

Evaluation of the Germination of Corn Seeds Treated and Irrigated with Magnetized Water

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KEYWORDS: Magnetic induction, irrigation, seed germination, seed treatment, corn, structured water.

- Received: October 30, 2021
- Revised: December 19, 2021
- Accepted: February 21, 2022
- Published: April 25, 2022

doi:10.14294/WATER.2022.S9

Abstract

Corn is one of the most economically important crops in Brazil, and sowing it requires special attention to soil water availability. Magnetized water irrigation is an alternative to irrigation and seed treatment. Thus, the objective of this work was to evaluate the germination of corn seeds treated and irrigated with magnetized water. The experiment was carried out in May 2021 in a greenhouse at Fazenda Água Limpa, belonging to the University of Brasília (UnB). Corn seeds were subjected to four irrigation treatments with magnetized water, namely: magnetic induction of 0.28 T (T1), 0.229 T (T2), 0.029 T (T3) and 0 T (control). The variables evaluated were germination percentage, mean germination time, fresh seedling mass, dry seedling mass and seedling vigor. The design used was completely randomized, with five replications. Water magnetization was performed using three magnetizers, Jiangsu YLD Water Processing Equipment Co. Ltd. (T1), Structured Water Agriculture Magnetizer (T2) and Magnetizer Industrial Technologies Inc. (T3). The studied levels of magnetic induction in the irrigation water, as variables germination percentage and seedling vigor, differentiated among themselves at the level of 5%. Mean germination time, seedling fresh mass and seedling dry mass did not differ between treatments.

Introduction

Corn is one of the main crops grown in Brazil and according to the Agricultural Cooperative of the Federal District Region (Web ref. 1), in the region of the Directed Settlement Program - PAD/DF, 47,600 hectares harbor corn crops. In addition to the commercial interest of large producers, the

culture of corn has significant sociocultural importance for small and medium producers, due to its wide application in fresh human and animal consumption.

Corn is one of the most interesting, cultivated plants in terms of its origin, structure and variation. It is only known in cultivation and, in its current form, shows no indication that it could survive without man's care. Research has developed such different types of maize that its cultivation is possible from the Equator to the limits of temperate lands, and from sea level to altitudes above 3,600 m. This adaptability, represented by varied genotypes, is parallel to the variety of its use as food, forage or in industry (Magalhães *et al.* 1995).

Crop production is predominantly divided into two annual crops, the first sown by the end of December (main crop) and the second from early January (safrinha). Thus, planning of sowing for optimizing the supply of water resources is important. In Brazil's Federal District, the rainy season occurs between the months of October and April, so the cultivation of corn outside this period can reduce seed germination, the duration of the vegetative stages of the plants, and productivity.

Corn is a quick germination plant. Under ideal conditions of light, temperature, and humidity of the environment in which the seed was sown, germination occurs four to five days after sowing, and corn is an excellent plant to make and demonstrate how to carry out a germination test (Macedo, 2014).

The basis for high productivity of any culture is related

to the establishment of plants in the field, which in turn depends on the rational management and quality of the seeds used (Machado *et al.* 2001).

The plant absorbs water from the soil to meet its physiological needs and, in this way, supply the need for nutrients transported along with the water, in the form of mass flow (Magalhães *et al.* 2006).

The process that begins with the resumption of growth by the seed embryo, developing to the point where it forms a new plant with full conditions to nourish itself, becoming independent, is called germination (Kramer and Kozłowski, 1972). Germination occurs in a sequence of physiological events influenced by factors external (environmental: light, temperature, availability of water and oxygen) and internal (inhibitors and promoters of germination) to the seeds, which can act by themselves or in interaction with others (Kramer and Kozłowski, 1972; Nassif *et al.* 1998).

In germination, after imbibition of the seed, it absorbs water and swells, the hydrated integument softens and breaks down, the growth tissues develop with the food supply by the cotyledons, the radicle emerges and fixes, the leaves begin to form, increasing the photosynthetic potential of the seedling, the absorption of nutrients from the environment begins, the cotyledons undergo abscission and the plant does not depend on the nutrients of the seed (Floriano *et al.* 2004).

Thus, the use of magnetized water during different food production processes, including the germination of seeds, is a promising technique but still lacking information for the best use.

