UNIVERSIDADE DE BRASÍLIA
PROGRAMA DE PÓS-GRADUAÇÃO EM AGRONOMIA
FACULDADE DE AGRONOMIA E MEDICINA VETERINÁRIA

DESEMPENHO AGRONÔMICO DA CULTURA DA ALFACE CRESPA CULTIVADA EM CAMPO E ESTUFA NO DISTRITO FEDERAL SOB DIFERENTES NÍVEIS DE INDUÇÃO MAGNÉTICA E LÂMINAS DE IRRIGAÇÃO

MATHEUS BARCELOS DE SOUSA

DISSERTAÇÃO DE MESTRADO EM AGRONOMIA

BRASÍLIA/DF

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RESUMO GERAL

A alface é uma planta anual, originária de clima temperado, certamente uma das hortaliças mais populares e consumidas no Brasil e no mundo. As plantas obtêm praticamente toda a água de que necessitam através do sistema radicular. Desta forma, uma irrigação adequada irá proporcionar as plantas a umidade adequada para seu desenvolvimento e auxiliará na absorção dos nutrientes. De acordo com pesquisas, a água, quando exposta a um campo magnético, tem sua estrutura alterada, provocando modificações em suas propriedades físico-químicas. Diante disso, o objetivo desta pesquisa foi quantificar os efeitos da água tratada magneticamente na cultura da alface cultivada em campo e em ambiente protegido. Para isso, foram avaliadas as alterações nos teores de clorofila e macro e micro nutrientes, além das variáveis de produção e crescimento da planta. O trabalho foi divido em três partes, com os experimentos sendo realizados em campo, em propriedade pertencente à Bacia do Descoberto, na cidade de Brazlândia e dentro de uma estufa da Fazenda Água Limpa (FAL), pertencente à Universidade de Brasília (UnB), na cidade de Brasília. Para o experimento em campo, os tratamentos foram constituídos por três níveis de indução magnética, aplicados na água de irrigação, além da testemunha com água não magnetizada, sendo os diferentes níveis de indução magnética adotados: T1 – 0,28 Tesla (T); T2 – 0,229 T; T3 – 0,029 T; T4 – 0 T (testemunha). Para a avaliação realizada em estufa, foram feitos dois experimentos, adicionando, além das induções magnéticas, lâminas de irrigação diferentes. Foram estudadas as lâminas de 50% e 100% da evapotranspiração da cultura (ETc). Os diferentes tratamentos responderam significativamente para as variáveis diâmetro de planta, massa foliar da parte aérea, área foliar, produtividade e proteína, para o experimento realizado a campo. Em relação ao experimento conduzido em estufa, as variáveis área foliar, altura de planta, diâmetro, nitrogênio, fósforo, magnésio, enxofre, ferro, manganês, cobre, zinco e proteína bruta, responderam significativamente aos tratamentos, quando estudadas as lâminas de 50% e 100%. Por fim, as variáveis nitrogênio, fósforo, potássio, cálcio, magnésio, enxofre, ferro, manganês, cobre, zinco, boro, proteína bruta, diâmetro de planta, peso, número de folhas e produtividade, quando submetidas às lâminas de 75% e 100%, responderam significativamente aos tratamentos.

Palavras-chave: campo magnético, irrigação, *Lactuca sativa* L.

GENERAL ABSTRACT

Lettuce is an annual plant, originating from a temperate climate, certainly one of the most popular and consumed vegetables in Brazil and the world. Plants obtain practically all the water they need through the root system. In this way, adequate irrigation will provide the plants with adequate humidity for their development and will assist in the absorption of nutrients. According to research, water, when exposed to a magnetic field, changes its structure, causing changes in its physical-chemical properties. Therefore, the objective of this research was to quantify the effects of magnetically treated water on lettuce grown in the field and in a protected environment. To this end, changes in chlorophyll and macro and micro nutrient levels were evaluated, in addition to plant production and growth variables. The work was divided into three parts, with the experiments being carried out in the field, on a property belonging to the Descoberto Basin, in the city of Brazlândia and inside a greenhouse at Fazenda Água Limpa (FAL), belonging to the University of Brasília (UnB), in the city of Brasília. For the field experiment, the treatments consisted of three levels of magnetic induction, applied to irrigation water, in addition to the control with non-magnetized water, with different levels of magnetic induction adopted: T1 – 0.28 Tesla (T); T2 – 0.229 T; T3 – 0.029 T; T4 – 0 T (witness). For the evaluation carried out in a greenhouse, two experiments were carried out, adding, in addition to magnetic inductions, different irrigation blades. The levels of 50% and 100% of crop evapotranspiration (ETc) were studied. The different treatments responded significantly to the variables plant diameter, aerial part leaf mass, leaf area, productivity and protein, for the experiment carried out in the field. In relation to the experiment conducted in a greenhouse, the variables leaf area, plant height, diameter, nitrogen, phosphorus, magnesium, sulfur, iron, manganese, copper, zinc and crude protein responded significantly to the treatments, when the 50% blades were studied. and 100%. Finally, the variables nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, copper, zinc, boron, crude protein, plant diameter, weight, number of leaves and productivity, when subjected to 75% and 100% responded significantly to treatments.

Keywords: magnetic field, irrigation, *Lactuca sativa* L.

SUMÁRIO

1. INTRODUÇÃO GERAL

Na produção de hortaliças é necessário ter critérios e técnicas mais avançadas, assim como, fazer uso de tecnologias inovadoras que promovam uma maior produção com menor utilização de recursos e insumos, não somente pelo desenvolvimento agrícola alcançado nos últimos anos mais também pelo importante lugar da produção e consumo de alimentos a nível mundial (PROHENS-TOMÁS; NUEZ, 2007).

Hoje em dia é vital encontrar soluções agro-produtivas que ajudem a substituir os métodos tradicionais e, principalmente, ajudar a incrementar os rendimentos com o mínimo dispêndio dos recursos (DE LA FÉ et al., 2010; MOYA et al., 2009).

Putti et al. (2015) avaliando o efeito da água tratada magneticamente no cultivo da alface, destacam o incremento na produtividade da cultura, na fitomassa verde e no número de folhas.

O magnetismo é amplamente utilizado no campo da Física, Medicina, Indústria e Comércio, e têm efeitos notáveis sobre os metais conhecidos há séculos, porém, no caso de organismos vivos suas influências são uma descoberta mais recente que ainda não foi totalmente desenvolvida ou disseminada. A aplicação do eletromagnetismo envolve uma série de condições experimentais que vão desde as diferentes formas de tempo de aplicação e exposição, o nível de indução eletromagnética, as frequências, as intensidades e ostipos de campos eletromagnéticos, porém é necessário estabelecer espaços para trabalhos mais específicos na área (MAHESHWARI; GREWAL, 2009).

Neste sentido, procura-se, através da utilização de magnetizadores com alta capacidade de vazão para irrigação, intensidade de indução magnética estática (IME) adequada a cada cultura e alta eficiência na distribuição das linhas de força do campo magnético, o aumento de produtividade por meio de alterações no metabolismo celular, promovendo maior hidratação celular, disponibilizando assim mais energia para o crescimento das plantas.

2. PROBLEMÁTICA E RELEVÂNCIA

Devido as crescentes preocupações ambientais dos últimos anos, especialmente em relação à escassez de água, na agricultura, pesquisas buscam estudar e entender os impactos da irrigação nos apectos produtivos e nutricionais das culturas.

Neste sentido, é fundamental o estudo da irrigação para otimizar seus processos e facilitar a sua correta aplicação, tanto em período, quanto na quantidade e possíveis tecnologias ou técnicas para seu maior aproveitamento.

3. OBJETIVOS

3.1 Objetivo geral

O objetivo geral desta pesquisa é quantificar os efeitos da água tratada magneticamente e de diferentes lâminas de irrigação, na cultura da alface cultivada em campo e em ambiente protegido.

3.2 Objetivos específicos

- Determinar e quantificar as alterações dos teores de clorofila e teor de macro e micronutrientes nas folhas da cultura;
- Avaliar os efeitos da água tratada magneticamente na cultura da alface, verificando número de folhas, área foliar, massa fresca, produtividade e qualidade bromatológica.

