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Development of *Raphanus sativus* L. is Stimulated by Irrigation with Magnetically Treated Water

Desenvolvimento do *Raphanus sativus* L. é Estimulado Pelo Uso de Irrigação com Água Tratada Magneticamente

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Abstract

Radish irrigation promotes the best development of the crop; however, at the same time, it has to be employed efficiently. The present work aims to determine the effect of magnetically treated water on the agronomic performance of *Raphanus sativus* L. The experimental design used was completely randomized with two treatments consisting of two types of irrigation [magnetically treated water (MTW) and without (WWMT)], with 3 replications of 20 plants each. Seeds of *Raphanus sativus* L. cultivar (Alegro radish) were used. Magnetic treatment was performed using a magnetic device with a nonuniform or heterogeneous static magnetic field between 100 and 200 mT. During crop development, the number of leaves (NL) and plant height (PH) were evaluated, and at harvest, the average fruit weight (FW) and radish diameter (RD) were evaluated. ANOVA showed that there were significant differences when comparing irrigation treatments in favor of MTW only for the variables NL at 21 days after sowing (DAS) and RD at the end of the crop cycle (35 DAS); however, MTW stimulated all the variables [plant height (9%), number of leaves (5%), fruit diameter (25%), and average fruit weight (4%)]. It was concluded that, under the conditions of this study, irrigation with magnetically treated water leads to changes in radish plant morphology and can be recommended as a treatment that stimulates crop development.

Keywords: Radish. Drip. Sustainable Production. Agronomic Management.

Resumo

A irrigação do rabanete promove o melhor desenvolvimento da cultura, entretanto, ao mesmo tempo tem que ser empregada de modo eficiente. O presente trabalho tem como objetivo determinar o efeito da água tratada magneticamente no desempenho agronômico do Raphanus sativus L. O delineamento experimental utilizado foi completamente aleatorizado com dois tratamentos que consistiram em dois tipos de irrigação [água com tratamento magnético (ACTM) e sem (ASTM)], com três repetições de 20 plantas cada. Foram empregadas sementes da cultivar de Raphanus sativus L. (rabanete Alegro). O tratamento magnético foi realizado através de um dispositivo magnético com um campo magnético estático não uniforme ou heterogêneo entre 100 e 200 mT. Durante o desenvolvimento da cultura foi avaliada número de folhas (NF) e altura da planta (AP), e na colheita foram avaliados o peso médio dos frutos (PF) e o diâmetro dos frutos (DR). A ANOVA mostrou que existe diferencias significativas quando comparados os tratamentos de irrigação a favor da ACTM apenas para as variáveis NF aos 21 dias após semeadura (DAS) e no DR ao final do ciclo da cultura (35 DAS), entretanto, a ACTM estimulou todas as variáveis [altura da planta (9%), número de folhas (5%), diâmetro dos frutos (25%), e peso médio dos frutos (4%)]. Concluiu-se que, nas condições deste estudo, a irrigação com água tratada magneticamente leva a alterações na morfologia das plantas de rabanete e pode ser recomendado como um tratamento que estimula o desenvolvimento da cultura.
Palavras-chave: *Rabanete. Gotejo. Produção Sustentável. Manejo Agronômico.*

1 Introduction

Radish (*Raphanus sativus* L.) becomes an attractive crop among vegetables due to its short cycle, nutritional contribution, rusticity and quick financial return (Matos *et al.*, 2016), being harvested 25 to 45 days after planting (Filgueira, 2008).

The Brazilian production of *R. sativus* is estimated at eight thousand tons according to the IBGE census (2017). In the southern and southeastern regions, production is concentrated due to the plant's requirement for a mild climate, cultivated in large numbers by small properties, in the green belt and semiarid regions (Sousa *et al.*, 2016). The productivity is quite variable, depending, for example, on the genotype used and on fertilization and irrigation management (Carvalho *et al.*, 2020).