Researchers consider that the prospect of using cheap magnetic energy to improve soil properties and plant growth and development may be of great practical importance (Mohamed *et al.* 2013). Magnetic and electromagnetic treatments are being used in agriculture, as a non-invasive technique, to improve seed germination and increase crop productivity (Martínez *et al.* 2009).

Several studies point to evidence that water exposed to the magnetic field has different properties from non-magnetically treated water. The main changes observed in magnetized water were the adsorption of water on surfaces (Ozeki *et al.* 1996), crystallization and precipitation of salts (Katsuki *et al.* 1996; Kronenberg, 1985), solubility of some minerals (Hasson *et al.* 1985; Herzog *et al.* 1989; Bogatin *et al.* 1999; Gehr *et al.* 1995) and surface tension (Joshi and Kamat, 1966).

Therefore, the objective of this work was to evaluate the germination of treated corn seeds irrigated with magnetically treated water.

Materials and Methods

Experiment Site

The experiment was carried out in May 2021 inside a greenhouse at the Água Limpa Farm, belonging to the University of Brasília (UnB) and located across the geographic coordinates of latitude 15°56'50" S and longitude 47°56'02" W. The altitude of the site is 1,080 m above sea level and the climate of the region is type Aw, according to the Köppen-Geiger climate classification (Peel *et al.* 2007), tropical with a dry season, with an average temperature of 23.2 °C and average rainfall of 1,660 mm year⁻¹, concentrated between the months of October and April.

Variety Used

The variety of corn used was Cativerde 02, produced by the Sustainable Rural Development Coordination of the State of São Paulo – CATI, marketed by BRSEEDS. The seeds have, according to the trader, a minimum purity of 98% and a minimum germination of 85%.

Treatments

The design used was completely randomized, with four treatments and five replications each. The different levels of magnetic induction adopted were: T1 – 0.28 Tesla (T); T2 – 0.229 T; T3 – 0.029 T; T4 – 0 T (control).

The magnetization of water occurs through the passage of its flow through a magnetic field, which is formed by magnets. The magnetic field varies according to the size and shape of the magnets, but once the magnets are installed, the magnetization intensity remains unchanged. To carry out the water magnetization, three different magnetizers were used, installed at the beginning of each main line, namely, Jiangsu YLD Water Processing Equipment Co., Ltd. (T1), Structured Water Agricultural Magnetizer (T2) and Magnetizer Industrial Technologies Inc. (T3).

The Jiangsu YLD Water Processing Equipment Co. is cylindrical in shape, with dimensions of 0.16 by 0.45 meters and a weight of 5 kilograms. Water flows through 4 channels between the magnets, with a water inlet diameter of 2 inches.

The Structured Water Agricultural Magnetizer has a magnetic induction intensity of 2,290 Gauss or 0.229 Tesla, evenly distributed across a 2-inch diameter and over a length of 0.098 m. In addition, 95% of the magnetic intensity is concentrated in its interior, meeting the international safety limits established by the World Health Organization and the International Commission on non-ionizing radiation protection (ICNIRP). Permanent magnets with a remaining magnetic induction intensity of 12,000 Gauss or 1.2 Tesla are used, and can be used at temperatures up to 80 °C. This product was developed to favor use in irrigation systems for food production in agriculture. It has a magnetization capacity of up to 11,000 liters of water per day at a speed of 2 m/s.

Magnetizer Industrial Technologies Inc. has a rectangular shape, with the magnets having dimensions of 0.1 by 0.065 meters. The magnetizer has two plates with two magnets in parallel and is installed directly to the irrigation piping.

The seeds were subjected to treatments through immersion for a period of 3 hours and 30 minutes, in a volume of 0.25 liters, according to the respective treatment, using fifty seeds per treatment. Subsequently, they were seeded in polystyrene trays, with 200 cells, filled with Bioplant brand substrate, and from then on, they were irrigated with the respective treatments at a frequency of four times a day for five minutes each. The first irrigation was at 8:00 am and the subsequent ones were every three hours. Irrigation was performed by nebulizer-type sprinklers, with three nebulizers per tray, with a flow rate of 9.3 liters per hour each.