4. REFERENCIAL TEÓRICO

4.1 Cultura

A alface (*Lactuca sativa* L.) é uma planta anual, originária de clima temperado, pertencente à família Asteracea, certamente uma das hortaliças mais populares e consumidas no Brasil e no mundo. Praticamente todas as cultivares de alface desenvolvem-se bem em climas amenos, principalmente no período de crescimento vegetativo. A ocorrência de temperaturas mais elevadas acelera o ciclo cultural e, dependendo do genótipo, pode resultar em plantas menores pois o pendoamento ocorre mais precocemente (HENZ; SUINAGA, 2009).

Evidências arqueológicas indicam que esta planta tem sido cultivada desde 4500 anos antes de Cristo (RYDER, 1999). Provavelmente, a alface evoluiu até o fenótipo atual, por meio de seleções e mutações, originárias da espécie silvestre *Lactuca serriola* L. que era utilizada como cultura forrageira e oleaginosa (SUINAGA et al., 2013). Isto é corroborado por Mou (2008), que atesta o cultivo de formas ancestrais de L. sativa, com os propósitos supracitados, no Egito. A partir de sua domesticação, a alface foi disseminada pela região do Mediterrâneo, nas eras Grega e Romana e a partir desta região, para o resto do continente europeu (SUINAGA et al., 2013).

A alface é uma cultura plantada e consumida em todo o território brasileiro, não obstante as diferenças climáticas e os hábitos de consumo (COSTA; SALA, 2005). Por esta razão, é uma das hortaliças mais cultivadas em hortas domésticas. Como sua vida pós-colheita é curta, normalmente as zonas produtoras concentram-se perto de áreas metropolitanas (HENZ; SUINAGA, 2009).

4.2 Irrigação

O tamanho e a natureza das partículas minerais, bem como o arranjo dos elementos estruturais, dão ao solo características próprias de armazenamento de água. Em termos gerais, a textura é o parâmetro mais intimamente relacionado à capacidade de armazenamento de água, podendo-se dizer que solos de textura arenosa apresentam menor capacidade de retenção de água do que solos argilosos (MAROUELLI; E SILVA; DA SILVA, 1996).

De acordo com Rodrigues et al. (2022), a agricultura irrigada é a modalidade especial da produção de culturas agrícolas, espécies florestais e pastagens, tendo como diferencial que a água é aplicada artificialmente para atender, total ou parcialmente, à demanda hídrica das plantas. Em 2017, no mundo, aproximadamente 272,2 milhões de hectares (Mha) foram cultivados efetivamente com uso da irrigação, representando aproximadamente 20% do total das terras cultivadas e contribuindo com aproximadamente 40% do total de alimentos produzidos (AQUASTAT, 2021).

As plantas obtêm praticamente toda a água de que necessitam através do sistema radicular. Da água absorvida, a planta não retém mais que 2%, sendo o restante transferido para a atmosfera pela transpiração, após vários processos fisiológicos. A água também pode se "perder" diretamente para a atmosfera através da evaporação do solo e da superfície vegetal molhada. A este processo de "perda" conjunta de água do solo e da planta para a atmosfera dá-se o nome de evapotranspiração. A água evapotranspirada deve ser totalmente reposta ao solo sob pena de comprometer o desenvolvimento das plantas e o sucesso do empreendimento (MAROUELLI; E SILVA; DA SILVA, 1996) com uma frequência a depender do solo, cultura e sistema de irrigação.

Apesar de a agricultura irrigada ser associada a um elevado nível tecnológico com frequência, é consenso que a irrigação brasileira ainda é praticada inadequadamente, com grandes desperdícios de água (MANTOVANI et al., 2007; MAROUELLI; SILVA; DA SILVA, 2008). É estimado que, não mais que 50% de toda a água captada para irrigação, sejam efetivamente utilizados pelas plantas (CHRISTOFIDIS, 2004). No entanto, nos últimos anos, estudos buscam aprimorar as técnicas e métodos utilizados na irrigação para reduzir este desperdício e aprimorar a sua aplicação. Dessa forma, a percepção geral sobre a irrigação vem sendo alterada, à medida que sua execução é aprimorada.

O desperdício de água na irrigação, além de aumentar os custos de produção, acarreta custos ambientais pelo comprometimento da disponibilidade e da qualidade da água. Essa situação tem levado muitos projetos de irrigação, em todo o mundo, a uma condição de baixa sustentabilidade econômica e socioambiental (CULLEN; THINKER, 2004; OSTER; WICHELNS, 2003).

Segundo Rosegrant et al. (2002), ações para melhorar a eficiência do uso de água na agricultura irrigada devem ser focadas nos níveis técnico, gerencial e institucional. Melhorias técnicas incluem a adoção de sistemas de irrigação mais avançados, como a aspersão e, principalmente, o gotejamento e a microaspersão, o uso conjunto de águas superficiais e subterrâneas, além do conceito de agricultura de precisão, incluindo estratégias para o monitoramento da demanda de água pelas plantas (MAROUELLI et al., 2011).

Ainda nas possibilidades de melhorias na eficiência do uso da água para a agricultura, parte da solução poderia ser resolvida com investimentos em ferramentas digitais integradas aos sistemas de irrigação. Associado a esse aspecto, poderiam ser previstos dispositivos adequados e eficientes de quimigação e de reúso de águas residuárias, onde couber (RODRIGUES et al., 2022).

Para o manejo adequado da água de irrigação é necessário o controle diário da umidade do solo e/ou da evapotranspiração, durante todo o ciclo de desenvolvimento da cultura; Para tanto, é indispensável o conhecimento de parâmetros relacionados às plantas, ao solo e ao clima, para determinar o momento oportuno de irrigar e a quantidade de água a ser aplicada (MAROUELLI; E SILVA; DA SILVA, 1996).

4.3 Água magnetizada

A água é um composto químico com a fórmula química H_2O: um átomo de oxigênio e dois átomos de hidrogênio, que estão unidos por ligações covalentes. A molécula de água não é linear, pois o átomo de oxigênio possui uma eletronegatividade superior à dos átomos de hidrogênio, resultando numa molécula com um momento de dipolo elétrico. A água também pode formar um número elevado de ligações de hidrogênio intermoleculares. Devido à covalência parcial da ligação de hidrogênio da água, os elétrons não são retidos por moléculas individuais, mas são facilmente distribuídos entre agrupamentos de moléculas de água que dão origem a regiões coerentes (DEL GIUDICE; FUCHS; VITIELLO, 2010), capazes de interagir com campos elétricos locais (MARÍN; LOHSE, 2010), indução magnética e radiação eletromagnética (MONTAGNIER et al., 2009). Esses agrupamentos (ou clusters) de compartilhamento de elétrons são denominados Domínios Coerentes (DC). Por ter essa propriedade de formar moléculas maiores a partir de uma molécula menor, constata-se que a água pode ser considerada como um polímero quando forma DC e que a molécula H_2O pode ser considerada como um monômero (ALVES, 2016).

A exposição da água à indução magnética provoca alterações das suas propriedades físico-químicas (VALLÉE et al., 2005). A água líquida é afetada pela indução magnética (CAI et al., 2009; PANG; DENG, 2008) que pode ajudar na sua purificação (AMBASHTA; SILLANPÄÄ, 2010). A água é diamagnética e pode levitar com uma indução magnética muito elevada (10 T) (IKEZOE et al., 1998). Valores de indução magnética menores (0,2 T) aumentam o número de ligações entre moléculas de água em monômeros (ZHOU et al., 2000) e também a tetraedralidade. Outros estudos mostram um aumento no tamanho do cluster de água em estado líquido causado pela indução magnética (CAI et al., 2009). Em contraste foi mostrado que a indução magnética na faixa 0,16 - 0,53 T pode reduzir o coeficiente de atrito da água em filmes finos, o que indica uma possível redução na força de ligação do hidrogênio (WANG et al., 2013).

Desde o início do século XX, relatórios têm tentado identificar a ação de campos magnéticos estáticos em muitos tipos de componentes celulares (KIMBALL, 1938). A literatura relaciona experimentos com intensidades de campo amplamente diversas: (10^{-6} a 10^{1} T); tempo de exposição (observação duradoura em tempo real, minutos, horas e até dias); organismos como sistemas microbianos, células vegetais, células de mamíferos, células humanas (MCCANN et al., 1993) e também constituintes intracelulares como microtúbulos (CHIONNA et al., 2005), proteínas (TORBET; RONZIERE, 1984) atividade enzimática (MALING; WEISSBLUTH; JACOBS, 1965) e ácidos nucléicos (POTENZA et al., 2004). Por esta razão, os resultados são confusos e dispersos numa constelação pouco clara de efeitos (ALBUQUERQUE et al., 2016).

