Magnetic fields: influence of their properties in the agricultural production process

Campos magnéticos: influencia de sus propiedades en el proceso de producción agrícola

Montero-Prado, Pablo; Almanza-Cruz, César

Pablo Montero-Prado
pablo.montero@utp.ac.pa
Universidad Tecnológica de Panamá, Panamá
César Almanza-Cruz
cesar.almanza@utp.ac.pa
Universidad Tecnológica de Panamá, Panamá

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orlando.aguilar@utp.ac.pa

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Abstract: Current efforts to achieve the Sustainable Development Goals to combat and eradicate hunger have led different specialized sectors of society to launch themselves in search of ways that lead to this end. In this sense, the research, development, and innovation (R+D+i) approach has generated various optimized methods to obtain the greatest possible benefits, through important contributions such as the development of varieties with greater resistance to pests and diseases, adverse weather conditions, use of biological agents, agriculture in a controlled environment, among others. The objective of this document is to show the advances in the application of magnetic fields as a tool to improve the productivity of different crops, as part of the techniques of recent application in the agricultural field. Considering the main treatment methods, application characteristics, and the explanation of the possible effects caused in plant entities. Attempts have been made to use scientific articles from different databases, but with significant levels of reliability, measured through the impact indices involved. With a few exceptions, the review of documents published, preferably in the last ten years, and based mostly on specialized conceptualizations was used as a way to find out what is going on with this topic right now.

Keywords: Cultivation, irrigation, magnetic fields, plants, seeds, water.

Resumen: . Los esfuerzos actuales por alcanzar los Objetivos de Desarrollo Sostenible para combatir y erradicar el hambre han llevado a distintos sectores especializados de la sociedad a lanzarse en la búsqueda de caminos que conduzcan a este fin. En este sentido, el enfoque de investigación, desarrollo e innovación (I+D+i) ha generado diversos métodos optimizados para obtener los mayores beneficios posibles, a través de importantes aportes como el desarrollo de variedades de mayor resistencia a plagas y enfermedades, a condiciones climáticas adversas, utilización de agentes biológicos, agricultura en ambiente controlado, entre otros. El objetivo de este documento es mostrar los avances en la aplicación de campos magnéticos como herramienta para mejorar la productividad de diferentes cultivos, como parte de las técnicas de reciente aplicación en el campo agrícola. Considerando los principales métodos de tratamiento, características de la aplicación, y la explicación de los posibles efectos ocasionados en las entidades vegetales. Se ha intentado utilizar artículos científicos de diferentes bases de datos, pero con importantes niveles de fiabilidad, medidos a través de los índices de impacto implicados. Como herramienta para conocer la situación actual de este tema, se enfocó, con contadas excepciones, la revisión de documentos publicados, preferentemente, durante la última década, basados principalmente en conceptualizaciones especializadas.

Palabras clave: Cultivo, riego, campos magnéticos, plantas, semillas, agua .

1. Introduction

The United Nations (UN), established in 2015, the 2030 schedule with the implementation of 17 Sustainable Development Goals (SDGs), to achieve a better world and better standards of living for populations [1]. The second objective of the SDGs proposes directing efforts

to Achieve Food Security, improve nutrition levels, and at the same time, Sustainable Agriculture that could allow reaching levels of "Zero Hunger" by 2030 [2].

In this respect, the Food and Agriculture Organization of the United Nations (FAO) affirms that the achievement of this objective is invariably necessary to

develop, strengthen, and innovate within current agricultural systems [3]. FAO has considered the promotion of cereal crops of great global importance because most of them are used for direct human nutrition. In addition, due to the need to increase the availability of protein for human consumption, through an increase in animal protein, it is necessary to explore the possibility of converting certain plant resources of considerable nutritional value into products of high protein value through forage production. [4-5].

Among the cereals with the greatest impact are corn, wheat, and rice, which are considered fundamental crops to achieve food security, considering that currently around 2,260tons are produced together per year [6]. These cereals can provide about 43% of the world's dietary calories, 37% of proteins, and 6% of fats [3].

