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ORIGINAL RESEARCH ARTICLE

Impact of Magnetized Irrigation Water Treatment on Nutrients Uptake and Water use Efficiency of Cowpea Cultivar (*Vigna unguiculata L.*)

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ABSTRACT
The study assessed the impact of magnetically treated water on the TVX-117 cowpea cultivar for nutrient uptakes and water use efficiency. The magnetic water improved absorption and nutrient assimilations that sustained cowpea growth. A rectangular magnetic water treatment unit of 230 mm x 150 mm x 130 mm designed using a metal plate of thickness 2 mm formed an enclosure for twelve pairs of neodymium magnets (N50 grade) of dimensions 50 mm x 25 mm x 10 mm. Irrigation water was treated with a magnetic flux of 1127.4 G and a mean flow rate of 2.86 litres per minute through the device. Irrigation of treated and ordinary water was done by applying 1.43 L at a 3-day irrigation interval for a bucket experiment under a transparent polythene garden. A completely randomized design was applied, and treatments were replicated ten times for magnetized and non-magnetized irrigation treatments. Significant differences exist between initial cowpea nutrients and nutrient uptakes of the harvested Cowpea as the coefficient of determination was $R^2 = 0.9801$; $p < 0.05$. The results indicated that Water Use Efficiency (WUE) for magnetized water-irrigated plants was 24.7% compared to 7.6% for control. Significant differences existed between their WUEs as the coefficient of determination value was $R^2 = 0.8130$; $p < 0.05$. Magnetized water improved water use efficiency, supporting better nutrient uptakes by cowpea seeds.

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Cowpea, Magnetized water, Neodymium magnet, Nutrients, Water use efficiency

INTRODUCTION
Soil, water, and air pollution occurred from an integrated advancement of crop production through the application of chemical additives in an attempt to boost food and energy output (Aladjadjiyan, 2012). Magnetic water proved to be cheap and environmentally friendly. Magnetic water is achieved when ordinary water flows through a magnetic water softener, such as electromagnetic induction or a permanent magnet, and it is referred to as magnetized water, magnetically treated water, or magnetic water (Adebayo *et al.*, 2022). The idea behind the magnetization of water is that each ion in the water experiences a Lorentz force acting in the opposite direction of each other when it moves through a magnetic field (Abedinpour and Rohani, 2017). Different substances behave differently when exposed to different magnetic fields, depending on whether polar or non-polar molecules. The main difference between the polar and non-polar molecules is the ability of the molecule's properties to coincide. It was pointed out by Zaidi *et al.* (2014) that polar molecules are adjusted randomly in the absence of a magnetic field while the dipoles are directed along the path of the field under the inducement of the magnetic field.

Research has indicated that the application of magnetic treatment to irrigation water can yield several advantages for agriculture, including higher crop yields, water conservation, early crop maturity, decreased plant diseases and soil alkalinity, enhanced crop quality, better fertilizer efficiency, and lower costs associated with farm operations (Hozayn and Abdul-Qados, 2010). The magnetic field affects water modification, reducing surface tension, viscosity, bonding angle, and other physicochemical properties of water (Babu, 2010; El-Sayed, 2014).

The properties of magnetized water are altered, and it becomes more energetic to flow, which is in charge of hormone and enzyme activation during germination and nutrient mobilization. It enhanced the process of dissolving slightly soluble salts and leaching excess soluble salts (Abedinpour and Rohani, 2017). The stimulatory influence of magnetic water was associated with increased

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plant growth and yield due to increased nutrient digestion and absorption, as illustrated in Figure 1.