Irrigation of *R. sativus* in times of drought should be done to complement the lack of rainwater, which in turn provides a greater result in production. Irrigation is a technique whose effectiveness has already been proven in this type of vegetable (Carvalho *et al.*, 2020; Sousa *et al.*, 2016). Currently, irrigation with magnetically treated water (MTW) has been gaining ground in agriculture. MTW has several benefits, including improvements in the quality and quantity of irrigation water, increased productivity water savings, reduced fertilizer use, reduced clogging in pipes, and the "memory effect" in water, among others (Aguilera *et al.*, 2016, 2021, 2023; Alemán *et al.*, 2019, 2022; Boix *et al.*, 2019; 2023; Carbonell *et al.*, 2017; Shine; Guruprasad; Anand, 2011).

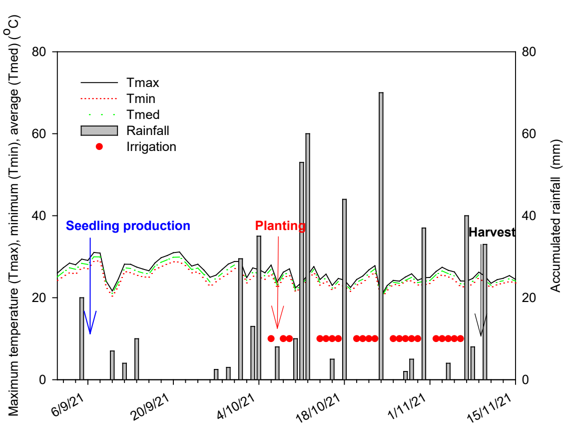
When considering the application of MTW in vegetables, several works have been developed in *Cucumis sativus* L. (Elías-Vigaud *et al.*, 2020; Feng *et al.*, 2018; Ghanbarpouri *et al.*, 2021; Pentoś *et al.*, 2022), *Solanum lycopersicum* L. (Aguilera; Martin, 2016; Agustrina; Nurcahyani, 2018; El-Yazied *et al.*, 2011; Ferrer-Dubois *et al.*, 2018; Martinez *et al.*, 2009; sw, 2022), *Daucus carota* L. (Górski *et al.*, 2019; Putti *et al.*, 2018; Umair *et al.*, 2020), *Beta vulgaris* L. (Alemán *et al.*, 2022; Hozayn *et al.*, 2020) and *Capsicum annum* L. (Aguilera *et al.*, 2021). All of them show the benefits that this physical treatment promotes in irrigation water and that it positively affects the productivity of several species of agricultural interest, which results in a higher yield of these crops treated with MTW.

Based on this background, the present work aims to determine the effect of magnetically treated water on the agronomic performance of *Raphanus sativus* L. under the conditions of Chapadão do Sul in Mato Grosso do Sul, Brazil.

2 Material and Methods

The experiment was conducted in the vegetable garden of the Gileade Association, a recovery home for drug addicts, as part of the entity's extension project with the Federal University of Mato Grosso (UFMS). According to the Koppen classification, the climate of the region is tropical humid (Aw), with dry winters and rainy summers, with annual precipitation, average temperature and relative humidity of 1,261 mm, 23.97 °C, and 64.23%, respectively (Alvares *et al.*, 2014). Information on the average behavior of these climatic variables during the conduct of the experiment is shown in Figure 1.

Figure 1 - Record of climatic variables maximum temperature (Tmax), minimum (Tmin), average (Tmed), accumulated rainfall (Rainfall) and irrigation (water) during the experiment in Chapadão do Sul. The figure highlights some of the moments in which the production of seedlings in the greenhouse and planting and harvesting in the field were carried out. The red dots represent the days in which irrigation took place