Generally, agricultural production can be affected by multiple factors such as temperature, light, wind, erosion, availability of nutrients, water, soil preparation, weeds, crop establishment, pests, pathogens, and, other biotic and/or abiotic factors [7-8]. In short, it is sought that the crops have superior germination characteristics, purity, reversible dormancy levels, use the least number of seeds per area, improve the vegetative development of the plant, and optimize the level of use of the different factors, maximizing the production of plants by cultivated area [9].

Currently, considerable amounts of non-certified seeds are used, which can be reflected in the decrease in their germination capacity and the effective physiological development of the plants, to the detriment of crop yields. One possibility is the improvement of crop yields per planted area, either by enhancing seed germination or increasing the physiological performance of plants.

Considering the above, it should be noted, that several studies indicate that it is possible to improve and even maximize the production capacity of different plant species by applying magnetic fields to the seeds, before the sowing process [10–17], on irrigation water [13], [15], [18], and in some cases, on the plants themselves [19-20].

This document aims to show the potential represented using different alternatives for the application of magnetic fields to improve and enhance the performance of different crops during the various stages of their

development, such as germination, growth, and fruiting of these. For this, multiple publications on this topic will be analyzed. Table 1 shows a summary of them, according to the different applications made, the crops that have been treated in each of them, and their corresponding findings. All these applications will be considered throughout this document.

1.1. Problematic

According to the Food and Agriculture Organization of the United Nations (FAO), as the population grows, the land and water resources for food production are diminishing. To avoid a crisis, they recommend directly addressing a variety of issues, including: 1). Production, governments should promote better crop and seed management techniques; 2). Poverty, small producers need the support and benefit of technologies and methods to cover small-scale needs; 3). Hybrid technology, despite the generation of high-yield varieties, the production costs of these are four or five times that of normal seeds, something out of the reach of most small farmers [21].

Poor germination, or its total failure, gives rise to a poor population of plants in crops made by direct sowing, and with low grain production yields. The low levels of germination in the seeds may be due to different circumstances: 1). Loss of seed viability; 2). Excessive seed dormancy; 3). Soil conditions (excessively dry, wet, or cold) are unsuitable for germination [9]. By achieving maximum seed yield, plant growth and yield can be enhanced through better fruits and higher crop yields [22- 23].

Due to the need for environmentally friendly treatments to improve and enhance crop yield, studies have emerged that involve the use of magnetic fields as physical treatments, to increase seed germination and seedling emergence as part of safe tools in agricultural production systems [24–28].

TABLE 1.
Summary of the achievements, according to the applications and specific conditions of the assays.

Application		Intensity of magnetic field (mT)	Time of treatment	Achievements	References
Seeds	sunflower (Helianthus annuus)	200	2h	> germination 13% > vigor I and II (treated seeds vs control)	[17]
	tomato (Pusa Ruby)	100 to 120	15 to 30 min	> germination 14% > vigor 40% > stem8.6% > root 33%	[29]
	onion (Allium cepa L.)	160	15min	> germination 40% > root 20% > leaves 43.6% > bulb weight 11%	[10]
	Triticale (x Triticosecale Wittmack)	150 to 250	24h	> germination 19%	[11]
	durum wheat (Triticum durum)	12.5	15, 30 and 45min	> germination 30% > chlorophyll 26.5%	[12]
	oil palm (Elaeis guineensis)	2.5, 5.0, 7.0, 9.0 and 11.0	1, 2, 3, 4 and 5h	> germination 96%	[15]
Plants	lemon balm (Melissa officinalis)	50, 100 and 150	5, 15 and 30min; 1 and 3h	> shoot growth 56% > bioactive and phenolic components	[19-20]
Irrigation water	celery (Apium graveolens) and pea plants (Pisum sativum)	3.5 to 136	3s	> vegetal material, celery 12% pea plants 7.8%	[13]
	Turnip (Brassica rapa L.)	211	30, 45 and 60min	> germination 25%	[18]
	Irrigation water oil palm (Elaeis guineensis)	2.5 to 11.0	24h	> upgrowth 210%	[15]

2. Materials and methods

2.1. Treatments

Multiple studies have been carried out that show the possibility of obtaining different interactions and results by applying magnetic fields on different parts of plants, from the seed to the irrigation water, at different times and intensities.