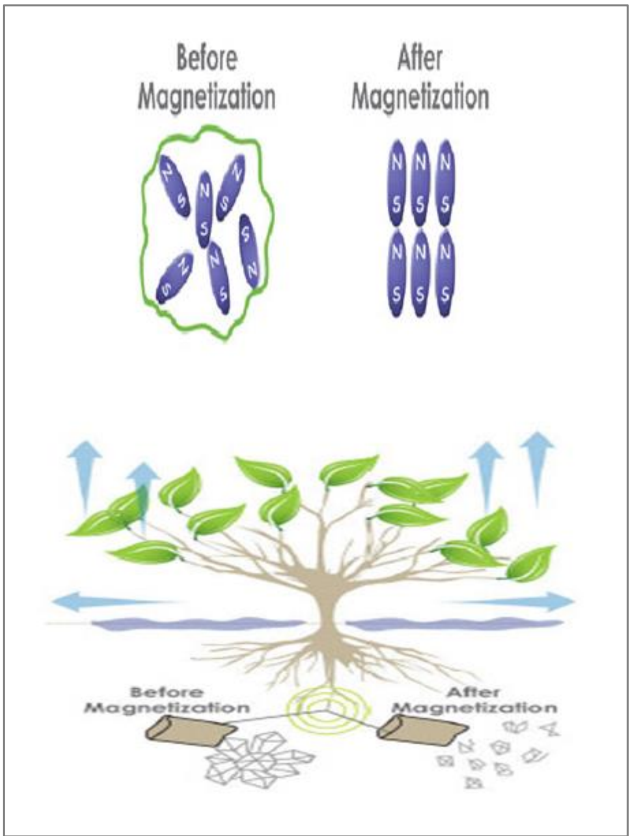

Figure 1: Magnetization processes and effects on crop Adopted from Babu (2010)

Following the magnetization process, water molecules align in the sequence "+-+-," as depicted in Figure 1 (Babu, 2010). There is an addition in protein and chlorophyll amounts based on the intensity of the magnetic field applied and phytohormones (Hozayn *et al*., 2016). The consumption of crops irrigated with magnetically treated water had no adverse effects because it reduces the level of bad cholesterol in humans and animals (Deshpande, 2014).

The nutrients needed for plant life cycle activities are categorized based on the concentration of nutrients in a plant. Soil nutrients are elements that aid in completing a plant's life cycle. The first category consists of structural elements like carbon (C), hydrogen (H), and oxygen (O); the second is made up of macronutrients that the plant needs in large amounts, like calcium (Ca), magnesium (Mg), sulphur (S), phosphorus (P), potassium (K), boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn). (Bender, 2012). The essential nutrients for plants' growth and development are mainly thirteen (Aladjadjiyan, 2010), which can be classified into macro-nutrients (elements that plants require in abundant quantities) and micro-nutrients (elements required by the plant in smaller quantities but are very vital for plant development). Plant nutrition, fertilization, and irrigation are controlled by the mobility and availability of these components, which are present in the soil and plant but vary in quantity. Accurate nutrient management solutions that increase crop yields, reduce fertilizer waste, and lower overall costs are made possible by knowing how nutrients function in the soil and plants. Due to the paramagnetic characteristics of the main atoms in plant cells and chloroplast, a magnetic field enhances the capacity of immobile plants to absorb nutrients and cations (Esitken and Tura, 2004). Plant photosynthesis, respiration rate, protein biosynthesis, cell division, enzyme activity, nucleic acid content, and growth-development period are a few of the processes fully impacted by magnetic fields. Plant photosynthesis, respiration rate, protein biosynthesis, cell division, enzyme activity, nucleic acid content, and growth-development period are a few of the processes that are fully impacted by magnetic fields (Aladjadjiyan, 2010; Seghatoleslami *et al*., 2015).

A nutrient element must travel to the root and interact directly with the root surface to be absorbed, especially immobile nutrients like P and K. The amount of root produced by the plant becomes essential to the total uptake of these nutrients.

Since crops require a large amount of water - roughly 70% of the water available to humans -and since irrigation coverage has been expanded, water use efficiency, or WUE, is crucial to the agricultural industry. By enhancing agricultural water use efficiency and consequently boosting crop WUE, this phenomenon has resolved disputes around water resources for agriculture and other uses, making it a significant objective for both agriculture and food security (Araus, 2004; Deng *et al*., 2006) cited by Medrano *et al*., (2015). WUE can be measured on two scales, such as the measurement of leaf photosynthesis and transpiration based on the hypothesis that it is a replica of whole-plant WUE and the measurement of whole-plant values to evaluate the WUE, though it is not popular as few reports are available that estimated at whole-plant stage (Gibberd *et al*., 2001; Tomas *et al*., 2012). When compared to other production factors, water deficit is an essential factor that can lessen water use without substantial yield reduction.

