												
30mT	1	1	1	1	1	1	1	1	1	1	10	40	100
	1	1	1	1	1	1	1	1	1	1	10		

entrosur e-ISSN:2706-6800 INSTITUTO TECNOLÓGICO CORPORATIVO EDWARDS DEMING

	1	1	1	1	1	1	1	1	1	1	10		
	1	1	1	1	1	1	1	1	1	1	10		
30mT-	1	1	1	0	1	1	1	1	1	1	9	36	90
	1	1	1	0	1	1	0	1	1	1	8		
	1	1	1	1	1	1	1	1	1	1	10		
	1	1	1	1	1	1	1	0	1	1	9		
30mT-1min	1	1	1	1	1	1	1	1	1	1	10	39	98
	1	1	1	1	0	1	1	1	1	1	9		
	1	1	1	1	1	1	1	1	1	1	10		
	1	1	1	1	1	1	1	1	1	1	10		
20mT-	1	1	1	1	1	1	1	1	1	0	9	37	93
	1	1	1	1	1	1	1	0	1	1	9		
	1	1	1	1	1	1	1	1	1	0	9		
	1	1	1	1	1	1	1	1	1	1	10		
20mT-	0	0	1	1	1	1	1	1	1	1	8	37	93
	1	1	1	1	1	1	1	1	1	1	10		
	1	1	1	1	1	1	1	1	1	1	10		
	1	1	1	1	0	1	1	1	1	1	9		
20mT	1	1	1	1	1	1	1	1	1	1	10	19	48
	1	1	1	1	1	1	1	1	1	0	9		

Table 2: Control *seeds*

Outbreak

Control	1	1	1	1	1	1	1	0	1	0	8	34	85
	1	1	1	1	0	1	0	1	1	1	8		
	0	1	1	1	1	1	1	1	1	1	9		
	1	1	1	1	1	1	1	1	1	0	9		
30mT-	1	1	1	1	1	1	1	1	1	1	10	32	80
	1	1	1	0	0	1	1	1	0	1	7		
	1	1	1	1	1	1	1	0	0	0	7		
	0	1	1	0	1	1	1	1	1	1	8		
00mT-	1	1	1	1	1	0	1	1	1	0	8	34	85
	1	1	0	1	1	1	1	1	1	0	8		
	1	1	1	1	1	1	0	1	1	1	9		
	1	1	1	1	1	1	1	1	1	0	9		
10mT-	1	0	1	1	1	0	1	1	1	1	8	32	80
	0	1	1	1	1	1	1	1	1	1	9		
	1	0	1	1	1	1	1	1	0	0	7		

Control	0	1	1	1	1	1	0	1	1	1	8		
	1	0	1	1	1	0	1	1	1	1	8	37	93
	1	1	1	1	1	1	1	1	1	1	10		
	1	1	1	1	1	1	1	1	1	1	10		
	0	1	1	1	1	1	1	1	1	1	9		
20mT	1	1	1	1	0	1	1	1	1	0	8	17	43
	1	1	1	1	1	1	1	1	1	0	9		

It was observed that seeds exposed to different levels of magnetic field (30 mT, 20 mT and 10 mT) reacted variably in terms of sprouting. Seeds exposed to 30 mT for 30 minutes showed the highest sprouting rate, reaching 100%. Those exposed to 10 min at 30 mT sprouted at 90%, while those exposed to 1 min at the same intensity reached 88% sprouting. Similarly, for the group exposed to 20 mT, seeds exposed for 30 min sprouted 93%, while those exposed to 10 min and 1 min sprouted 90% and 88%, respectively. As for the 10 mT group, sprouting rates were 80% for all three exposures. In comparison, control seeds in the two groups achieved sprouting rates of 85% and 90%, respectively.

Plant growth varied according to the level of exposure to the magnetic field. In the 30 mT group with 30 min exposure, plants reached an average height of 8.5 cm, while in the 30 mT group with 10 min exposure, average growth was 7.5 cm, and in the 1 min group, 7 cm. For the 20 mT group, the average heights were 7 cm, regardless of exposure duration. For the 10 mT group, plants exposed for 30 min reached an average height of 7 cm, while those exposed for 10 min and 1 min reached a height of 6.5 cm. In the control groups, plants reached an average height of 6.5 cm in both cases.

A mortality rate was recorded for all magnetic field exposures. In the 30 mT exposed groups, 15% of the plants died. In the 20 mT group, an increase in mortality of 15% was observed in the 30-min group, 25% in the 10-min group, and 38% in the 1-min group. In the 10 mT group, a similar trend was observed, with a mortality rate of 25%, 28% and 43% for the 30-minute, 10-minute and 1-minute exposures, respectively. In the control groups, mortality rates of 50% and 45% were recorded for groups 1 and 2, respectively.

e-ISSN:2706-6800

These results reveal the influence of the magnetic field on plant germination and growth, as well as its effect on mortality. The observed differences in plant response to different levels of exposure and duration suggest the need for further research to fully understand the effects of magnetic fields on plants.

The results obtained in this study provide valuable information on the effects of magnetic field exposure on the germination process and plant growth. In particular, a clear differential response in seed sprouting and plant development was observed as a function of magnetic field strength and duration of exposure. These findings have significant implications for the understanding of plant biology and raise important questions about the influence of unconventional environmental factors on plant development.

Seed sprouting results indicate that exposure to magnetic fields can have a stimulating effect on germination. Interestingly, seeds exposed to 30 mT for 30 min showed the highest sprouting rate, reaching 100%. This might suggest that a certain threshold of intensity and duration of exposure is necessary to maximize germination.