Parameters Evaluated

For the germination evaluation, the following parameters were considered: (Hozayn *et al.* 2018)

Germination Percentage (%):

The total number of germinated seeds was counted daily, and the percentage was calculated on day 14 after planting according to the following equation:

$$\text{Germination (\%)} = \frac{\text{Total number of germinated seeds}}{\text{Total number of evaluated seeds}} \times 100$$

Mean Germination Time (MET):

It was calculated based on the equation of Ellis and Roberts (1981):

$$MET = \frac{\sum_{i=1}^n D_i n_i}{\sum_{i=1}^n n_i}$$

Where n is the number of seeds that germinated (emerged) on days D and D is the number of days counted from the beginning of germination.

Fresh Seedling Mass:

Twenty-five normal seedlings were measured 14 days after planting to determine fresh mass (gram) using a scale.

Seedling Dry Mass:

The seedlings that were used for fresh mass were dried in a hot air oven at 70 °C for 48 hours to obtain the seedling dry mass (gram) under laboratory conditions (Krishnasamy *et al.* 1990).

Seedling Vigor:

It was calculated following Abdul Baki and Anderson (1973) as:

$$\text{Seedling vigor} = \text{Emergence (\%)} \times \text{dry seedling weight}$$

Statistical Analysis

The data were subjected to analysis of variance by the F test at 5% significance and the means between treatments were compared by the regression test, using the software for statistical analysis Sisvar version 5.6 – DEX/UFLA.

Results and Discussion

The raw data collected throughout the experiment for the treatment at the magnetization level of 0.28 Tesla are distributed in *Table 1*.

Table 1. Germination raw data for the 0.28 Tesla magnetic level.

		Days after seeding														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	GT
R1	GS	0	0	0	0	4	1	0	0	0	0	0	0	1	0	6
R2	GS	0	0	0	0	6	0	0	0	0	0	0	1	0	0	7
R3	GS	0	0	0	0	3	2	0	1	0	0	0	0	0	0	6
R4	GS	0	0	0	1	3	1	0	0	0	1	1	1	0	0	8
R5	GS	0	0	0	0	0	6	1	1	0	0	0	0	0	0	8

GS: germinated seeds. GT: germinated total. R1: first repetition. R2: second repetition. R3: third repetition. R4: fourth repetition. R5: fifth repetition.

The raw data collected throughout the experiment for the treatment at the magnetization level of 0.229 Tesla are distributed in *Table 2*.

Table 2. Germination raw data for the 0.229 Tesla magnetic level.

		Days after seeding														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	GT
R1	GS	0	0	0	2	3	1	1	0	1	0	0	0	0	0	8
R2	GS	0	0	0	2	5	1	1	0	0	0	0	0	0	0	9
R3	GS	0	0	0	2	4	1	2	1	0	0	0	0	0	0	10
R4	GS	0	0	0	3	1	1	0	0	0	0	0	1	1	0	7
R5	GS	0	0	0	0	7	1	1	0	0	1	0	0	0	0	10

GS: germinated seeds. GT: germinated total. R1: first repetition. R2: second repetition. R3: third repetition. R4: fourth repetition. R5: fifth repetition.

The raw data collected throughout the experiment for the treatment at the magnetization level of 0.029 Tesla are distributed in *Table 3*.

Table 3. Germination raw data for the 0.029 Tesla magnetic level.

		Days after seeding														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	GT
R1	GS	0	0	0	0	7	0	0	1	0	0	0	0	0	0	8
R2	GS	0	0	0	0	6	0	2	1	0	0	0	0	0	0	9
R3	GS	0	0	0	0	7	0	0	0	0	0	0	0	0	0	7
R4	GS	0	0	0	0	7	2	1	0	0	0	0	0	0	0	10
R5	GS	0	0	0	1	6	1	1	1	0	0	0	0	0	0	10

GS: germinated seeds. GT: germinated total. R1: first repetition. R2: second repetition. R3: third repetition. R4: fourth repetition. R5: fifth repetition.

The raw data collected throughout the experiment for the control treatment are distributed in *Table 4*.

The different levels of magnetization used in seed treatment and irrigation significantly influenced ($p < 0.05$) the variable percentage of germination (%) (*Table 5*). Seed germination occurred in all treatments, with treatments T2 and T3, 0.229 and 0.029 T, respectively, those with the highest average, with the value of 88% of germinated seeds (*Figure 1*). Also, treatments T2 and T3 presented

mean value for the percentage of germination 29.41% greater than the control. Also, treatments T2 and T3 presented average value for the percentage of germination 29.41% greater than the control.