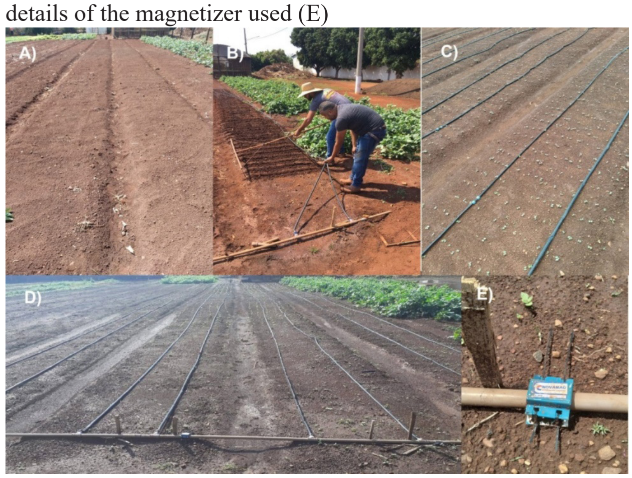


Source: Data from INMET (2021)

Prior to the installation of the experiment, a soil sample collected from the 0-10 cm depth was taken, and the chemical composition of the soil was determined. The sample manifested pH values in H_2O of 4.89, K of 460.00 mg dm^{-3}, P of 7.06 g dm^{-3}, Ca of 5.30 cmol dm$_c^{-3,}$ Mg of 13.97 cmol dm$_c^{-3}$, Al of 0.00 cmol$_c$ dm^{-3}, H+Al of 4.05 cmol$_c$ dm^{-3}, cation exchange capacity at pH 7.0 of 5.30 cmol$_c$ dm^{-3}, base saturation of 13.97% and organic matter of 60.86 g dm^{-3}.

The soil was prepared one month before planting using a tractor type "Tobata". The 30 cm of the superficial layer was mixed, after which the soil was corrected, and the necessary fertilizations were carried out with bovine manure and tanned poultry litter in a proportion of 2:1, superficially applied at a ratio of 5 kg m^2. The beds were raised with a hoe (Figure 2).

Figure 2 - Details of the installation of the experiment in the garden of the Gileade Association in Chapadão do Sul, MS, Brazil. Soil preparation (A), planting preparation (B), beginning of radish germination (C), general view of the experiment (D) and details of the magnetizer used (E)



Source: experimental data.

The experimental design used was completely randomized with two treatments consisting of two types of irrigation [water with magnetic treatment (MTW) and without (WWMT)], with 3 replications of 15 plants each. Seeds of the *Raphanus sativus* L. cultivar (Alegro radish) were used. Generally, plants of this cultivar are hardy, vigorous, with good leaf cover, round and large in shape with excellent red coloration. They easily form bundles and tolerate cracking and isoporization during their growing cycle, which can be between 20 and 28 days (Feltrin, 2022).

Seeds were sown in 1.20 m wide beds at a spacing of 0.25 m between rows and 0.10 m between plants (Figure 2D). Weed suppression was carried out weekly by hand. No product was applied to control diseases and pests, as there was no need for their use.

The magnetic treatment was carried out using a magnetic device composed of permanent magnets that were designed, built and characterized at the National Center for Applied Electromagnetism (CNEA) in Santiago de Cuba, Cuba (Gilart *et al.*, 2013). These devices have a nonuniform or heterogeneous static magnetic field between 100 and 200 mT

(Figure 2E). The irrigation system was established with two rows per bed with a Streamline™ Plus Netafim drip irrigation hose and 30 cm emitter spacing. Irrigation provided 1.3 L h^{-1}, and irrigation was applied whenever necessary (Figure 1). A total of 21 irrigations were applied from seedling transplanting to fruit harvest.

During the month in which the experiment was conducted, the following variables were analyzed weekly: number of leaves (NL, unid) and plant height (PH, cm). The harvest was carried out at 30 days after germination (DAG), where the weight of 15 fruits per repetition was evaluated and with them the average weight of the radish (FW, g) and the diameter of the fruits per repetition was estimated (RD, cm). The measurements were made with the aid of a ruler graduated in centimeters, and the weights were measured on an analytical balance.

The experimental data were submitted to tests to verify the assumptions of normality and homogeneity by the Kolmogorov–Smirnov test. Subsequently, the data were submitted to joint analysis of variance (ANOVA), and when significant, the means were compared by the Fisher-Snedecor F test at the 5% probability level. Pearson's correlation analysis was performed, and with the obtained correlations, a correlation network was carried out. Statistical analyses were performed using Rbio software (BHERING, 2017) and the SigmaPlot 10.0® program (Systat Software Inc.) was used to make the graphs.