2.1.1. Seed

The seeds represent one of the most important links in the development of crops because it is the structure that contains the condensed resources, at rest, necessary for the generation of a new plant. Due to this, efficient development of it is required [23].

Vashisth & Nagarajan [17] reported applying magnetic fields from 0 to 250mT in steps of 50mT from 1 to 4h in steps of 1h to sunflower seeds (Helianthus annuus). Of these treatments, 50 and 200mT for 2h produced the maximum yield, achieving an increase of 13% in the germination of treated seeds compared to untreated seeds. They also evaluated the germination speed, given by the number of germinated seeds per day. The control showed a speed of approximately 27 seeds per day, while, for the treated seeds, the speed was 33 seeds per day (200mT, 2h). Additionally, the vigor indexes I and II were considered, the vigor index I was calculated by dividing the germination percentage by the length of the seedling (stem and roots), the vigor index II was calculated by dividing the germination percentage by the weight of the dehydrated seedling (stem and roots), finding that the vigor index I varied from 1,500 to 3,000 for the control and the treated seedling, the vigor index II, varied from 3.3 to 4.4 approximately (200mT, 2h). However, a linear relationship was not found between the intensities of the applied magnetic field and the improvement in the different parameters evaluated.

Treatment of tomato seeds (tomato variety from North India - Pusa Ruby) with magnetic fields increased their germination levels by 14% compared to the control (120mT, 15min). The vigor of the seedlings increased by 40% in the treated seeds concerning the control seeds (100mT, 30min), in the treated seed. The length of the seedlings increased from 9.3 to 10.1cm at the stem and from 7.2 to 9.6cm at the root (100mT, 30min). Measurements were made on 8 days [29].

On the other hand, in tests carried out on dry onion (Allium cepa L.) seeds, it was found that the germination potential was 7.5% at 7 days and 11% at 14 days (160mT,

15min). In the same study, it was found that the daily growth of the roots varied from 10mg/day in the control to 12mg/day in the treated plants. In the case of the leaves, the growth varied from 14mg/day to 75mg/day (160mT, 15min). The average weight of the bulbs produced (grams) increased by 11.15% in the treated seeds comparing to the controlled ones (160mT, 15min). In this sense, the yield of the bulbs per growing area (Kg/m2) improved by 40% in the treated seeds concerning the untreated seeds (160mT, 15min) [10].

Triticale (x TriticosecaleWittmack), a cereal obtained from the cross between wheat and rye, was tested. The seeds treated with magnetic fields achieved an improvement in the germination level of 19% compared to the untreated seeds (150 to 250mT, 24h). Seedling length measurements were made at 2, 4, and 6 days after "sowing", observing significant improvements of the treated seeds compared to the control seeds in 71, 77, and 68% respectively (250mT, 24h), which indicates that the seedling with seed treatment developed faster and more abundantly [11].

Studies have been carried out on the application of magnetic fields to seeds of durum wheat (Triticum durum), variety simeto and grecale [12]. A magnetic field intensity of 12.5mT was applied for 15, 30, and

45min. They were able to demonstrate significant improvements in the levels of germination, development, and growth of the plants. The germination level of the seeds treated for 15, 30, and 45min improved from 15.07, 21.85, and 30.46% respectively, for the variety simeto and, 9.93,

12.37 and 12.94% concerning the control, for the grecale variety. Most importantly, they found that higher levels of yield were achieved in kg/ha of the treated crop compared to untreated crops.