São várias as aplicações da indução magnética na área da saúde, indústria e agricultura de forma a possibilitar a abertura de uma vasta gama de novas linhas de pesquisa (ALVES, 2016). Serdyukov & Novitskii (2013) demostraram o impacto do campo magnético permanente com densidade de fluxo magnético entre 185 e 650 μT sobre as atividades de enzimas antioxidantes em mudas de rabanete (*Raphanus sativus* L. var. radicula D.C.) de 5 dias, que suprimiu a atividade de superóxido dismutase em mudas cultivadas na escuridão e da catalase tanto na escuridão como na luz.

Conforme Alves (2016), referenciando Maffei (2014), a exposição de diferentes espécies de plantas a intensidades de SMF (static magnetic field) moderadas na agroindústria com valores superiores a indução geomagnética (em geral, inferior a 100 μT), podem promover: 1) o aumento da germinação de sementes com 99 mT; 2) o aumento no comprimento da raiz/da área de superfície/do volume na faixa de 250 mT; 3) o aumento dos radicais superóxidos e H2O2 entre 100 e 250 mT; 4) a redução do nível do radical O^2 entre 150 e 200 mT; 5) o aumento do peso seco de sementes e raízes entre 50 e 200 mT; 6) o aumento do comprimento e do peso com 125 mT. Dessa forma, é possível observar uma correlação entre a SMF e a resposta das plantas, sendo este comportamento importante para compreender a habilidade das plantas de perceber e responder rapidamente a variação de SMF pela alteração na expressão gênica e de fenótipo. Compreender o efeito da indução geomagnética sobre a vida poderá proporcionar conhecimento para compreender a evolução das formas de vida no nosso planeta e poderá ajudar no avanço científico de novos sistemas de suporte à vida em futuras explorações espaciais (MAFFEI, 2014).

5. METODOLOGIA

Para melhor avaliar as diferentes respostas da cultura da alface aos diferentes níveis de indução magnética, aplicados na irrigação, o estudo foi realizado em ambiente de campo e em estufa, com a finalidade de aplicar a metodologia da magnetização em ambas as formas de cultivo da cultura no Distrito Federal.

Para a apresentação deste trabalho, os resultados foram divididos em dois capítulos, sendo cada um deles focados em aprofundar sobre os dados em cada ambiente de cultivo.

Com a divisão e escrita por capítulos, cada um destes será submetido a revistas, para suas publicações em formato de artigo, para as revistas Contribuiciones a Las Ciencias Sociales e Revista de Gestão Social e Ambiental, respectivamente. Dessa forma, os capítulos estão apresentados na formatação para as revistas.

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7. CAPÍTULO I

DESEMPENHO AGRONÔMICO DA CULTURA DA ALFACE CRESPA CULTIVADA EM CAMPO NO DISTRITO FEDERAL SOB DIFERENTES NÍVEIS DE INDUÇÃO MAGNÉTICA

AGRONOMIC PERFORMANCE OF CRISPY LETTUCE CROPPED IN THE FIELD IN THE FEDERAL DISTRICT UNDER DIFFERENT LEVELS OF MAGNETIC INDUCTION

ABSTRACT

Lettuce stands out among the most consumed and produced vegetables in Brazil. In a scenario where concerns about water are growing more and more, magnetized water appears as an alternative in irrigation. The objective of the experiment was to evaluate the agronomic performance of lettuce, grown in the field, in the Federal District, under different levels of magnetization applied to irrigation water. The experiment was conducted on private vegetable producing property, in the city of Brazlândia. The crop was subjected to four irrigation treatments with magnetized water, namely: magnetic induction of 0.28 T, 0.229 T, 0.029 T and 0 T (control), with the purpose of evaluating its nutritional and production variables, in the time of harvest. Changes in the levels of chlorophyll, macro, micronutrients, plant production and growth variables were evaluated. The data were subjected to analysis of variance and the means compared using the Tukey test, at a 5% probability level. The analyzes were carried out using the SISVAR program. The studied levels of magnetic induction in irrigation water, such as variable diameter of the frills, fresh mass of the aerial part and productivity differed from each other at a statistical level.

KEYWORDS: ***Lactuca sativa* L., magnetic field, water.**

DESEMPENHO AGRONÔMICO DE ALFACE CULTIVADA NO CAMPO NO DISTRITO FEDERAL SOB DIFERENTES NÍVEIS DE INDUÇÃO MAGNÉTICA

RESUMO

A alface se destaca entre as hortaliças mais consumidas e produzidas no Brasil. Num cenário onde as preocupações com a água crescem cada vez mais, a água magnetizada surge como uma alternativa na irrigação. O objetivo do experimento foi avaliar o desempenho agronômico da alface, cultivada a campo, no Distrito Federal, sob diferentes níveis de magnetização aplicados à água de irrigação. O experimento foi conduzido em propriedade privada produtora de hortaliças, na cidade de Brazlândia. A cultura foi submetida a quatro tratamentos de irrigação com água magnetizada, sendo eles: indução magnética de 0,28 T, 0,229 T, 0,029 T e 0 T (controle), com a finalidade de avaliar seu as variáveis nutricionais e de produção, no momento da colheita. Foram avaliadas alterações nos níveis de clorofila, macro, micronutrientes, produção vegetal e variáveis de crescimento. Os dados foram submetidos à análise de variância e as médias comparadas pelo teste de Tukey, ao nível de 5% de probabilidade. As análises foram realizadas por meio do programa SISVAR. Os níveis estudados de indução magnética na água de irrigação, como diâmetro variável das crespas, massa fresca da parte aérea e produtividade diferenciaram-se entre si a nível estatístico.

PALAVRAS-CHAVE: ***Lactuca sativa*** **L., campo magnético, água.**

7.1 INTRODUCTION

Several studies point to evidence that water exposed to the magnetic field has different properties than untreated water. The main changes observed in water were the adsorption of water on surfaces (OZEKI et al., 1996), the crystallization and precipitation of salts (KATSUKI et al., 1996; KRONENBERG, 1985), the solubility of some minerals (BOGATIN et al., 1999; GEHR et al., 1995; HASSON; BRAMSON, 1985; HERZOG et al., 1989) and surface tension (WANG; WEI; LI, 2018).

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

When treating seeds before sowing, chemical methods are often applied, which mainly consist of treating the seed with various products. Such methods are recognized as harmful to the environment because they are not selective towards wildlife, although the pesticides introduced are often very efficient.

Currently, with the proposal for the rational use of agricultural land, greater importance is attributed to some physical seed treatment methods for pre-sowing, commonly considered more environmentally friendly (PODLESNY, 1998). Special attention should be paid to the magnetic field, which can stimulate some processes that occur in seeds and plants (PHIRKE; KUBDE; UMBARKAR, 1996).

As mentioned before, when water is subjected to the influence of magnetic fields, crystallization and precipitation occur in solutions, a process that affects its crystal structure, which shows that its morphology is altered (FREITAS, 1999). Maheshwari & Grewal (2009) carried out studies using saline water for irrigation in different crops; In these, a magnetizer was used to treat the water; Then, it was noticed that the cultures reacted differently when irrigated with saline water with magnetic treatment and without treatment. Lin & Yotvat (1990), using magnetic water treatment in production of different crops, evaluated that crops irrigated with this type of water showed considerable differences in relation to those irrigated with conventional water (without magnetic treatment).

According to Netto et al. (2005), the indirect determination of chlorophyll content in leaves can be used as a tool to diagnose the integrity of the photosynthetic system, when plants are subject to environmental adversities.

Magnetically treated water interferes with plant physiology. Some studies indicate that there is an interaction between soil and water. According to Mostafazadeh-Fard et al. (2011), in studies to evaluate localized irrigation with magnetized water, the soil presented higher humidity when compared to the soil irrigated with non-magnetized water.

The classification of plant products is regulated by law 9,972 of May 25, 2020 and by decree Number 6,268 of November 22, 2007, through official classification standards; The official classification standard is the set of identity and quality of plant products established by the Ministry of Agriculture, Livestock and Supply (MAPA) through Normative Instructions - INs; That said, the currently classification of lettuce in CEASA-DF is divided into: extra and special (CEASA, 2023). It is classified as extra lettuce that which presents standardization uniform, maximum expression of the cultivar's characteristics, complete development and absence of defects. On the other hand, in addition to the characteristics presented above, special type lettuce presents tolerance for some defects within of the limits described in IN 69/2018 - MAPA.