The WUE is the efficiency with which water is released to generate crops. It is a function of crop physiological factors such as crop species, genotype, net runoff, drainage below the root zone and biomass, evaporation, and transpiration. WUE is defined as the ratio of either the dry or fresh weight of shoot and root to the cumulative water consumed or the grain yield (GY) ratio to the water consumed during crop growth, as shown in Equation 1. Hence, water use efficiency is measured in kg/m^3 water used by crop plants.

$$WUE = {GY}/{WR} \qquad (1)$$

Where,

WUE - Water use efficiency (kgm^{-3}),

GY - Crop yield (kg),

WR - Water requirement of the crop (m^3).

Cowpea (*Vigna unguiculata L. Walp.*) serves as food for man, livestock feeds, a source of income generation, and soil manure (Agyeman *et al*., 2014).

The research studied the impact of magnetic-treated irrigation water on the uptake of nutrients and WUE of the cowpea cultivar (TVX-117) under a transparent garden.

MATERIALS AND METHODS

Research area description

The study area was Kwara State University Malete, in Moro Local Government Area of Kwara State, Nigeria (Figure 2). Malete town is between Latitude 8°42`0``N and Longitude 4°28`0``E in the North Central of Nigeria. Wet and dry climates indicate a tropical climate with an annual rainfall between 1000 mm to 1500 mm. The elevation of the study site is 258.8 m above sea level, and the air temperature is uniformly high between 25°C and 30°C in the wet season and 33°C to 34°C during the dry season (Adebayo *et al*., 2021).