Oil palm (Elaeis guineensis) seeds have, as a characteristic, difficulty in the germination process, considering that normally it can take 6 to 12 months. In addition, they maintain a 40% probability of failure [30]. Given this situation, the behavior of oil palm seeds was studied at different intensities of magnetic fields (2.5, 5.0, 7.0, 9.0, and 11.0mT) during five different exposure

times (1, 2, 3, 4, and 5h). The seeds treated with a magnetic field intensity of 9.0mT, for 4h, achieved better performance, achieving a germination level of 96% at 30 days of the trial. In the other treatments, slightly lower germination levels were observed, compared to no control seed germinated in this same period, which represents significant improvements in the capacity and

germination time of oil palm seeds exposed to magnetic fields [15].

2.1.2. Plants

A variant in the use of magnetic fields to improve crop yields focuses on exposing the seedlings after germination.

In this respect, it has been shown that the application of three different magnetic fields (50, 100, and 150mT) with 5 different exposure times (5, 15 and 30min, 1 and 3h) on lemon balm plants (Melissa officinalis) promotes better propagation and growth of its shoots, with an increase of up to 50.6% compared to the control. In addition, a higher number of shoot regeneration was observed (from 3.3 to 8.5 shoots for the bud tip explant and from 2.8 to 9.3 shoots for the hypocotyl bud explant). The increased content of bioactive and phenolic components, as well as its corresponding enzyme involved, the phenylalanine ammonium lyase (PAL). In addition, a better response was observed due to the stress generated, through the free radical scavenging activity of the enzymes superoxide dismutase (SOD) and catalase (CAT) [19-20].

2.1.3. Irrigation water

Water is one of the necessary factors for all life processes. In agricultural activities, it becomes an essential resource for continuous use to obtain food. It is necessary to emphasize that water can be modified, with relative ease, by the action of magnetic fields [13], [15], [31].

Maheshwari & Singh Grewal [13], point out that the use of magnetized water significantly increases the yield and productivity of celery (Apium graveolens) and pea plants (Pisum sativum), by 12 and 7.8% respectively, with respect to untreated plants, using ranges of 3.5 to 136mT.

On the other hand, Haq et al., [18], point out that, by using magnetic field treatment on irrigation water, with an intensity of 211mT at variable times of 30, 45 and 60minutes, it was possible to achieve considerable improvements over the germination levels of turnip seeds (Brassica rapa L.), reaching germination levels of 72,

79.5 and 90% compared to 64.5% of the untreated seeds. Sudsiri et al., [15], reported that it was possible to find significant differences in the growth rate of young oil palms irrigated with water treated with magnetic fields (2.5 to 5.0mT), compared to plants irrigated with water

without treatment. For this, they used normal water (water + ions, pH of approximately 8.2, and electrical conductivity of approximately 600µsiemens/m) subjected to magnetic fields generated by strontium isotropic permanent magnets for 48 hours. After exposure, the treated water showed a conductivity of close to 1400µsiemens/m. The results indicate that the oil palm plants, with magnetically treated irrigation water, grew 3 times faster than the plants irrigated with normal water, at a rate of 3.1mm/day for the treated plants against 1 mm daily in the plants without treatment.

2.2. Mechanism of action

Various studies have been carried out to find out the effect caused by the application of magnetic fields directly on different kinds of seeds and on the water used to irrigate them. Although satisfactory results have been found in most of them, the physiological effect that promotes the satisfactory development of plants is not entirely clear.

Some research suggests the possibility that the application of magnetic fields interferes with the calcium ion sequestration mechanism, modifying the concentration of these in the seedling system, and generating accelerated cell division activity [29], [32].

On the other hand, the possibility has been raised that the applied magnetic fields can generate modifications in the enzymatic activity [12],[17]. Katsenios et al., [12], reported that from the fourth day of the application of the treatments (15, 30, and 45min) the observed enzymatic activity of α-amylase was significantly higher compared to the untreated seeds (control). Additionally, they found that the chlorophyll content (µg/cm2) of the durum wheat plants was significantly higher in the magnetic field treatments to the control, for the simeto variety, varying from 24.54 to 26.5% in the simeto variety and 3.55 to 9.01% in grecole variety. Vashisth & Nagarajan, [17], in turn, reported that, in sunflower seeds, the activity of the enzyme α-amylase is increased in the magnetically treated seeds. α-amylase is the enzyme responsible for the degradation of the nutrient reserves contained in the seed, which implies a greater availability of nutrients during the first stages of germination and growth of the seedlings.