The objective of the experiment was to evaluate the agronomic performance of lettuce, grown in the field, in the Federal District, under different levels of magnetization applied to irrigation water.

7.2 MATERIAL AND METHODS

The experiment was conducted in the field in a generalized randomized block design (GRBD), with four treatments and five replications. The research site is located on a private farm, in the rural area of Brazlândia, in the Federal District, a region known for vegetable production.

The choice for the GRBD design was due to the fact that the soil was not homogeneous and the slope present in the area in which the experiment was conducted (FERREIRA, 2000). The sampling unit consisted of a plot measuring 1.5 meters (m) wide and 3.0 m long, with a total area of 4.5 m^2. The spacing between plants was 0.2 m, and the spacing between rows was 0.3 m.

Regarding the experimental design, the experimental plots had the following dimensions: 2 m x 1 m, with three rows of plants, two borders and one row of useful plants. The treatments consisted of three levels of magnetic induction, applied to irrigation water, in addition to the control with non-magnetized water.

The drip irrigation system worked by gravity, using water from an elevated source, providing a pressure of 16 meters water column (mwc) in the irrigated area. Drippers, from Irritec, with a spacing of 30 cm, operating with a working pressure lower than 98 kPa (~10 mwc) were used, with a flow rate of approximately 2.0 L h-1.

The magnetizers were installed at the entrance to the main line of each treatment. A 1.1/2″ Hunter PGV solenoid valve with flow control was installed in each main line, which – together with the Hunter X-Core 201 irrigation controller – enabled irrigation automation. The determination of reference evapotranspiration ET0 during the experiment was carried out using the Penmann-Montheith method (Bulletin FAO-56) (ALLAN; PEREIRA; SMITH, 1998).

The daily meteorological data for estimating ET0 were obtained from the National Institute of Meteorology (INMET) automatic meteorological station in Brazlândia (station Brazlândia-A042). The cultivation coefficients (Kc) applied were obtained in accordance with the literature (BERNARDO, 2009; DOORENBOS, 1992; MAROUELLI; SILVA; DA SILVA, 2008). The duration of the phases was determined according to the vegetative development of the crops, obtaining the crop evapotranspiration (mm day-1) by multiplying the reference evapotranspiration ET0 (mm day-1) by the cultivation coefficient (Kc) (mm).

The lettuce seedlings, cultivar Vanda, were purchased from a horticultural store, in plastic trays with two hundred cells.

To verify the effect of the different magnetic levels in irrigation water, the following variables were analyzed:

- Number of leaves: after harvesting, all the leaves of each plant from all treatments were separated form stalk using a knife and the number of leaves per plant was counted;
- Plant height: the measurement was made with the aid of a measuring tape, on the day of harvest. For the analysis, the plant was measured from the height of the ground to the highest part of the plant;

- Fresh mass of the aerial part: after harvesting, the aerial part was separated from the roots and, with the aid of a digital scale graduated in 0.001 g, the total aerial part was weighed, considering the leaves and stem;
- Diameter: with the help of a measuring tape, the plant diameter was measured;
- Productivity: Using the weight value of the plants, a calculation was made to estimate the production in an area of one hectare;
- Chlorophyll content: the measurement of chlorophyll content was carried out using the ClorofiLog-CFL 1030 equipment, which measured the levels of total chlorophyll;
- Leaf area: using the Easy Leaf Area Free application, the leaf area of each plant was measured on different dates after transplant (DAT);
- Macronutrient content: to quantify macronutrient content, leaf samples were sent to the Soloquímica Laboratory.

Assessments were carried out at seven, fourteen, twenty eight, thirty five and fourty oone days after transplantation (DAT). The data were subjected to analysis of variance, and the means were compared using the Tukey test, at a 5% probability level. The analyzes were carried out using the computer program System for Analysis of Variance (SISVAR) (FERREIRA, 2000).

7.3 RESULTS

The different levels of magnetic induction applied to the irrigation water significantly influenced ($p < 0.05$) the fresh mass of the aerial part (FMAP) of the curly lettuce plant. The treatment with a magnetic induction level of 0.229 T obtained the highest FMAP value 332.44 g (Table 1), presenting an increase of 16.71% in relation to the control.

Okasha et al. (2022), studying the effects of common irrigation water, magnetically treated common irrigation water, saline water and magnetically treated saline water found significant effects on various investigated lettuce crop parameters when subjected to the experimental treatments. The data showed that the magnetically treated saline water treatments improved the fresh mass of the lettuce crop and the water productivity for both studied cultivars.

The different magnetization levels did not statistically influence the variable number of leaves (Table 1). However, the control, without magnetization, obtained the highest average, while the treatments presented a lower number of leaves, with the lowest average observed for magnetization of 0.029 T, with a loss of 13.40%, in relation to the control.

For the productivity variable, treatment with magnetized water, at a level of 0.229 T, presented a significant result, with an increase of 16.71%. This result was expected, when observing the fresh mass of the aerial part values, as they were used for the calculation (Table 1).

Despite being sold per unit in markets, lettuce is sold in boxes at supply centers in Brazil. At the main supply center in Brasília (CEASA), the crop is separated into boxes, varying from 3 to 5 kilograms, depending on the marketing season, with the weight of the unit varying between 166.66 and 277.78 grams for classification extra and between 125 and 208.33 grams for the special classification (CEASA, 2023).

Thus, it is possible to observe that, despite causing some reductions in the observed variables, the lettuce crop presented production within the commercial parameters required in all treatments.

The different magnetization levels did not statistically influence the variable plant height (Table 1). However, the control, without magnetization, obtained the highest average, while the treatments presented a lower plant height, with the lowest average being observed for the magnetization of 0.280 T, with a loss of 11.80%, in relation to the control.

Table 1. Average values plant height, diameter, fresh mass of the aerial part, number of leaves and productivity of depending on different magnetization levels.

Magnetization levels (T)	FMAP (g)	Number of leaves	Productivity (ton ha-1)	Plant height (cm)	Diameter (cm)
0	284.84 ab	52.84 a	31.65 ab	22.88 a	26.72 ab
0.029	218.08 b	45.76 a	24.23 b	22.68 a	24.92 b
0.229	332.44 a	51.72 a	36.94 a	22.08 a	27.52 a
0.280	285.52 ab	52.72 a	31.73 ab	20.18 a	26.76 ab
CV (%)	18.31	9.54	18.31	11.19	4.51
P < 0.05	0.03	0.12	0.03	0.3	0.03

Averages with different letters differ from each other statistically ($p < 0.05$). CV: Coefficient of variation; FMAP: Fresh mass of the aerial part;

It was observed that the diameter of the curly lettuce plant responded to the different levels of magnetic induction applied to the irrigation water. The treatment with a magnetic induction level of 0.229 T obtained the highest value of 27.52 cm, 2.99% higher than the control. On the other hand, the treatment with 0.029 T showed a reduction of 6.74% when compared to the control.

Olowolaju & Ajayi (2021), study aimed at examining the biological effects of magnetically treated water on growth performance, biochemical attributes and yield of Vigna unguiculata (cowpea) under screenhouse conditions in 2019 season. The treatments were divided into two regimes. The first regimes were supplied daily with magnetized water and the second regime was watered daily with tap water. Leaf area ratio (26.80 cm), net assimilation rate (3.54 g m−2 day−1), tissue water contents (86.86) and crop growth rate (17.31 gm m-2 day-1) of Vigna unguiculata treated with magnetized water were higher than the Leaf area ratio (4.37 cm), net assimilation rate (1.69 g m−2 day−1), tissue water contents (79.37) and crop growth rate (9.81 gm m-2 day-1) of control plants.

These variables, plant height and diameter, are directly related to leaf area. Although the diameter presented significant results, the leaf area measurements during the crop cycle did not show a statistical difference between the means for the treatments studied (Table 2).

Table 2. Average values of leaf area depending on different magnetization levels.

Magnetization levels (T)	Leaf area (cm2)			
	14 DAT	21 DAT	28 DAT	35 DAT
0	78.70	109.52	147.54	193.95
0.029	51.98	72.42	104.22	147.73
0.229	64.90	110.88	161.04	234.50
0.280	63.15	103.68	127.75	194.72
CV (%)	29.02	32.66	34.66	24.94
P < 0.05	0.22	0.25	0.29	0.09

CV: Coefficient of variation; DAT: days after transplant.

It is possible to observe that, although the treatment with magnetized water at the level of 0.029 T had a lower average during the crop cycle, the lettuce had continuous leaf area development for all treatments. At 35 days after transplantation, the treatment with 0.229 T presented an average higher than the control by 20.91% while the magnetic induction level of 0.029 T presented an average 23.83% lower than the control.

