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Impact of magnetization of irrigation water on growth, yield and nutritional qualities of tomato under deficit irrigation

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Abstract

Tomato is a vegetable crop commonly grown in Nigeria and consumed by most people. It contains vitamins and vital nutrients that are essential for good health. This study was conducted to determine the effect of magnetization of irrigation water on the growth, yield and nutritional qualities of tomatoes under deficit irrigation. Tomato seeds ('Roma VF' and 'UC 82B' varieties) were planted in 96 buckets (11 liters capacity), 48 buckets for magnetized water (MW) and 48 buckets for non-magnetized water (NMW), grown in a greenhouse and harvested 82 days after planting. The irrigation water was treated with 30 pieces of 10×25×50 mm neodymium magnets (1.2 Tesla). The tomato plants were subjected to deficit irrigation to determine the effect on the performance of tomatoes at 100% (1 liter), 80% (0.8 liters), 60% (0.60 liters) and 50% (0.50 liter) water requirement. Each treatment was replicated 6 times for both MW and NMW. The MW increased the growth of 'Roma VF' and 'UC 82B' varieties by 5.44-38.10% and the stem girth by 21.13-49.01%. MW increased the yield of 'Roma VF' variety by 110.00%, 36.00%, 6.26% and 24.00% for 100%, 80%, 60% and 50% of water application, respectively but increased the yield of 'UC 82B' variety by 56.52% for 100% water application. MW also improved vitamin A and C content by 7.89-27.94% and 0.45-19.06%, respectively. The concentrations of Lead were slightly higher in the tomato irrigated with MW than in the NMW but values of other heavy metals were not consistent and very close for both MW and NMW.

Keywords: available water; deficit irrigation; drip irrigation; magnetized water; tomato; vitamin C; paired t-test

Introduction

Tomato (*Solanum lycopersicum* L.) is a vegetable crop commonly grown in Nigeria and consumed by most people in the country. It contains good nutritional values such as vitamins A, C, K, E and other vital nutrients essential for good health, prevent some diseases and proper functioning of the body systems. Tomato

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is a protective food because it contains a high amount of antioxidants like Lycopene, an antioxidant pigment responsible for tomato's red colour and protects the body against diseases (Singh *et al*., 2022). In Nigeria, there is inadequate availability of fertilizer to improve soil fertility for growing crops, including tomatoes, inadequate availability of water during the dry season for irrigation and poor water quality typically affect the yield of tomatoes. Erba *et al.* (2013) reported that tomato fruit's variety and ripening stage were the main factors affecting the nutritional values of tomatoes. Ugonna *et al*. (2015) reported that Nigerian tomato farmers are having problems with improved technology for growing tomatoes, inadequate and expensive inputs (such as hybrid seeds, fertilizer, insecticides, and herbicides), high postharvest losses, inadequate processing and marketing infrastructure, low yield and productivity of tomatoes. Water availability to meet the evapotranspiration requirement typically affects growth of tomato plants, photosynthesis rate, fruit production and quality of tomato (Sánchez-Rodríguez *et al*., 2011; Chand *et al*., 2020). Ali *et al.* (2021) reported that tomatoes contain nutritional values such as minerals, vitamins, proteins, essential amino acids, monounsaturated fatty acids, carotenoids containing Lycopene and other food essential compounds. Ali *et al.* (2021) also pointed out that tomatoes have carotenoid containing Lycopene and tomato-based food products to protect body against cancer, cardiovascular diseases, cognitive function and osteoporosis. Therefore, there is a need for continuous research to improve the yield and nutritional qualities of tomatoes against the factors militating production, especially in some developing countries.

Irrigation water with magnetic field to become magnetized water could accelerate plant growth, enhance crop yield, save irrigation water and reduce the effect of deficit irrigation on crop growth and yield (Kareem, 2018; Abd-Ellateef and Mutwali, 2020; Abou El-Yazied, 2011). Surendran *et al*. (2016) reported that magnetization of irrigation water improved cow pean's growth rate and yield using magnetic flux densities of 1800 - 2000 G when the water was allowed to flow through the magnetic field for 10 minutes and a flow rate of 2 liters/s. Kareem (2018) reported that irrigating tomato plant with magnetized water increased the water use efficiency (water productivity) by 78% and the yield of tomatoes by 52.68%. Sadeghipour and Aghaei (2013) also pointed out that magnetized water increased water use efficiency of cowpea by 22%. Fakhri *et al*. (2018) reported that magnetized water increased tomato seeds' germination rate, accelerated plant growth, and increased tomato's fresh and dry weight. Rawabdeh (2014) pointed out that magnetic treatment of irrigation water increased the uptake of essential elements (N, P and K) compared to plants irrigated with non-magnetized water.