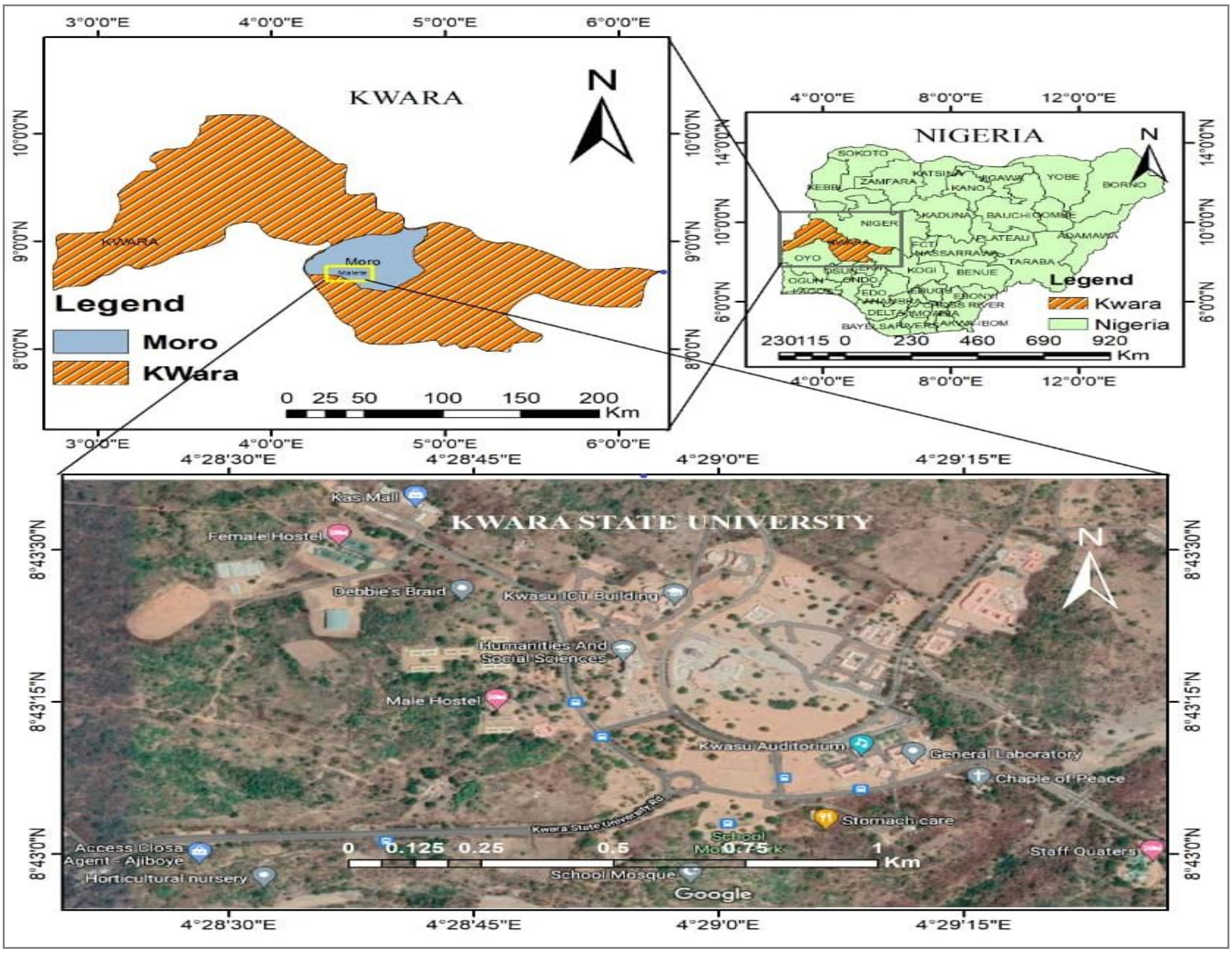

Figure 2: Map showing the study site Adopted from fieldwork (Adebayo *et al*.,2022)

Construction of transparent garden

The transparent garden shed was constructed with wood, while the top and part of the sides were covered with a transparent nylon of 2 mm thick. The shed was covered with polythene so rainwater or dew could not reach the cowpea plants other than the magnetized water. Dimensions of the shed were 9.0 m x 7.0 m x 4.0 m at the centre, and three sides were covered with nylon while the front end was covered with a wire screen (wire mesh) to allow air movement within the garden shed. The door was positioned at the front end, measured as 2.1 m x 0.9 m covered with a wire screen.

Magnetic water treatment

The treatment chamber was constructed using a metal plate of thickness 2.0 mm to design a rectangular frame of dimensions 230 mm long, 150 mm wide, and 130 mm high. It was partitioned into three equal parts, 230 mm x 50 mm x 130 mm. A hole of 20 mm diameter was centrally made at both sides to accommodate the passage of 12.7 mm diameter, 5.0 mm thick PVC pipe of 280 mm connected to form S - shape within the chamber (Figure 3). The time of flowing water within the magnetic flux is a function of the design and construction technology of the magnetic treatment chamber, taking into cognizance the pipe diameter and shape configurations (Adebayo *et al.*, 2022). Water flow along the pipe must cut the field at the right angle.

The magnetic flux was generated within the chamber by positioning twenty-four neodymium magnets, with each magnet weighing 84.5 grams fixed to a metal frame, as shown in Figure 3.

The water was allowed to flow through the three pipes in contact with the magnets, increasing the treatment period within the magnetic field. A rubber hose of length 360 mm and 12.7 mm diameter was connected to the tap that supplied untreated water from the 30 litres capacity bucket into the treatment chamber and also connected to the treatment chamber to serve as the outlet that released the treated water into the buckets labelled treated water (Figure 4). The gross weight of the treatment chamber is 3.0 kg. The average water flow rate of two runs from 30 litres bucket received at the outlet after passing through the magnetic fields was 2.86 $Lmin^{-1}$, as shown in Figure 4.

Magnetic flux measurement

Magnetic flux densities in the water treatment chamber were determined using a digital magnetic flux meter or Gauss meter model TD 8620 manufactured in China. It can measure a maximum flux density of 200 mT - 2000 mT with resolution and accuracy of 10 μT and ±1%, respectively. Measurement could be taken in millitesla (mT) or gauss (G) through a conversion button (Figure 5). The sensitive probe was inserted into the pipes at the inlet and outlet ends of the treatment chamber and the hold button would be pressed once a constant magnetic flux density reading was observed on the meter. The maximum magnetic flux reading recorded at the inlet and outlet ends was 1127.4 G.