Table 4. Germination raw data for the control treatment.

		Days after seeding														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	GT
R1	GS	0	0	0	0	4	0	0	1	0	0	0	0	0	0	5
R2	GS	0	0	0	0	2	2	0	0	0	1	0	1	0	0	6
R3	GS	0	0	0	1	3	0	1	0	0	1	0	0	0	0	6
R4	GS	0	0	0	1	5	1	0	0	0	0	1	0	0	0	8
R5	GS	0	0	0	1	2	2	2	0	1	1	0	0	0	0	9

GS: germinated seeds. GT: germinated total. R1: first repetition. R2: second repetition. R3: third repetition. R4: fourth repetition. R5: fifth repetition.

Table 5. Analysis of variance for the percentage of germination variable.

Germination percentage					
Source of variation	DF	SS	MS	FC	Pr>Fc
Treatment	3	1815	605		0.0433*
Standard error	16	2840	177.5		

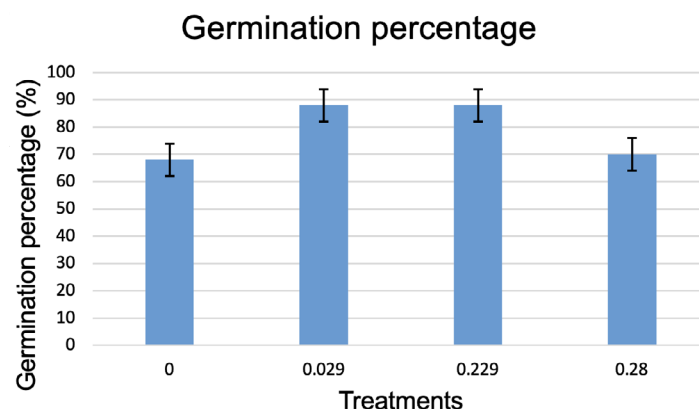


Figure 1. Mean values for percentage of corn seed germination as a function of magnetic induction levels applied in irrigation water of 0; 0.029; 0.229 and 0.28 T.

The regression equation (*Figure 2*) that most adequately represented the germination percentage response to the different levels of magnetic induction applied to the

irrigation water was the quadratic model with the correlation coefficient $R^2 = 0.9114$.

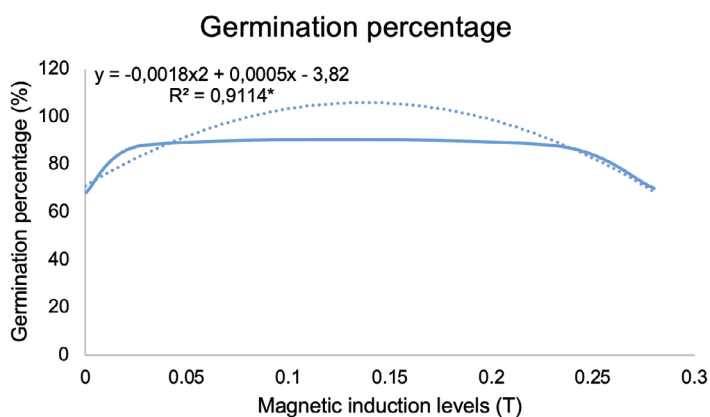


Figure 2. Percentage of maize seed germination as a function of magnetic induction levels applied in irrigation water of 0; 0.029; 0.229 and 0.28 T.

With a growing demand for healthier foods, research, and development of technologies capable of increasing productivity without affecting the environment, is essential. In this scenario, research on the magnetization of water used for irrigation has been carried out to develop a technique with low environmental impact and which can positively increase the productive and nutritional aspects of plants. Furthermore, it is an easy-to-apply technique, and its use can be an alternative to accelerate the germination process of seeds with greater dormancy.

Flores (2019) studied the effects of running water by magnetism and far infrared on sorghum germination and water relations. The author observed a higher percentage of sorghum (*Sorghum bicolor*) seed germination for mineral and reverse osmosis waters submitted to magnetism and far infrared, in relation to the control, without treatment with magnetism and far infrared. Aguilera and Martin (2016), working with seedling germination of *Solanum lycopersicum* L. under irrigation with magnetically treated water, at the level of 0.12 Tesla, and untreated water, obtained a higher germination percentage for magnetized water. Vieira *et al.* (2020), working with the production of vegetable seedlings under seed magnetization and the use of magnetized water, found higher values for percentage of germination for the treatment in which the seedlings were irrigated with water treated with an Irrifex magnetizer (0.15 T).