3 Results and Discussion

The results described in Table 1 indicate that the irrigation treatment had an effect only on the variables NL at 21 DAG ($P<0.05$) and DR ($P<0.001$). Most CVs were adequate for field experiments, with values below 30%, showing the accuracy of the data obtained (Table 1).

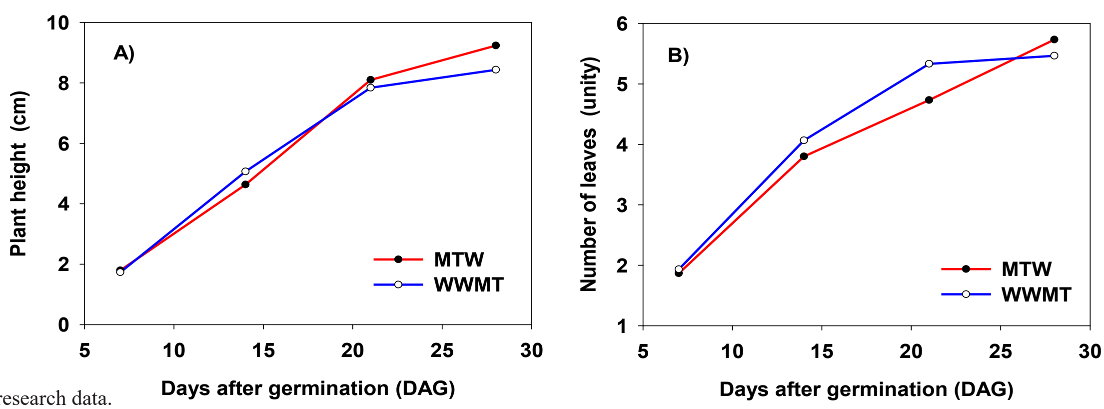
Table 1. ANOVA *P value* results when evaluating agronomic variables in *Raphanus sativus* L. irrigated with magnetically treated water.

Treatment	***P value***									
	----------------- PH[1] (cm) ---------- -----				**----------------- NL (unity) --------- ------**				**FW (g)**	**RD (cm)**
	7 DAG	**14 DAG**	**21 DAG**	**29 DAG**	**7 DAG**	**14 DAG**	**21 DAG**	**29 DAG**		
Irrigation	0.76	0.34	0.62	0.28	0.56	0.30	*	0.25	0.77	***
CV[2]	29.7	24.5	17.8	22.7	16.2	17.5	14.2	11.0	33.3	13.7

[1]PH: plant height, NL: number of leaves, FW: average fruit weight of radishes, RD: radish diameter, DAG: days after germination. [2]CV: coefficient of variation. * and *** significance by F test at 0.05 and 0.001 of probability.
Source: research data.

When evaluating the height of *R. sativus* plants, no significant differences were evidenced between their values over the 30 days after germination of seeds in the field (Figure 3A). The number of leaves (Figure 3B) was evaluated and showed that during the first 21 days, the control treatment (WWMT) promoted the highest leaf development, manifesting significant differences only at 21 days after transplanting. However, in the last evaluation (29 DAG), close to the harvest point, there was an inversion, and the MTW treatment showed higher values with an increase of 5% (Figure 3B), without showing significant differences from the control. These results correspond with those obtained by Touati *et al.* (2013). They determined for *R. sativus* that pretreatment with a static magnetic field of 100 mT for 3 h improved seedling growth and induced a significant increase in biomass production of 8-day-old seedlings. For their part, Ospina-Salazar *et al.* (2018) evaluated the accumulation of fresh and dry biomass and leaf area in this plant species after irrigation with magnetically treated water between 0 and 156 mT but did not observe a stimulation of the treatment compared to the control employed.