Experimental setup

Soil for planting Cowpea

The experimental soil used for cultivating the Cowpea was excavated at the Latitude 8^{o} 43´15´´N, Longitude 4^{o} 28´53´´E, and altitude of 296.4 m using an auger at a depth of 35 cm below the soil surface. The soil sample was analysed at the soil and water laboratory, Landmark University, Omu-aran, Nigeria, to obtain its physiochemical properties using atomic absorption spectrophotometers and other general laboratory equipment (Adebayo *et al.*, 2022), as shown in Tables 1 and 2, respectively.

Planting of Cowpea

The buckets used for planting in the study were 26 cm high with top and bottom diameters of 26.8 cm and 20 cm, respectively. The cowpea cultivar (TVX-117) seed was procured from the Department of Crop Science, Faculty of Agriculture, Kwara State University, Malete. The mean moisture content value of the cowpea cultivar analysed by moisture meter model KT100S was 7.4%. Four cowpea seeds were sown in each bucket at 20 mm depth throughout under transparent garden conditions. Thinning of seedlings to two was carried out 15 days after planting (DAP). Irrigation water application of magnetized and ordinary water was calculated to determine the designed irrigation water and irrigation interval.

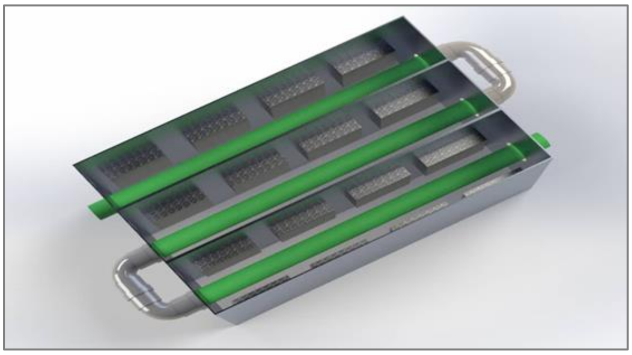

Figure 3: Neodymium magnetic treatment chamber (Adopted from fieldwork)

Figure 4: Neodymium magnetic treated water set up (Adopted from fieldwork)

Figure 5: Digital magnetic gauss meter (Model TD 8620)(Adopted from fieldwork)

Table 1: Soil chemical properties

Parameters	Values	Units
pH	5.87	-
N	24	[mgL^{-1}]
P	5.4	[mgL^{-1}]
K	26.1	[mgL^{-1}]
Nickel	8.50	[mgL^{-1}]
Ca	28	[mgL^{-1}]
Na	4.487	[mgL^{-1}]
Mg	150	[mgL^{-1}]
Pb	0.031	[mgL^{-1}]
Organic Matter	0.628	[%]
Organic Carbon	0.360	[%]
CEC	3.60	[$molkg^{-1}$]

Table 2: Soil physical analysis

Sand (%)	Silt (%)	Clay (%)	Textural Class
81.0	13.5	5.5	Sandy loam

Estimation of irrigation water

The volume of irrigation water (IW) supplied to the cowpea plant was calculated using Equation 2 according to (Duzdemir *et al*., 2014).

$$IW = \frac{W_{FC} - \frac{W}{\rho}}{1 - LF} \quad (2)$$

Where,

W_{FC}- Weight of bucket at field capacity (kg),

W- Weight of bucket before irrigation (kg),

ρ - Bulk density of water (1.0 kg/L),

LF - Leaching fraction (0.30 for LF was used for this experiment based on Ayers and Westcot (1985) assumption.

Estimation of the volume of irrigation water to be applied using equation 2,

Empty bucket = 335 g (0.335 kg)

Bucket + soil before irrigation (W) = 3408 g (3.408 kg)

Soil only = 3073g (3.073 kg)

The volume of water applied to reach saturation level = 2.0 L

The volume of water drained after 24 hours (field capacity) = 1.0 L

Bucket + soil after saturation (W_{FC}) = 4408 g (4.408 kg)

$$IW = \frac{4.408 - 3.408/_{1.0}}{1 - 0.30} = \frac{1.00}{0.70} \approx \mathbf{1.43\ L}$$