There was no significant effect of the levels of magnetic induction applied in the irrigation water on the mean values of mean germination time (Table 6). Although

there was no significant difference between treatments, the one with the lowest mean germination time was T3 (0.029 T), with a mean value of 5.41 days (Figure 3).

Table 6. Analysis of variance for the mean germination time variable.

Mean germination time					
Source of variation	DF	SS	MS	FC	Pr>F _c
Treatment	3	2.9772	0.9924	3.055	0,0586 ^{ns}
Standard error	16	5.1976	0.3248		
Total corrected	19	8.1748			
CV (%)	9.56				
Average	5.963	Number of observations: 20			

DF: degree of freedom. SS: sum of squares. MS: mean square. CV (%): coefficient of variation. NS: non-significant. (P>0.05). *: significant at the 5% level (p<0.05). **: significant at the 1% level (p<0.01).

Despite the fact that the different levels of magnetic induction do not significantly represent the variation in the mean germination time of maize seeds, this parameter can still be represented by a quadratic regression, at a significance level of 5%, with a coefficient of correlation $R^2 = 0.8075$.

$$\text{Mean germination time} = 0.00006x^2 + 0.00003x + 2.47$$

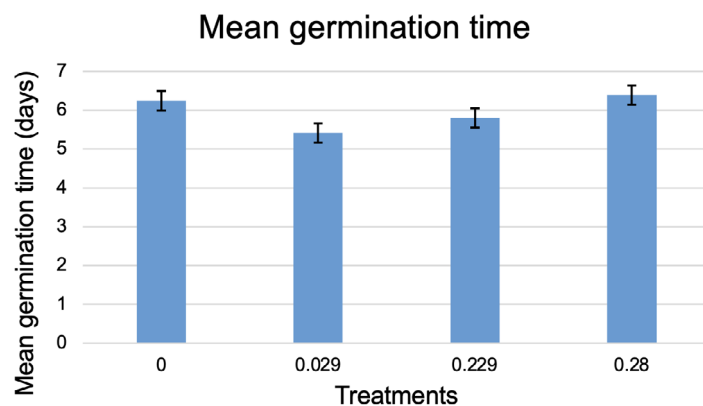


Figure 3. Mean values for mean germination time of corn seeds as a function of magnetic induction levels applied in irrigation water of 0; 0.029; 0.229 and 0.28 T.

Mahmood and Usman (2014), cited by Flores (2019), evaluated the effect of magnetic treatment (235 mT; flow 3L/min) in four types of water for irrigation (sewage, saline solution, irrigation channel and tap) in the germination of seeds, germination rate and speed, germination index and root growth of maize (*Zea mays*), submerging them in water for 24 hours, and verified that treatments with water treated by magnetism promoted the germination of maize seeds, reducing germination time in 17.9%. Vieira *et al.* (2020), working with the production of vegetable seedlings under seed magnetization and the use of magnetized water, found higher values for mean germination time for the treatment in which seeds were treated with an Irrifes magnetizer (0.15 T).

There was no significant effect of the levels of magnetic induction applied in the irrigation water on the mean values of seedling fresh mass (Table 7).

Although there was no significant difference between treatments, the one with the highest value for seedling fresh mass was T1 (0.28 T), with an average value of 2.44 grams (Figure 4).

Table 7. Analysis of variance for seedling fresh mass variable.

Fresh seedling mass					
Source of variation	DF	SS	MS	FC	Pr>Fc
Treatment	3	0.528	0.176	1.853	0.1783 ^{ns}
Standard error	16	1.52	0.095		
Total corrected	19	2.048			
CV (%)	14.27				
Average	2.16	Number of observations: 20			

DF: degree of freedom. SS: sum of squares. MS: mean square. CV (%): coefficient of variation. NS: non-significant. (P>0.05). *: significant at the 5% level (p<0.05). **: significant at the 1% level (p<0.01).