Chlorophylls are located in chloroplasts, this organelle being the continent of photosynthesis, this is where two important reactions occur: photochemistry, in the thylakoid membranes and the biochemistry, in the chloroplast stroma; Such organelles, in addition to chlorophylls, they contain other pigments called accessories, such as carotenoids (carotenes and xanthophylls) (STREIT et al., 2005).

Total chlorophyll was calculated from the sum of the pigments chlorophyll A (Chl A) and chlorophyll B (Chl B). As discussed by Streit et al. (2005), the photosynthetic pigments present and its abundance varies according to the species; Chl a is the pigment used to perform photochemistry (the first stage of the photosynthetic process), while the Other Pigments help absorb light and transfer of radiant energy to the centers of reaction, thus being called pigments accessories; Chlorophyll b is synthesized through oxidation of the methyl group of chlorophyll a to an aldehyde group.

At the end of the measurements, it was observed that the magnetization of 0.229 presented higher averages, while the lowest average was obtained with the 0.280 T treatment (Table 3).

Table 3. Average values of depending on different magnetization levels.

Magnetization levels (T)	Total chlorophyll (FCI)				
	14 DAT	21 DAT	28 DAT	35 DAT	42 DAT
0	19.68	21.15	19.99	18.89	19.45
0.029	20.07	21.28	20.85	19.72	19.54
0.229	21.32	21.73	21.58	20.35	20.21
0.280	21.04	21.06	21.48	19.39	19.26

CV (%)	7.50	8.49	6.59	7.31	7.95
P < 0.05	0.33	0.94	0.29	0.47	0.79

CV: Coefficient of variation; DAT: days after transplant; FCI: Falker Chlorophyll Index.

The stress caused to the plant by light is frequent under tropical conditions, and the concentration of chlorophylls and carotenoids are indicators of the plant's susceptibility to light intensity (VIEIRA, 1996). Chlorophylls tend to be photo-oxidized under high irradiation and, due to carotenoids can prevent the photo-oxidation of chlorophylls, the relationship between chlorophylls and carotenoids can be used as a potential indicator of photo-oxidative losses caused by strong irradiation (HENDRY; PRICE, 1993).

This photo-oxidation, addressed by the authors, may be one of the indications for the reduction that occurred in the average values of total chlorophyll from 28 days after transplanting. Despite the decrease in average values for total chlorophyll, this variable, alone, did not affect the development of plants, in relation to their leaf area, as seen in Table 2.

The different levels of magnetic induction applied to irrigation did not significantly affect the protein content (Table 4). For this variable, the treatment with the lowest average value was the magnetization of 0.029 T, while the treatment of 0.229 T obtained the highest average.

Table 4. Average values of protein, phosphorus, potassium, calcium and magnesium depending on different magnetization levels.

Magnetization levels (T)	Protein (%)	Phosphorus (g Kg-1)	Potassium (g Kg-1)	Calcium (g Kg-1)	Magnesium (g Kg-1)
0	8.12 a	3.43 a	42.40 a	10.17 a	3.73 a
0.029	6.68 a	3.11 a	37.64 a	8.10 a	3.39 a
0.229	8.72 a	5.03 a	34.35 a	7.25 a	3.19 a
0.280	6.83 a	7.90 a	34.39 a	7.54 a	3.42 a
CV (%)	14.41	83.07	17.63	20.42	16.06

P < 0.05	0.03	0.27	0.22	0.07	0.52

Averages with the same letter do not differ statistically from each Other. CV: Coefficient of variation.

Phosphorus is a primary macronutrient and is treated as essential because it is closely linked to plant development and growth. It is responsible for storing and transferring energy, such as glucose, fructose and ATP. Although magnetization levels did not have a significant effect on phosphorus, the treatment that obtained the highest average was 0.280 T, 130.32% higher than the control treatment.

Along with nitrogen, potassium is one of the elements most extracted by plants and its deficiency causes reductions in growth and the formation of the lettuce "head" (KANO; CARDOSO; VILLAS BÔAS, 2010). In adequate amounts, potassium performs several functions in the plant, such as: control of cell turgidity, activation of enzymes involved in respiration and photosynthesis, regulation of the opening and closing processes of stomata, transport of carbohydrates, transpiration, resistance to frost, drought , salinity and diseases; increase resistance to lodging, in addition to being directly associated with the quality of agricultural products (DAVIS et al., 1997; MALAVOLTA, 1980; (MARSCHNER; MARSCHNER, 2012).

The different treatments studied did not show a significant effect on potassium. However, a reduction in mean values was seen for plants subjected to magnetized irrigation, while the highest mean was observed for the control. A similar result was obtained for the average values of calcium and magnesium, with the control showing higher averages, despite not having a statistically significant difference.

7.4 CONCLUSION

The different levels of magnetic induction applied to irrigation water significantly affected the variables of aerial part fresh mass, productivity and diameter. The magnetization that obtained the highest averages, in these variables, was at the level of 0.229 T.

There was no significant effect of the different levels of magnetic induction applied in irrigation on the variables number of leaves, plant height, leaf area, total chlorophyll and nutrients (protein, phosphorus, potassium, calcium and magnesium). Despite this, the plants showed growth within the required commercial standards.

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8. CAPÍTULO II

AGRONOMIC PERFORMANCE OF LETTUCE GROWN IN A GREENHOUSE IN THE FEDERAL DISTRICT UNDER DIFFERENT LEVELS OF MAGNETIC INDUCTION AND THREE IRRIGATION DEPTHS

AGRONOMIC PERFORMANCE OF LETTUCE GROWN IN A GREENHOUSE IN THE FEDERAL DISTRICT UNDER DIFFERENT LEVELS OF MAGNETIC INDUCTION AND IRRIGATION DEPTHS

ABSTRACT

Lettuce stands out among the most consumed and produced vegetables in Brazil. Studies show that magnetically treated water undergoes physical and chemical changes. In general, the objective of research on the use of magnetically treated water in irrigated agriculture is to reduce the amount of water used while maintaining productivity and product quality. The experiment was carried out in a greenhouse at Fazenda Água Limpa (FAL), belonging to the University of Brasília (UnB). The different levels of magnetic induction adopted were: T1 – 0.28 Tesla (T); T2 – 0.229T; T3 – 0.029T; T4 – 0 T (control), applied in irrigation, using two depths, 50% and 100% of crop evapotranspiration. Macro and micronutrients were evaluated, in addition to plant production and growth variables. The different treatments responded significantly to the variables nitrogen, phosphorus, magnesium, sulfur, iron, copper, zinc, crude protein, plant height and diameter.

KEYWORDS: *Lactuca sativa* L., magnetic field, water.

DESEMPENHO AGRONÔMICO DE ALFACE CULTIVADA EM ESTUFA NO DISTRITO FEDERAL SOB DIFERENTES NÍVEIS DE INDUÇÃO MAGNÉTICA E LÂMINAS DE IRRIGAÇÃO

RESUMO

A alface se destaca entre as hortaliças mais consumidas e produzidas no Brasil. Estudos mostram que a água tratada magneticamente sofre alterações físicas e químicas. Em geral, o objetivo das pesquisas sobre o uso de água tratada magneticamente na agricultura irrigada é reduzir a quantidade de água utilizada, mantendo a produtividade e a qualidade do produto. O experimento foi realizado em casa de vegetação da Fazenda Água Limpa (FAL), pertencente à Universidade de Brasília (UnB). Os diferentes níveis de indução magnética adotados foram: T1 – 0,28 Tesla (T); T2 – 0,229T; T3 – 0,029T; T4 – 0 T (controle), aplicados na irrigação, sendo utilizadas duas lâminas, 50% e 100% da evapotranspiração de cultura. Foram avaliados macro e micronutrientes, além de variáveis de produção e crescimento das plantas. Os diferentes tratamentos responderam significativamente às variáveis nitrogênio, fósforo, magnésio, enxofre, ferro, cobre, zinco, proteína bruta, altura e diâmetro de planta.