The amount of irrigation water (IW) = 1.43 L

Crop evapotranspiration (ET_c) of Cowpea

The maximum value of reference evapotranspiration (4.70 $mmday^{-1}$) for Ilorin during the wet season was adopted according to Chineke *et al.* (2011).

$$ET_c = K_c \times ET_o \quad (3)$$

K_c = 1.15 ET_o= 4.70 $mmday^{-1}$

$$ET_c = 1.15 \times 4.70 \frac{mm}{day} = \mathbf{5.41 mm\ day^{-1}}$$

Where;
ETc: crop evapotranspiration ($mmday^{-1}$),
Kc: crop coefficient (dimensionless),
ETo: reference crop evapotranspiration ($mmday^{-1}$).

Determination of net depth of irrigation (d_n)

The net depth of irrigation (d_n) was computed after 30% irrigation water depletion, as stated below in Equation 4;

$$d_n = 30\%\ AW \quad (4)$$

$$d_n = \frac{30}{100} \times 55.96 = \mathbf{16.79\ mm}$$

Where;
d_n: net depth of irrigation (mm),
AW: available water (mm).

Determination of irrigation interval (I_v)

The interval between one irrigation event to the next irrigation is known as the irrigation interval, was determined by Equation 5, reported by Michael (2008) as;

$$I_v = \frac{d_n}{ET_C} (days) \quad (5)$$

$$I_v = \frac{16.79}{5.41} = 3.10 \approx \mathbf{3\ days}$$

Treatments and statistical analysis

The treatments experimented with were the irrigation cowpea under the transparent shed with magnetized water, MTW (T1), and non-magnetized water, NMTW

(T2). The treatments were replicated ten times using a completely randomized design (CRD). Statistical analysis was done using GraphPad Prism 9 and OriginPro 8.0 packages to obtain an analysis of variance (ANOVA) and regression analysis.

Calculation of water use efficiency

Water use efficiency (WUE) was determined by the ratio of grain yield ($kgha^{-1}$) and volume of water applied by irrigation (m^3ha^{-1}) during the growth regime (Suchitra and Babu, 2011).

$$WUE = \frac{\text{Grain yield } (kg/ha^{-1})}{\text{Volume water applied } (m^3ha^{-1})} \quad (6)$$

Estimation of nutrient uptake by Cowpea

The chemical uptake by cowpea plants, mainly the heavy metals, was estimated by analysing the planting materials compared with the nutrients of harvested cowpea seeds were analysed at the Agricultural and Biosystems Engineering Laboratory, Landmark University, Omu-Aran, Kwara State, Nigeria.

RESULTS AND DISCUSSION

Effects of Magnetic Field on Irrigation Water

Chemical analyses were carried out on two irrigation water experiments in the study, as shown in Table 3. Micro-structures of the treated and ordinary irrigation water were examined through scanning electron microscopy (SEM) through the JSM-7600F scanning machine. Irrigation water after passing through the magnetic treatment devices improved the values of these cations except P^+, which decreased after treatment. Improvements in these elements resulted from the destabilisation of ionic balance between adsorbed cations and anions within magnetic fields (Vallee, 2005). There were increments obtained in the values of anions when compared with non-magnetic water. The existence of interfacial effects through the gas bubbles was responsible for changes in anion contents in magnetized water. The positive differences in the viscosities of magnetized water were due to minimum molecular energy utilised with greater activation energy generated. Reduction in total water hardness based on the increasing coagulation level of large particles lodging with the water flow rather than depositing scale. SEM micrographs of irrigation water treated with neodymium magnetic fields showed finely micro-structures (Figure 6A) compared to micro-structures of ordinary water where clusters resulted from the no-stability of water particles (Figure 6B). The neodymium magnetic water softener changed the physicochemical properties of water caused by magnetic fields like hydrogen bonding, polarity, surface tension, conductivity, pH, and salt solubility (Grewal and Maheshwari, 2011). Results obtained from analysis of variance and correlation of magnetic and non-magnetic water indicated a significant difference at a 95% confidence level as $p < 0.05$. The results were in agreement with the results obtained by Adebayo *et al.* (2021), where the magnetic field increased the pH, cations and anions, viscosity, electrical conductivity, and total hardness compared to non-magnetic water.