Mahmood and Usman (2014), working with magnetization in different types of water, observed an increase in the fresh mass of seedlings, after 15 days of planting, of 24.8%, 21.3%, 20.1% and 17.4%, respectively, compared to the control treatment.

There was no significant effect of the levels of magnetic induction applied in the irrigation water on the mean values of seedling dry mass (Table 8). Although there was no

significant difference between treatments, the one that obtained the highest value for seedling dry mass was T2 (0.229 T), with an average value of 0.276 grams (Figure 5).

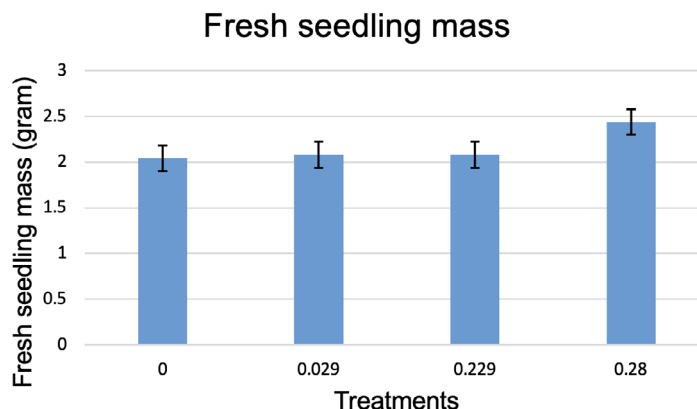


Figure 4. Mean values for fresh mass of maize seedlings as a function of magnetic induction levels applied in irrigation water of 0; 0.029; 0.229 and 0.28 T.

Vieira *et al.* (2020), working with the production of vegetable seedlings under seed magnetization and the use of magnetized water, found higher values for shoot dry mass for the treatment in which seedlings were irrigated with water treated with an Irrifes magnetizer (0.15 T). Pradela *et al.* (2018), working with a Sylocimol Rural magnetizer, found a significant difference for shoot dry mass for the lettuce crop, the result being superior for the treatment using magnetization.

Table 8. Analysis of variance for the seedling dry mass variable.

Dry seedling mass					
Source of variation	DF	SS	MS	FC	Pr>Fc
Treatment	3	0.0029	0.0010	0.746	0.5404 ^{ns}
Standard error	16	0.0029	0.0013		
Total corrected	19	0.0238			
CV (%)	14.27				
Average	2.16	Number of observations: 20			

DF: degree of freedom. SS: sum of squares. MS: mean square. CV (%): coefficient of variation. NS: non-significant. (P>0.05). *: significant at the 5% level (p<0.05). **: significant at the 1% level (p<0.01).

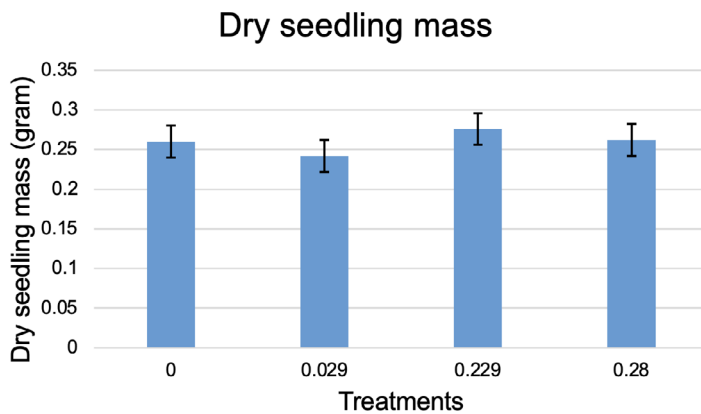


Figure 5. Mean values for dry mass of maize seedling as a function of magnetic induction levels applied to irrigation water of 0; 0.029; 0.229 and 0.28 T.

Table 9. Analysis of variance for the seedling vigor variable.

Seedling vigor					
Source of variation	DF	SS	MS	FC	Pr>Fc
Treatment	3	122.51	40.84	2.418	0.1041 ^{ns}
Standard error	16	270.21	16.88		
Total corrected	19	392.72			
CV (%)	13.89				
Average	20.35	Number of observations: 20			

DF: degree of freedom. SS: sum of squares. MS: mean square. CV (%): coefficient of variation. NS: non-significant. (P>0.05). *: significant at the 5% level (p<0.05). **: significant at the 1% level (p<0.01).