PALAVRAS-CHAVE: *Lactuca sativa* L., campo magnético, água

8.1 INTRODUCTION

Lettuce (*Lactuca sativa* L.) stands out among the most consumed and produced vegetables in Brazil, since, when consumed fresh, it has nutritional properties as a source of vitamins and minerals (FILGUEIRA, 2003). The cultivation of this vegetable is traditionally carried out in beds using sprinkler and drip irrigation. Due to their sensitivity to climatic factors such as temperature, light and carbon dioxide concentration, plants require monitoring regarding water application (EMBRAPA, 2014). In this scenario, the water supply process is present in the most diverse production sectors, studies have associated the use of magnetized water with properties such as surface tension, pH, viscosity and conductivity (ESMAEILNEZHAD et al., 2017).

Studies show that magnetically treated water undergoes physical and chemical changes, where the clusters of water molecules are reduced, assuming simpler forms, with stronger bonds between them. These changes allow for greater ease of penetration into plant cell membranes, which suggests acceleration of plant growth (SURENDRAN; SANDEEP; JOSEPH, 2016; TOLEDO; RAMALHO; MAGRIOTIS, 2008).

This reduction in the molecular structure of water allows for a larger molecular surface and, consequently, a greater quantity of ions that can come together, enabling greater contact with other molecules.

In general, the aim of research into the use of magnetically treated water in irrigated agriculture is to reduce the amount of water used, maintaining productivity and product quality. Some researchers show that irrigation with magnetically treated water is an ecological alternative and brings numerous benefits to agriculture, such as increased productivity, reduced water consumption, early ripening, better seed germination, reduced diseases, increased quality of plant, increased absorption of nutrients and minerals in seeds and fruits, increased efficiency in the use of fertilizers and reduced operational costs, in addition to allowing the use of low-quality water for irrigation (saline or waste) in saline soil (ABEDINPOUR; ROHANI, 2016; BABALOO et al., 2018; EL-SHAFIK EL-ZAWILY et al., 2019; HOZAYN et al., 2016; KONEFAŁ-JANOCHA et al., 2018; MAHESHWARI; GREWAL, 2009; SILVA; DOBRÁNSZKI, 2014; YUSUF; OGUNLELA, 2017).

The experiment aimed to evaluate the agronomic performance of lettuce, grown in a greenhouse, in the Federal District, under different levels of magnetization applied to irrigation water and under two different irrigation depths.

8.2 MATERIAL AND METHODS

8.2.1 Experiment location

The experiment was carried out inside a greenhouse at Fazenda Água Limpa (FAL), belonging to the University of Brasília (UnB) and located at 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. The region's climate 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 to april.

8.2.2 Magnetization

The magnetization of water occurs when its flow passes through a magnetic field, which is formed by magnets. The magnetic field varies in intensity, depending on the size and shape of the magnets; however, once the magnets are installed, the magnetization intensity remains unchanged.

To carry out water magnetization, three different magnetizers were used, installed at the beginning of each main line, of the respective treatments, namely: Jiangsu YLD Water Processing Equipment Co., Ltd. (T1), Structured Water agriculture magnetizer (T2) and Industrial Magnetizer Technologies Inc. (T3).

8.2.3 Treatments

The design used was completely randomized (CR), with a factorial scheme with eight 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).

Each replication consisted of 12 black polyethylene pots with a capacity of 12.5 liters, four per line, with the central line being used as a useful area for the experiment, containing a red latosol collected at a depth of 20 cm as substrate. The spacing between pots was 20 cm, and the experiment was conducted with one plant per pot. Each plot had the following dimensions: 0.95 m wide and 1.90 m long, with a total area of 1.805 m², and a total of 240 pots.

To correct soil acidity and fertility, an analysis of the collected soil was carried out, with the parameters corrected to the levels recommended for the crop, according to the planting region.

The lettuce seedlings, cultivar Vanda, were purchased from a horticultural store, in plastic trays with two hundred cells.

The culture was transplanted after correcting the soil with basic fertilizer, using one seedling per pot. Irrigation was carried out with the respective treatments at a frequency of four times a day, according to water needs, taking into account evapotranspiration. The first irrigation at eight o'clock and subsequent irrigations spaced three hours apart. Irrigation schedules were conducted during farm staff working hours to ensure supervision of application across all irrigations. Irrigation was carried out using drippers, one dripper per pot, with a flow rate of 6 liters per hour, each.

To verify the different responses of lettuce to different irrigation depths, one hundred percent of the evapotranspiration and fifty percent of the evapotranspiration were considered.

8.2.4 Variables

To verify the effect of the different irrigation levels, the following variables were analyzed:

- Number of leaves: after harvesting, all the leaves of each plant from all treatments were separated using a knife and the number of leaves per plant was counted;
- Fresh mass of the aerial part: after harvesting, the aerial part was separated from the roots and, with the aid of a digital scale graduated in 0.001 g, the total aerial part was weighed;
- Mass: the plants, after harvesting, were weighed on a digital scale, graduated in 0.001g;
- Diameter: with the help of a measuring tape, the plant diameter was measured;
- Productivity: Using the weight value of the plants, a calculation was made to estimate the production in an area of one hectare;
- Macro and micronutrient content: to quantify macro and micronutrient content, leaf samples were sent to the Soloquímica Laboratory.

The data were subjected to analysis of variance, and the means were compared using the Tukey test, at a 5% probability level. The analyzes were carried out using the computer program System for Analysis of Variance (SISVAR) (FERREIRA, 2000).

8.3 RESULTS

The interaction between the different levels of magnetic induction had a significant effect on the variable nitrogen. The interaction that obtained the highest average was the control, without magnetization, with the irrigation depth of 50% of the crop's evapotranspiration, presenting an average of 25.79 g Kg-1 (Table 5).

As said by Resende et al. (2005), lettuce is a crop made up basically of leaves and responds greatly to nitrogen fertilization; Nitrogen deficiency slows down plant growth and induces absence or poorhead formation, older leaves become yellowish and fall off easily.

Table 5. Average values of nitrogen depending on different magnetization levels.

Magnetization levels (T) x Dephts of irrigation	Nitrogen (g Kg-1)			
	0	0.029	0.229	0.280
50%	25.79 aA	23.95 aAB	25.42 aA	19.99 aB
100%	21.12 bA	18.96 bA	19.51 bA	18.26 aA
CV (%)	12.88			
P < 0.05 (treatment)	0.0103			
P < 0.05 (repetition)	0.0000			
P < 0.05 (interaction)	0.3812			

CV: Coefficient of variation. Averages with identical lowercase letters do not differentiate between each other in the same column. Averages with equal capital letters do not differentiate between them, on the same line.

Phosphorus levels were significantly affected by the interaction between different levels of magnetic induction and irrigation depths, with the highest average observed for the control with an irrigation depth of 50% (Table 6).

Table 6. Average values of phosphorus depending on different magnetization levels.

Magnetization levels (T) x Dephts of irrigation	Phosphorus (g Kg-1)			
	0	0.029	0.229	0.280
50%	1.90 aA	1.71 aAB	1.58 aAB	1.31 aB
100%	1.33 bA	1.39 aA	1.57 aA	1.64 aA
CV (%)	18.19			
P < 0.05 (treatment)	0.7344			
P < 0.05 (repetition)	0.1258			
P < 0.05 (interaction)	0.0075			

CV: Coefficient of variation. Averages with identical lowercase letters do not differentiate between each other in the same column. Averages with equal capital letters do not differentiate between them, on the same line.

Among the functions of potassium (K) is enzymatic activation, regulation of the opening and closing of stomata and osmotic control of tissues; In this context, adequate management of soil fertility It is a powerful tool for achieving potential productivity of cultivars (OLIVEIRA JUNIOR; CASTRO; OLIVEIRA, 2018).

Potassium levels were not significantly affected by the interaction between the different levels of magnetic induction and the irrigation depths. The highest average observed was for the treatment with 0.280 T and the 100% irrigation depth (Table 7). This result demonstrates that it is possible to reduce the applied irrigation depth with no significant reduction in potassium concentration in leaves.

Table 7. Average values of depending on different magnetization levels.

Magnetization levels (T) x Dephts of irrigation	Potassium (g Kg-1)			
	0	0.029	0.229	0.280
50%	44.97 aA	49.69 aA	49.57 aA	42.11 aA
100%	47.79 aA	42.64 aA	46.69 aA	50.63 aA
CV (%)	14.50			
P < 0.05 (treatment)	0.9076			
P < 0.05 (repetition)	0.8706			

P < 0.05 (interaction)	0.0772

CV: Coefficient of variation. Averages with identical lowercase letters do not differentiate between each other in the same column. Averages with equal capital letters do not differentiate between them, on the same line.