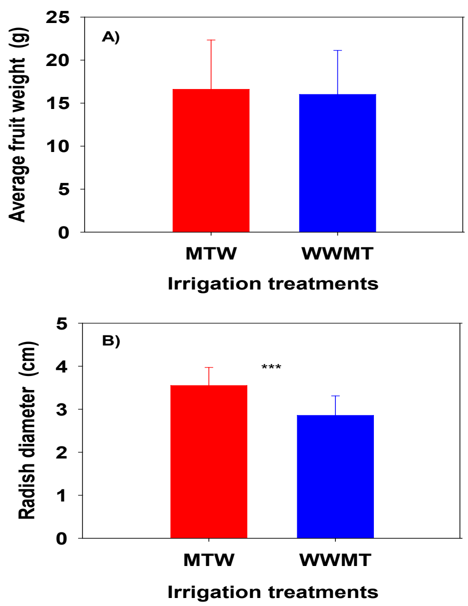
Figure 3 - Plant height (A) and number of leaves (B) over 30 days after germination of *Raphanus sativus* L. irrigated with magnetically treated water (MTW) and without (WWMT), Chapadão do Sul, MS, Brazil. * significant differences at p<0.05 of probability by F test. n=15



Source: research data.

Photosynthetic activity is stimulated by greater leaf area, which is closely associated with the number of leaves the plant has that are photosynthetically active. Leaves are able to contribute to the formation of more assimilates for the plant. This photosynthetic process has been stimulated in several crops by the use of MTW, resulting in greater development and accumulation of reserves in the plant (Elías-Vigaud *et al.*, 2020; Fen *et al.*, 2018; Ghanbarpouri *et al.*, 2021; Pentoś *et al.*, 2022). Dubois *et al.* (2022), in *Solanum lycopersicum* L. plants grown with magnetically treated water between 100 and 200 MT, had a high content of *a, b* and total chlorophyll. These authors indicated that the high photosynthetic activity improved the adaptation of the plants to the growing conditions.

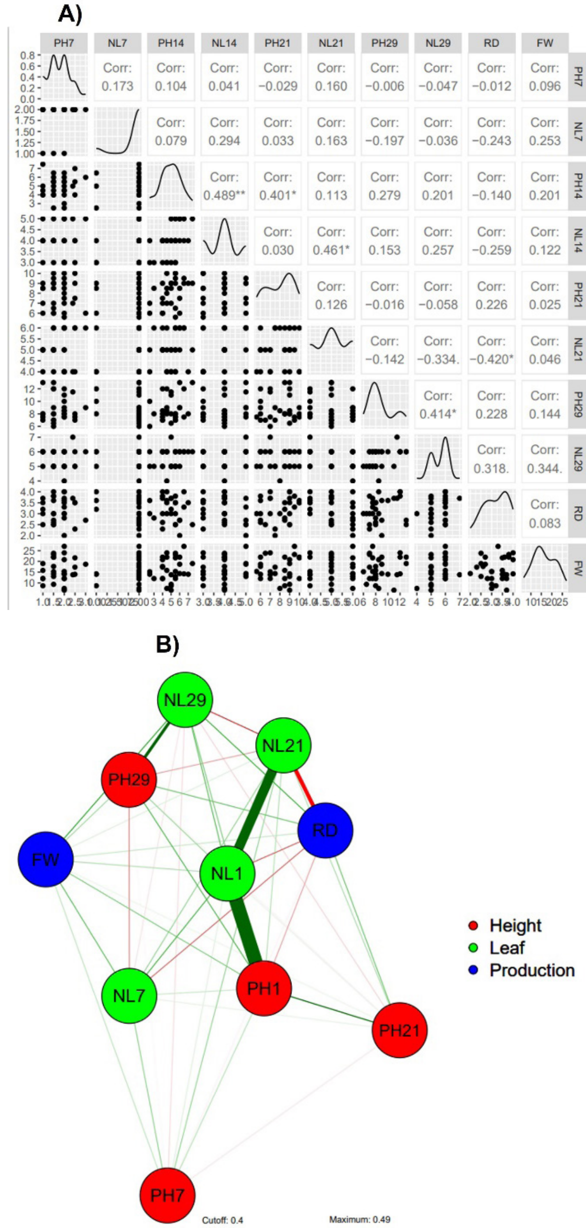
Figure 4 - Average fruit weight (A) and radish diameter (B) at 35 days after germination of *Raphanus sativus* L. irrigated with magnetically treated water (MTW) and without (WWMT). Chapadão do Sul, MS, Brazil. *** significant differences at p<0.001 of probability by F test. n=15



Source: experimental data.