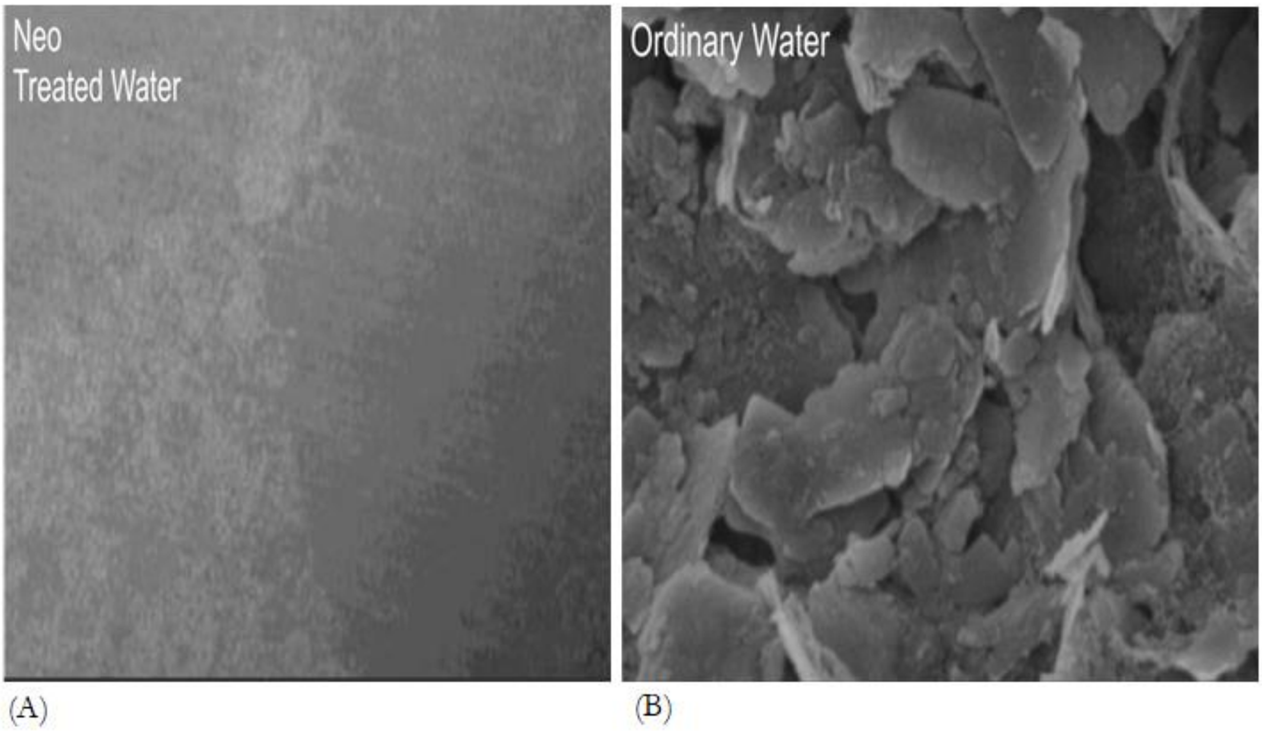

Figure 6: Scanning electron microscope (SEM) micrographs of irrigated water (Adopted from fieldwork)
(A) SEM micrograph of magnetized water (x 700); (B) SEM micrograph of non-magnetized water (x 700)