The interaction between the magnetization applied to the irrigation water and the different irrigation depth did not significantly affected the calcium variable, with the 100% crop evapotranspiration depth, with 0.280 T magnetization, presenting the highest average, with a value of 8.69 g Kg-1 (Table 8).

Table 8. Average values of depending on different magnetization levels.

Magnetization levels (T) x Dephts of irrigation	Calcium (g Kg-1)			
	0	0.029	0.229	0.280
50%	7.03 aA	8.30 aA	8.29 aA	7.38 aA
100%	7.98 aA	7.06 aA	8.19 aA	8.69 aA
CV (%)	17.86			
P < 0.05 (treatment)	0.6432			
P < 0.05 (repetition)	0.6121			
P < 0.05 (interaction)	0.1915			

CV: Coefficient of variation. Averages with identical lowercase letters do not differentiate between each other in the same column. Averages with equal capital letters do not differentiate between them, on the same line.

The same was observed for magnesium, with the interaction not presenting a statistical effect (Table 9).

Table 9. Average values of depending on different magnetization levels.

Magnetization levels (T) x Dephts of irrigation	Magnesium (g Kg-1)			
	0	0.029	0.229	0.280
50%	1.75 bA	1.84 aA	1.86 bA	1.72 bA
100%	2.17 aA	1.98 aA	2.21 aA	2.41 aA
CV (%)	12.85			
P < 0.05 (treatment)	0.5420			
P < 0.05 (repetition)	0.0000			

P < 0.05 (interaction)	0.1479

CV: Coefficient of variation. Averages with identical lowercase letters do not differentiate between each other in the same column. Averages with equal capital letters do not differentiate between them, on the same line.

According to Stipp & Casarin (2010), even though sulfur may be partially supplied by the atmosphere and organic matter, artificial sources of this nutrient cannot be avoided, requiring a very careful recommendation to be successful. in the use of this element.

For sulfur, the different irrigation depths and magnetization levels significantly affected the average values, with the highest average being presented for the control with 50% irrigation (Table 10).

Table 10. Average values of depending on different magnetization levels.

Magnetization levels (T) x Dephts of irrigation	Sulfur (g Kg-1)			
	0	0.029	0.229	0.280
50%	13.36 aA	11.36 aAB	9.51 aAB	7.08 aB
100%	6.89 bA	7.18 bA	4.81 bA	4.09 aA
CV (%)	31.91			
P < 0.05 (treatment)	0.0016			
P < 0.05 (repetition)	0.0000			
P < 0.05 (interaction)	0.5048			

CV: Coefficient of variation. Averages with identical lowercase letters do not differentiate between each other in the same column. Averages with equal capital letters do not differentiate between them, on the same line.

When there is a deficiency of this secondary macronutrient, protein synthesis is inhibited because sulfur is a participant in two essential amino acids (cystine and methionine), as a result of which plants have a lower chlorophyll content and less developed roots (RAIJ, 2011). Results with sulfur fertilization are not only obtained in vegetables, most crops have shown a satisfactory response (SOARES et al., 2017).

As mentioned by Ramos et al. (2018), the mineral iron is an essential micronutrient for vegetables, whose function is to stimulate plant development and facilitate the occurrence of metabolic reactions that activate enzymes participating in the process photosynthetic. In this way, iron is essential for the proper functioning of the process respiratory, nitrogen fixation and transfer of electrons (ALEXANDRE et al., 2012). A deficiency of this metal can be noticed initially in the youngest leaves that assume yellowish color and, as a consequence, the inhibition of chlorophyll synthesis, which can become whitish (LAURETT et al., 2017).

The interaction between the different irrigation depths and magnetization levels statistically affected the average values for iron, with the highest average being presented for the treatment with 50% irrigation and 0.029 T, obtaining averages higher than the 100% depth cultivated in the same period (Table 11).

Table 11. Average values of depending on different magnetization levels.

Magnetization levels (T) x Dephts of irrigation	Iron (mg Kg-1)			
	0	0.029	0.229	0.280
50%	187.60 aA	243.57 aA	224.33 aA	192.88 aA
100%	157.47 aB	172.66 bAB	201.68 aAB	229.60 aA
CV (%)	20.20			
P < 0.05 (treatment)	0.1029			
P < 0.05 (repetition)	0.1005			
P < 0.05 (interaction)	0.0460			

CV: Coefficient of variation. Averages with identical lowercase letters do not differentiate between each other in the same column. Averages with equal capital letters do not differentiate between them, on the same line.

It was observed that manganese levels varied between treatments, but not statistically, at the 5% level. Despite this, for the magnetization of 0.280 T, the 100% irrigation depth presented superior results. These results demonstrate that, for manganese, it is possible to reduce the water applied without loss of nutrient levels (Table 12).

Table 12. Average values of depending on different magnetization levels.

Magnetization levels (T) x Dephts of irrigation	Manganese (mg Kg-1)			
	0	0.029	0.229	0.280
50%	60.22 aA	63.63 aA	59.06 aA	49.67 bA
100%	63.69 aA	58.48 aA	61.56 aA	67.01 aA
CV (%)	15.22			

P < 0.05 (treatment)	0.8391
P < 0.05 (repetition)	0.1283
P < 0.05 (interaction)	0.0698

CV: Coefficient of variation. Averages with identical lowercase letters do not differentiate between each other in the same column. Averages with equal capital letters do not differentiate between them, on the same line.

Copper is considered an essential micronutrient for plants, it acts in the constitution of many enzymes and proteins, maintaining fundamental performance in processes such as photosynthesis, respiration, detoxification of superoxide radicals and lignification (SOUZA et al., 2018). Its deficiency can drastically induce a reduction in enzymatic activities, while excess can cause toxicity (CUNHA FILHO, 2013).

It was observed that copper levels varied between treatments, with the maximum obtained being in treatments with 50% irrigation depth and without magnetization (Table 13).

Table 13. Average values of depending on different magnetization levels.

Magnetization levels (T) x Dephts of irrigation	Copper (mg Kg-1)			
	0	0.029	0.229	0.280
50%	3.25 aA	3.10 aA	3.13 aA	2.49 bB
100%	2.86 bA	2.72 bA	2.85 aA	3.02 aA
CV (%)	9.24			
P < 0.05 (treatment)	0.0996			
P < 0.05 (repetition)	0.1365			
P < 0.05 (interaction)	0.0013			

CV: Coefficient of variation. Averages with identical lowercase letters do not differentiate between each other in the same column. Averages with equal capital letters do not differentiate between them, on the same line.

The interaction between treatments presented statistically significant results, with the highest average being observed for the treatment with 0.280 T and irrigation depth of 100% of ETc, while the lowest average was observed for the first depth of 100% without magnetization (Table 14).

Table 14. Average values of depending on different magnetization levels.

Magnetization levels (T) x Dephts of irrigation	Zinc (mg Kg-1)			
	0	0.029	0.229	0.280
50%	22.32 aA	21.49 aA	22.73 aA	15.96 bA
100%	18.33 aA	18.07 aA	22.52 aA	22.89 aA
CV (%)	19.49			
P < 0.05 (treatment)	0.2953			
P < 0.05 (repetition)	0.8906			
P < 0.05 (interaction)	0.0170			

CV: Coefficient of variation. Averages with identical lowercase letters do not differentiate between each other in the same column. Averages with equal capital letters do not differentiate between them, on the same line.

According to Yuri et al. (2006), zinc in leaves is associated with low molecular weight complexes, free ions and insoluble forms in the cell wall, and can become inactive inside the cell through complexation with phosphorus. Its essentiality for the function and/or structure of several dehydrogenases, proteinases and peptidases found in plants was reported by Welch & Norvell (1993), being classified as a partially mobile element in plants (PEASLEE; ISARANGKURA; LEGGETT, 1981).

The average boron values did not present a significant result (Table 15). Once again, this result demonstrates that it is possible to maintain statistically equal averages by reducing the water applied in irrigation.

Table 15. Average values of depending on different magnetization levels.

Magnetization levels (T) x Dephts of irrigation	Boron (mg Kg-1)			
	0	0.029	0.229	0.280
50%	7.74 aA	7.52 aA	6.86 aA	6.91 aA
100%	6.13 aA	7.13 aA	7.49 aA	7.89 aA
CV (%)	21.71			
P < 0.05 (treatment)	0.9154			
P < 0.05 (repetition)	0.8458			
P < 0.05 (interaction)	0.2665			

CV: Coefficient of variation. Averages with identical lowercase letters do not differentiate between each other in the same column. Averages with equal capital letters do not differentiate between them, on the same line.