Another hypothesis generated in test son pea seeds is that the application of magnetic fields influences the structure of the cell membrane, modifying its permeability, affecting its metabolic pathways through

the transport of ions through it [33]. In this same way, García and Arza [34], found that the seeds treated with magnetic fields, considerably increase the levels of water absorption, they consider that the magnetic fields interact with the ionic currents, modifying the osmotic pressure and the concentration of ion on both sides of the cell membrane.

On the other hand, the application of magnetic fields may influence the defense capacity of seeds and plants against the attack of infections, as reported by Agustrina,

R. et al., [35], by evaluating the response of tomato seeds treated against infection caused by Fusarium oxysporum. Additionally, it is possible that some of the characteristics achieved through the application of magnetic fields in the seeds, such as early germination of these, generate a greater development of the root system of the seedlings, allowing greater efficiency in the processes of extraction of nutrients and soil moisture

[33].

The magnetic treatment may produce stability of the pH of the water through the variation of its ionization, due to the modification of the bonds [36]. This same variation can cause variations in the concentration and availability of calcium (Ca), phosphorus (P), nitrogen (N), potassium (K), sodium (Na), magnesium (Mg) in the soils used for crops [37-38].

2.3. Adverse effects

It is worth mentioning that, throughout the literature review carried out, no negative effects were found that can be directly linked to the use of magnetic fields in the different application alternatives. However, it was shown that the results do not reflect linear behavior in all the cases studied.

3. Results and Discussion

Advantages of the technique

In a general way, it is necessary to point out that organisms are naturally influenced by terrestrial magnetism. Nevertheless, an interaction produced outside this area will have some repercussions on the vital processes of the organisms involved [8], [14]. Currently, there is no consensus on the most effective combination of strength and duration [29]. However, various morphological and geometric arrangements have been designed to generate external magnetic fields for different purposes. For example, applications that induce

the orientation of water molecules, for example, it orders, stabilizes, and facilitates the freezing of refrigeration processes [39]. In addition to this, it has been shown that it is possible to activate and accelerate the growth of microorganisms and plants using weak magnetic fields, that is, of low intensity [40]. This indicates to us the viability of manipulating this force of nature for our benefit.

The conditions currently used in the various studies carried out to visualize the effects generated on the seeds and the development of the plants do not represent a risk to the individual health of the species and of the human being [17]. However, conditions and limitations have been established to ensure the safety of exposed organisms. European regulations [16], establish levels of 2T for normal work situations and 8T for controlled working conditions. Considering intensities greater than 7T as ultra-high fields, magnetic fields of 1.5 to 3T, strong intensities.

In fact, the magnetic and electromagnetic treatments that are being used in agriculture are considered non- invasive conditions and tools, on the contrary, they are considered affordable, clean, safe, and environmentally friendly methods [15], [33], [41–43].

4. Conclusions

Increasing the yield of different crops by improving the performance and development of seeds and plants is not a very insignificant objective for many organizations and governments worldwide. If we consider that this potential is intrinsically involved with the fulfillment of some of the United Nations Sustainable Development Goals: a). Goal 1. “End of Poverty”; b). Objective 2. “Zero Hunger”; c). Objective 10. “Reduction of Inequalities”. All of this would make it possible to achieve a considerable social impact by improving the income of producers and other indirect beneficiaries, which would make it possible to overcome poverty levels, fighting at the same time inequality towards producers, through access to technologies such as tools to improve production systems. For the adoption of this technology as an environmentally friendly tool, it is necessary to carry out multiple studies that allow adapting the application characteristics according to the properties of each crop, and according to the specific conditions of the region where the farms will be established.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interest.

CONTRIBUTION AND APPROVAL OF THE AUTHORS

The contribution of each author is specified below: Research, P.M., C.A.; Conceptualization, P.M.; Preparation and correction of the article, P.M., C.A.; Supervision, PM.

All authors affirm that the final version of this article was read and approved.

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