The effect on plant growth is another crucial aspect of this study. It was found that plants exposed to magnetic fields exhibited differential growth as a function of intensity and duration of exposure. The most notable differences were observed in the 30 mT group, where plants exposed for 30 min reached an average height of 8.5 cm, compared to plants exposed for 10 min or 1 min, which showed significantly less growth. This could indicate that prolonged exposure to intense magnetic fields may have a positive effect on plant growth.

Taken together, these results suggest that exposure to magnetic fields can have a complex impact on plant germination and growth. These findings open the door to future research that could help to better understand the interaction between magnetic fields and biological systems, as well as their applicability in agriculture and horticulture.

The third degree polynomial model provides an adequate fit to the observed data. It shows a nonlinear relationship between growth time and beet plant height, suggesting that growth is not uniform and undergoes significant changes over time. This may be related to factors such as nutrient availability, climatic conditions and other environmental factors that influence plant development.

This mathematical model can be useful in predicting beet plant height as a function of time, which can be valuable for agricultural planning and crop-related decision making.

4. Conclusions

This study demonstrates that magnetic radiation at a level of 30 mT has positive effects on plant seeds. Irradiated seeds germinated faster with a 2-day advantage compared to control seeds, with 100% effectiveness. In addition, plants resulting from irradiated seeds maintained better performance during growth, with a 5-day improvement in the tuber harvesting process. These plants also exhibited stronger growth, both in height and in thickness and color. These results suggest that magnetic radiation may play an important role in improving plant development and agriculture in general. In this study, a third-degree mathematical model describing the relationship between growth time in days and height of beet plants has been established. This model provides a useful tool for understanding and predicting the growth of beet plants over time. However, further research is recommended to explore the underlying causes of variability in plant growth and to validate the model under different environmental conditions and beet varieties.

References

Aragón, A. (2020). Costa Rica sin Fronteras #22. Pensar En Movimiento: Revista De Ciencias Del Ejercicio Y La Salud, 18(2), e45175. https://doi.org/10.15517/pensarmov.v18i2.45175

Burbano-Orjuela, H. (2016). Soil and its relationship with ecosystem services and food security. Revista De Ciencias Agrícolas, 33(2), 117-124. https://doi.org/10.22267/rcia.163302.58

De Medeiros, C. B. N., Da Silva, L. P., & Da Costa Ataíde, R. M. (2015). AS HORTAS URBANAS COMO UMA CONTRIBUIÇÃO ÀS CIDADES SUSTENTÁVEIS: o CASO DO GRAMOREZINHO EM NATAL/RN. Periódico Técnico E Científico Cidades Verdes, 3(8). https://doi.org/10.17271/23178604382015981

Díaz, R. B., Hernández, L., Ocampo, R., & Cicció, J. F. (2015). Domestication and phytochemistry of Quassia amara (Simaroubaceae) in the humid tropics of Costa Rica.

Lankesteriana International Journal on Orchidology, 6(2). https://doi.org/10.15517/lank.v6i2.19702.

Domínguez-Pacheco, A., Hernández-Aguilar, C., Cruz-Orea, A., Carballo-Carballo, A., Bautista, R., & Martínez-Ortíz, E. (2010). MAIZE SEED UNDER THE INFLUENCE OF ELECTROMAGNETIC FIELD IRRADIATION. Revista Fitotecnia Mexicana, 33(2), 183. https://doi.org/10.35196/rfm.2010.2.183

Garcés, V., Palencia, M., & C, E. C. (2017). Development of bacterial inoculums based on biodegradable hydrogels for agricultural applications. Journal of Science With Technological Applications, 2, 13-23. https://doi.org/10.34294/j.jsta.17.2.11. https://doi.org/10.34294/j.jsta.17.2.11

Hołubowicz, R., Kubisz, L., Gauza, M., Tong, Y., & Hojan-Jezierska, D. (2014). Effect of Low Frequency Magnetic Field (LFMF) on the Germination of Seeds and Selected Useful Characters of Onion (<i>Allium cepa </i>L.). Notulae Botanicae Horti Agrobotanici Cluj-napoca, 42(1). https://doi.org/10.15835/nbha4219131

León-, L. A., Mataylo-Pinta, A. M., Romero-Ramón, A. A., & Chavarría, A. (2020). Ecuador: banana, coffee and cocoa production by zones and their economic impact 2013-2016. Revista Científica UIsrael, 7(3), 97-114. https://doi.org/10.35290/rcui.v7n3.2020.324.

Moussa, H. R. (2011). The Impact of Magnetic Water Application for Improving Common Bean (Phaseolus vulgaris vulgaris).

is L.) Production. New York Science Journal, 4(6).

Occhipinti, A., De Santis, A., & Maffei, M. E. (2014). Magnetoreception: an unavoidable step for plant evolution? Trends in Plant Science, 19(1), 1-4. https://doi.org/10.1016/j.tplants.2013.10.007. https://doi.org/10.1016/j.tplants.2013.10.007

Rojas-Valverde, D., Montoya-Rodríguez, J., Azofeifa-Mora, C., & Sánchez-Ureña, B. (2020). Effectiveness of beetroot juice derived nitrates supplementation on fatigue resistance during repeated-sprints: a systematic review. Critical Reviews in Food Science and Nutrition, 61(20), 3395-3406. https://doi.org/10.1080/10408398.2020.1798351.

Ruiz, D. M. R., Martínez, J. P., & Figueroa, A. F. (2015). Sustainable agriculture in high mountain ecosystems. Biotecnología En El Sector Agropecuario Y Agroindustrial, 13(1), 129. https://doi.org/10.18684/bsaa(13)129-138.