The different magnetization levels and the different amounts of water applied, according to the depth differentiation, affect the protein content averages. The treatment with the highest average was reducing irrigation to 50% without magnetization (Table 16).

Table 16. Average values of depending on different magnetization levels.

Magnetization levels (T) x Dephts of irrigation	Crude protein (%)			
	0	0.029	0.229	0.280
50%	16.11 aA	14.97 aAB	15.89 aA	12.49 aB
100%	13.20 bA	11.85 bA	12.19 bA	11.42 aA
CV (%)	12.88			
P < 0.05 (treatment)	0.0103			
P < 0.05 (repetition)	0.0000			
P < 0.05 (interaction)	0.3815			

CV: Coefficient of variation. Averages with identical lowercase letters do not differentiate between each other in the same column. Averages with equal capital letters do not differentiate between them, on the same line.

As reported by (LEMOS, 2020), some authors reported that magnetic treatment of irrigation water provided an increase in viscosity and a decrease in the surface tension of the water, which made so that soil moisture remains longer (AL-OGAIDI et al., 2017; MOSTAFAZADEH-FARD et al., 2011; SURENDRAN; SANDEEP; JOSEPH, 2016). With the reduction in surface tension and the increase in soil moisture, water molecules come into contact with a greater number of molecules, being transmitted through the roots more easily.

Lemos (2020), studying the influence of magnetically treated water on the production and irrigation management of lettuce, used two types of water (magnetically treated water - AM and water without magnetic treatment - AC) and four water tensions in the soil to start of irrigations (T1 – 15 kPa, T2 – 25 kPa, T3 – 40 kPa and T4 – 70 kPa) verified differentiation in irrigation frequency between treatments, observing a greater number of irrigations with a decrease in water tension in the soil and in the use of common water (without magnetic treatment). According to research carried out by Zlotopolski (2017), it was found that the water tension in the soil when irrigating the lettuce with the control group (without treatment), the soil reached more negative values than the treatment with magnetically treated water.

This facts may explain why, even with the reduction in the amount of water applied by irrigation, some variables present statistically superior results.

Although the different levels of magnetization applied to the irrigation water did not present a statistical difference between them, the different irrigation depths presented a significant result, with the depth of 100% presenting a superior result for the magnetizations of 0.029 and 0.229. (Table 17). This result demonstrates that although magnetization does not significantly affect plant height at some magnetization levels, there may be a reduction in the water applied, without loss of height When not applying magnetization or higher levels as 0.280 T.

Table 17. Average values of depending on different magnetization levels.

Magnetization levels (T) x Dephts of irrigation	Plant height (cm)			
	0	0.029	0.229	0.280
50%	17.74 aA	15.41 bA	15.70 bA	15.74 aA
100%	17.67 aA	18.10 aA	18.31 aA	17.10 aA
CV (%)	10.63			
$P < 0.05$ (treatment)	0.4462			
$P < 0.05$ (repetition)	0.0069			
$P < 0.05$ (interaction)	0.2939			

CV: Coefficient of variation. Averages with identical lowercase letters do not differentiate between each other in the same column. Averages with equal capital letters do not differentiate between them, on the same line.

The different levels of magnetization showed statistically significant results for the diameter, with a depth of 50% showing a superior result without magnetization (Table 18).

Sronsri et al. (2022), studying the influence of the magnetic generator device on both the quality and quantity of lettuce grown by a circulating hydroponic method, showed the nutrient solution, magnetized by using the magnetic generator, had an impact on plant height, producing better results as compared to the unmagnetized solution. Average plant heights for magnetized and unmagnetized conditions were found to be 3.24 ± 0.80 cm and 2.23 ± 0.74 cm for the first week, while in the second week, plant heights of 5.52 ± 0.88 cm and 3.74 ± 1.09 cm were obtained, respectively.

Table 18. Average values of depending on different magnetization levels.

Magnetization levels (T) x Dephts of irrigation	Diameter (cm)			
	0	0.029	0.229	0.280
50%	22.25 aA	19.44 aAB	19.88 aAB	18.69 aB
100%	19.42 bA	19.64 aA	20.78 aA	17.57 aA
CV (%)	10.23			
P < 0.05 (treatment)	0.0287			
P < 0.05 (repetition)	0.2720			
P < 0.05 (interaction)	0.1957			

CV: Coefficient of variation. Averages with identical lowercase letters do not differentiate between each other in the same column. Averages with equal capital letters do not differentiate between them, on the same line.

Lemos (2020), studying the development and production of lettuce irrigated with water subjected to magnetic treatment, found no significant differences (P<0.05) in the modification of the type of water and water tension in the soil to start irrigation in the length results and stem diameter; Furthermore, it was also observed that the use of water subjected to magnetic treatment resulted in a lower value of maximum exposure area of approximately 528 cm2 for magnetically treated water, and 658 cm2 when using ordinary water.

Despite being sold per unit in markets, lettuce is sold in boxes at supply centers in Brazil. At the main supply center in Brasília (CEASA), the crop is separated into boxes, varying from 3 to 5 kilograms, depending on the marketing season, with the weight of the unit varying between 166.66 and 277.78 grams for classification extra and between 125 and 208.33 grams for the special classification (CEASA, 2023).

Although there was no significant result for the interaction between magnetization and irrigation depths, not all treatments presented averages within the commercial standard. Treatments with reduced irrigation presented higher averages, falling into one of the crop sales classes (Table 19).

Table 19. Average values of depending on different magnetization levels.

Magnetization levels (T) x Dephts of irrigation	FMAP (gram)			
	0	0.029	0.229	0.280
50%	182.10 aA	144.35 aA	157.75 aA	169.05 aA
100%	137.80 aA	116.30 aA	158.85 aA	111.50 aA
CV (%)	31.23			
P < 0.05 (treatment)	0.4165			
P < 0.05 (repetition)	0.0340			
P < 0.05 (interaction)	0.5276			

CV: Coefficient of variation. Averages with identical lowercase letters do not differentiate between each other in the same column. Averages with equal capital letters do not differentiate between them, on the same line.

For the variable number of leaves, the interaction between treatments showed no statistical difference, as did the fresh mass of the aerial part as expected (Table 20).

Lemos (2020), studying the development and production of lettuce irrigated with water subjected to magnetic treatment, did not observe significant differences ($P<0.05$) for commercial fresh mass, due to the variation in water tension in the soil at the start of irrigation. However, with water subjected to magnetic treatment, a reduction in commercial fresh mass was observed with an increase in water tension in the soil.

Table 20. Average values of depending on different magnetization levels.

Magnetization levels (T) x Dephts of irrigation	Number of leaves			
	0	0.029	0.229	0.280
50%	33.80 aA	31.20 aA	33.10 aA	33.20 aA
100%	32.90 aA	32.68 aA	32.90 aA	32.15 aA
CV (%)	11.92			
P < 0.05 (treatment)	0.8704			
P < 0.05 (repetition)	0.8935			
P < 0.05 (interaction)	0.8811			

CV: Coefficient of variation. Averages with identical lowercase letters do not differentiate between each other in the same column. Averages with equal capital letters do not differentiate between them, on the same line.

8.4 CONCLUSION

For the variables nitrogen, phosphorus, magnesium, sulfur, iron, copper, zinc, crude protein, plant height and diameter, it was possible to observe that the reduction in irrigation depth with magnetization Applied to irrigation water obtained superior results, demonstrating that the interaction between magnetization and reduction in irrigation is an alternative to reduce the amount of water applied and increase average nutrient values.

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9. CONCLUSÕES GERAIS

Diante dos resultados obtidos, é possível observar que a magnetização da água de irrigação, pode ser uma alternativa para buscar melhorias na produção da alface, tanto em condições de campo, quanto em casa de vegetação ou estufa. Além disso, a tecnologia pode ser utilizada em conjunto com diferentes lâminas de irrigação, para obter resultados e reduzir o consumo de água.

No entanto, a disponibilidade de diferentes magnetizadores é limitada, dificultando as pesquisas com uma variedade maior de intensidades de magnetização, incluindo estudos com tratamentos equidistantes.

Além disso, os experimentos e, consequentemente, a literatura, ainda são escassos, fato que dificulta a escolha das intensidades de magnetização, bem como da metodologia a ser aplicada.

Portanto, a água magnetizada se apresenta como uma boa tecnologia para a cultura da alface, porém carece de mais pesquisas para descobrir os melhores níveis de magnetização e as possíveis lâminas de irrigação a serem aplicadas.