Magnetic treatment of irrigation water is a promising technology for improving crop productivity and it is a non-chemical method which could not cause soil degradation or pollute the environment. Water is a paramagnetic substance with positive and negative charges and the orientation of the molecules of water changes under the influence of a magnetic field. Babu (2010) reported that magnetized water has properties of reduced surface tension, smaller water molecules with tiny water clusters and increased solubility of the magnetized water to dissolve more macro and micro-elements which could make more nutrients available for plant growth. In addition, the magnetization of irrigation water enhanced tomato plants' absorption rate of water from the soil for evapotranspiration compared to non-magnetized water (Yusuf and Ogunlela, 2017). The effect magnetization of water by the magnetic field on the water structure depends on the magnetic flux density, time of exposure of magnetic induction, the flow rate of water through the magnetic field and temperature of the water with the range of magnetic flux density varied from 0.1 to 0.8 T (Cai *et al*., 2009).

Tomato is a vegetable fruit that is commonly consumed globally by many people and consumption of vegetable is one of the sources of intake of heavy metals, which can cause cancer and other diseases to man (Sultana *et al*., 2021). High concentrations of heavy metals such as Cadmium, Chromium, Copper, Lead, Manganese, Nickel and Zinc in tomatoes could make them toxic for human consumption, which could affect the nutritional quality of the tomato (Hellen and Othman, 2014; Sultana *et al*., 2021). Tomato plants and other vegetable plants could easily absorb heavy metals from the soil and retain them in edible tomato fruits (Hellen and Othman, 2014; Sultana *et al*., 2021). Magnetization of irrigation water that enhanced better absorption of plant nutrients from the soil could also increase the uptake of heavy metals by the tomato plant and affect the quality of the tomato. Therefore, there is also a need to check the effect of magnetization of irrigation water on the concentration of heavy metals in tomato fruits and compare it with the FAO/WHO permissible limits of heavy metals in vegetables to avoid the consumption of tomatoes that cause cancer and other diseases to man.

Drip irrigation is a method of irrigation in which water is applied directly to the point where the plant is planted or near the plant through an emitter or dripper fitted to a plastic pipe drop by drop (Ranjan and Sow, 2020). Deficit irrigation is a system of irrigation in which the water requirement by the plant is not supplied. Still, a certain percentage of water requirement, like 50%, 60%, 70%, 80% or 90% is applied to use the little available water for crop production. Deficit irrigation (inadequate supply of water to plant) is normally practiced where water is limited to reduce the cost of irrigation water and is better practiced during the plant's vegetative growth. Efereres and Sorian (2006) defined deficit irrigation as the application of water below the evapotranspiration requirements of a plant. With the system of deficit irrigation, water demand for irrigation could be reduced and the water is saved which could be diverted for other uses. However, with deficit irrigation, the plant would under-go water shortage which could affect the growth rate and yield, especially during the flowing or fruiting stage. The objectives of this study were to determine the impact of magnetization of irrigation water on the growth, yield and nutritional qualities of 'Roma VF' variety and 'UC 82B' variety tomatoes.

Materials and Methods

Location of the study

The study was conducted at the Institute of Technology, Kwara State Polytechnic, Ilorin, Nigeria. Ilorin lies on latitude 8°30N and longitude 4°35E, about 340 m above the mean sea level (Akpenpuun and Busari, 2016). Ilorin is in the Southern Guinea Savannah of the Ecological Zone of Nigeria, with a mean annual rainfall of about 1,300 mm. The wet season starts at the end of March and ends in October while the dry season starts in November and ends in March (Ogunlela, 2001). The mean minimum and maximum temperatures of Ilorin are 18 °C and 38 °C, with a mean relative humidity of 77.50% and a daily mean sunshine hour of 7.1 h.

Description of greenhouse and buckets used for growing the tomato

The greenhouse is a simple garden shed 10 m in length, 8 m wide, 3 m in height at the centre and 2 m high on both sides constructed using wood. The top of the greenhouse was covered with transparent nylon (2 mm in thickness) and 1 m of the sides of the greenhouse were also covered with the nylon from the top to prevent rain water from reaching the tomato during the experiment. In addition, all the sides of the greenhouse from bottom to 1 m high were covered with a screen (wire-mesh) to prevent the entrance of birds, rodents, goats and insects into the greenhouse. In addition, a door was provided for entrance and exit. The area covered with wire-mesh provides ventilation for the plant and there is an opening at the top of the greenhouse to exit of vapour and ventilation. The garden shed (greenhouse) is shown in Figure 1.