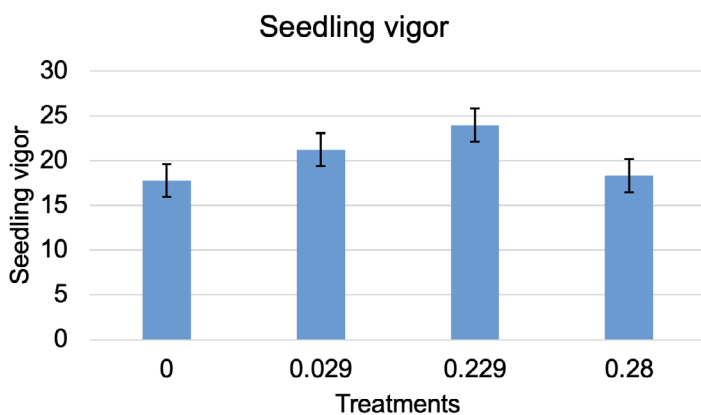


Figure 6. Mean values for corn seedling vigor as a function of magnetic induction levels applied in irrigation water of 0; 0.029; 0.229 and 0.28 T.

The different magnetization levels used in seed treatment and irrigation did not affect the seed vigor variable at the 5% level (Table 9). The treatment that obtained the highest mean for the seedling vigor parameter was T2 (0.229 T), with an average value of 23.99 (Figure 6).

The regression equation (Figure 7) that most adequately represented the germination percentage response to the different levels of magnetic induction applied to the irrigation water was the quadratic model with the correlation coefficient $R^2 = 0.9992$.

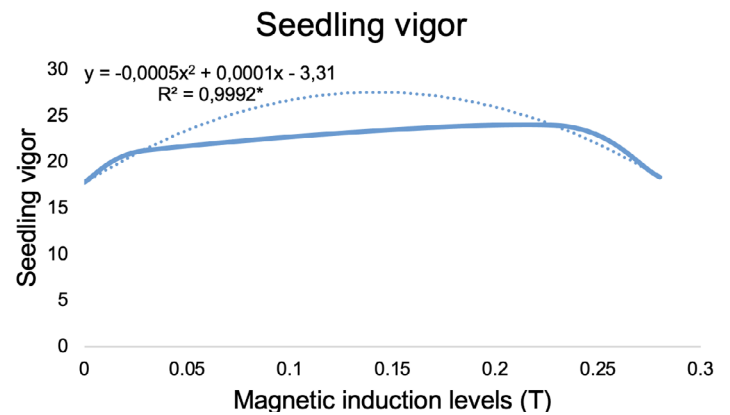


Figure 7. Seedling vigor of corn seeds as a function of magnetic induction levels applied in irrigation water of 0; 0.029; 0.229 and 0.28 T.

Conclusion

The different levels of magnetic induction applied via seed treatment and irrigation water, in corn seeds, significantly influenced (p<0.05) the variable percentage of germination. There was no significant effect of the different levels of magnetic induction applied in the irrigation water on the variables mean germination time, fresh seedling mass, dry seedling mass and seedling vigor. Since it is a technology with recent application to agriculture, further research is needed to assess the impact of using other levels of magnetization.

Discussion with Reviewers (DWR)

Reviewer: The variety of corn used, Cativerde 02, according to the trader BRSEEDS, has a minimum purity of 98% and a minimum emergence of 85%. How can these characteristics influence the percentage of emergence found in the study?

Authors: Because the corn seed used is a variety and not a transgenic one, the variability presented in the data occurred. Variety corn results from a natural cross between seeds of the same lineage, different from a hybrid seed, which is obtained by two other varieties. With the use of transgenic seeds, the germination in the control would be quite homogeneous, due to the characteristic of the seed.

Reviewer: How could the presented research contribute to the studies about the molecular structure of water and its connection with water management?

Authors: The magnetic water treatment modifies the water clusters, thus altering their structure. This change, according to research cited in the article, alters, among some parameters, the absorption of water by plants. Thus, more research could be done in order to discover the different impacts of magnetically treated water on agricultural production. Among these possibilities, this research stands out, which demonstrates that by treating and irrigating maize seeds, it is possible to increase the germination percentage and, thus, ensure homogeneous production.

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