The average fruit weight of *R. sativus* (Figure 4A) and fruit diameter (Figure 4B) were quantified, and a stimulus for both traits was found in favor of the use of magnetically treated water (MTW) with increments of 3% and 25%, respectively, compared to the control. The average fruit weight (Figure 4A), although with higher values in favor of MTW (16.59 g), did not differ from the control (WWMT = 16.00 g). The benefits that this physical treatment promotes in irrigation water are positively associated with the productivity of several species of agricultural interest, promoting a greater performance of vegetables such as *Cucumis sativus* L. (Elías-Vigaud *et al.*, 2020; Feng *et al.*, 2018; Ghanbarpouri *et al.*, 2021; Pentoś *et al.*, 2022), *Solanum lycopersicum* L. (Agustrina; Nurcahyani, 2018; Aguilera; Martin, 2016; El-Yazied *et al.*, 2011; Martinez *et al.*, 2009; Nurbaity; Nuraini; Agustine, 2022; Zamora *et al.*, 2020;), *Daucus carota* L. (Putti *et al.*, 2018; Górski *et al.*, 2019; Umair *et al.*, 2020), and *Beta vulgaris* L. (Alemán *et al.*, 2022; Hozayn *et al.*, 2020).

Figure 5 - Pearson correlations (A) and correlation network (B) obtained when considering the values of the variables plant height (PH) and number of leaves (NL) at 7, 14, 21 and 29 days after transplanting, radish diameter (RD) and average fruit weight (FW) per plot at 35 days after germination of radish irrigated with (MTW) and without (WWMT) magnetically treated water. Chapadão do Sul, MS, Brazil



Source: research data.

R. sativus L. is a crop that manifests rapid growth, and if you consider that his cycle is a maximum of 45 days, which depends on the ability of the plant to produce photoassimilates. When observing the correlations between the variables measured in the experiment, we observed that moderate and significant correlations were obtained between NL14 x PH14 (r=0.49, p<0.01), NL21 x NL14 (r=0.46, p<0.05), NL29 x PH 29 (r=0.41, p<0.05), and RD x NL21 (r=-0.42, p<0.05).

In plants, there is a direct correlation between the number of leaves and plant height and between the number of leaves and the diameter of the fruits of *Raphanus sativus* L. obtained. All these results show that a greater leaf area promotes a greater production of assimilates, which in turn promotes a greater production of fruits.

Different investigations have shown the benefit that stationary or alternating magnetic fields have on the seed and plant development of several species (Alemán *et al.*, 2019; Boix *et al.*, 2019; Carbonell *et al.*, 2017). Radhakrishnan *et al.* (2019) indicated that magnetic fields regulate plant functions and growth and increase tolerance against environmental stresses.

The *R. sativus* plants evaluated responded positively to irrigation with MTW at the end of the cycle favoring accumulation in the fruit if we consider that in the plant development, the treatment did not differ from the control. The stimulus or response of plants when exposed to magnetic fields may vary from one species to another and depends on the timing and intensity of treatment application (Dubois *et al.*, 2019; Kaur; Singh, 2022; Saletnik *et al.*, 2022; Sarraf *et al.*, 2020). Hafeez *et al.* (2023) suggested that magnetic fields can efficiently increase the growth and yield of many crops. They also indicated that they have an important role in changing physiological processes such as respiration, photosynthesis, nutrient uptake, water relations and biochemical attributes.

However, the results obtained show that the technique continues to be of importance and promotes the improvement of the production of radish mainly near harvest, thus determining the yield and quality of the final product.

4 Conclusion

The magnetically treated water stimulated all the variables [plant height (9%), number of leaves (5%), fruit diameter (25%), and average fruit weight (4%)] that promote increased radish production.

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