Effects of magnetic water on cowpea nutrients uptake

The interaction between the nutrient uptake of the planting seeds and the harvested seeds is shown in Figure 7. The response of the TVX-117 cultivar was $R^2 = 0.9801$, indicating that there were significant differences between initial cowpea nutrients and the nutrient uptake of harvested Cowpea. The results align with the research outcomes obtained by El-Sayed (2014) that irrigation of broad bean plants with magnetized water improved potassium, calcium, and phosphorus contents in plant roots, shoot systems, and fruits compared with ordinary water. The major heavy elements Fe, Zn, Cu, and Mn are essential nutrients useful in human and animal tissue development. The cation uptake capacity and immobile plant nutrient assimilation were increased by a magnetic field (Esitken and Turan, 2004). The magnetic field positively influenced the paramagnetic effects of different atoms within the plant cells and chloroplast (Aladjadjiyan, 2012). The Magnetic treatment of irrigation water improved N and K desorption from colloidal soil complexes, significantly improving the two elements available to the plants and promoting better plant growth and yield. Magnetic field treatment has significantly improved the quality parameters compared to non-magnetic field treatment for all the elements studied in French bean pods. The maximum seed protein (21.69 g/100 g), vitamin A (678.57 IU), potassium (207.16mg/100 g), and calcium (38.67 mg/100 g) were recorded (Kishore *et al.*, 2023)

Table 3: Chemical compositions of irrigation water

Parameters	Treated Water	Ordinary Water	Units
Ca	42	10	[mgL^{-1}]
Mg	50	26	[mgL^{-1}]
K	21	11	[mgL^{-1}]
Na	1.28	0.96	[mgL^{-1}]
Pb	0.01	0.01	[mgL^{-1}]
Cr	0.14	0.07	[mgL^{-1}]
P	0.84	1.35	[mgL^{-1}]
CO_3^{2-}	32	10	[mgL^{-1}]
SO_4^{2-}	17	8	[mgL^{-1}]
NO_3^-	6.8	3.9	[mgL^{-1}]
Cl	36	26	[mgL^{-1}]
pH	6.38	5.10	-
EC	170.8	165.4	[μscm^{-1}]
Viscosity	3300	2650	[Mpa.s]
Total Hardness	16	60	[mgL^{-1}]

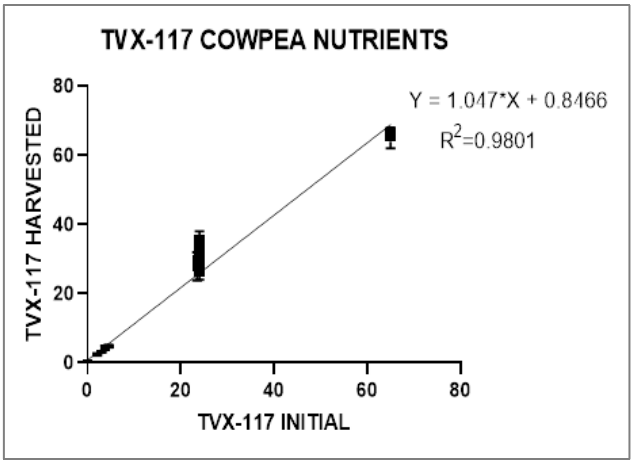

Figure 7: Regression analysis of the nutrient uptake by Cowpea

Effects of magnetic water on the water use efficiency of Cowpea

Compared to the control treatment (Tc), the mean WUE of the magnetic treatment plant (T1) was 7.6% and 24.7%, respectively. Treatment (T1) improved water use because of minimal evapotranspiration and transpirational water loss.

The findings confirmed the findings of a study conducted by Shrief and El-Mohsen (2015), which showed that increased water use efficiency and per unit area led to improvements in grain yield. The treatment and control water use efficiencies differed significantly ($R^2 = 0.01830$; $p < 0.05$), according to regression analysis. Irrigation with MTW at different moisture regimes increased the relative water content and WUE in plants of jojoba (*Simmondsia chinensis*), as well as with an improved content of magnesium, calcium, and phosphorus, as reported by Zúñiga *et al.* (2016).

CONCLUSIONS

The results showed that magnetically treated water changed water's chemical and physical compositions through magnetic fields. Thereby, magnetic fluxes acted as water softeners. Magnetized water (T1) enriched the nutrients (cations and anions) which supported plant growth and development of cowpea plants compared to non-magnetized water (Tc). These results were attributed to magnetization, where the water molecules easily absorbed nutrients available to plants. The protein contents and other nutrients like phosphorus, potassium, calcium, magnesium, and copper contents were significantly increased in the harvested seeds of magnetized irrigation water compared to nutrients obtained in the control treatment. Seedlings irrigated with magnetized water possessed better WUE than control treatments, with 24.7% compared to 7.4%, respectively.

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