Ninety-six (96) buckets were used to grow the two varieties of tomato ('Roma VF' variety and 'UC 82B' variety) with 24 buckets for each variety for the magnetized and non-magnetized water. The bucket has a capacity of 11 liters, 263 mm in diameter and 235 mm in height. The bottom of each bucket contains five (5) holes drilled with 5 mm drill to allow excess water drainage from the bucket. The 96 buckets were filled with sandy loam to a depth of 210 mm and 25 mm to top was left in each bucket. The soil used in this study was obtained from the same place that is rich in organic matter and thoroughly mixed to have homogenous soil fertility. A total of 13 kg of the soil was put in each bucket giving a total of 1,248 kg of soil for experiment. The buckets were arranged with 8 rows and 12 buckets on a row with 6 buckets for 'Roma VF' variety and 6 buckets for 'UC 82B' variety as shown in Figure 2. The physico-chemical properties of the soil are presented in Table 1.

Figure 1. Pictorial of the greenhouse

Figure 2. Arrangement of the buckets with the soil and germinated tomato plants in the greenhouse

Table 1. Physico-chemical properties of the soil

Soil parameters	Value
Sand content (%)	78.00
Silt content (%)	17.78
Clay content (%)	4.22
Bulk density (g/cm^3)	1.262
pH	6.77
Organic matter (%)	5.78
Organic carbon (%)	2.95
Nitrogen (%)	0.82
Phosphrus (%)	10.58
Calcium (mg/kg)	5.94
Magnesium (mg/kg)	1.24
Sodium (mg/kg)	6.39
Potassium (mg/kg)	8.32
Electrical conductivity (μS/cm)	511.27

Magnetization of the irrigation water

Magnetization of irrigation water means producing magnetized water with magnetic field for the tomato plants. The magnetized water was produced during the irrigation when the water flowed through the magnetic treatment unit (20 cm by 50 cm rectangular metallic pipe and 100 cm long) that was fixed into the pipe to supply water to the tomato plants in the greenhouse. Neodymium magnet (N52 model) which is powerful with magnetic flux density ranging from 1.2 - 1.5 Tesla (12,000 – 15,000 Gauss), was used to produce the magnetized. Thirty (30) pieces of neodymium magnets (10 × 25 × 50 mm) were used to produce the magnetized water. Fifteen (15) pieces of the magnet were arranged on one side of the rectangular metallic pipe and the remaining 15 pieces of the magnet were arranged on the other side of the rectangular pipe as shown in Figure 3.

Figure 3. Pictorial view of the arrangement of the magnets on the rectangular metallic pipe

When the water flows through the pipe, the magnetic field will flow across the water at a right angle to obey Fleming's right angle rule which states that the flow of water must be perpendicular to the flow of the magnetic field. If the flow of water is not perpendicular to the direction of the magnetic field but parallel to it or flowing in the same direction, the force of the magnetic field would not act on the water and there would be no effect of the magnetic field on the water. The irrigation water would not be magnetically treated. The magnetic flux density inside the rectangular magnetic treatment unit through which the water flows was measured to be 2,350 G using a Gaussmeter (with Model GM-2 by Alpha Lab Inc). The water was treated through the magnetic field for 60 s during irrigation. The chemical properties of water before and after magnetization that were treated for 60 s, 120 s and 180 s are presented in Table 2.

Table 2. Chemical properties of the water before and after magnetization

Water parameters	T_1	T_2	T_3	T_0
pH	8.000	7.450	7.950	8.100
N (%)	0.053	0.070	0.044	0.079
Na^+ (mg/L)	1.695	1.680	1.715	1.720
K^+ (mg/L)	0.415	0.390	0.385	0.350
Ca^{2+} (mg/L)	1.070	0.665	0.645	0.480
Mg^{2+} (mg/L)	0.460	0.335	0.330	0.315
Fe^{2+} (mg/L)	0.320	0.325	0.275	0.475
Pb^{2+} (mg/L)	0.010	0.025	0.030	0.015
Mn^{2+} (mg/L)	0.055	0.055	0.040	0.015
Zn^{2+} (mg/L)	0.020	0.025	0.020	0.010

Cd^{2+} (mg/L)	ND	ND	ND	ND
Cr^{2+} (mg/L)	ND	ND	ND	ND

T_1 = Magnetized water treated for 60 s, T_2 = Magnetized water treated for 120 s,
T_3 = Magnetized water treated for 180 s, T_0 = Control (Non-magnetized water), ND = Not detected

Planting of tomato seed, irrigation of the tomato plant and determination of some plant parameters

Two varieties of tomato seeds ('Roma VF' and 'UC 82B') were planted at about 20 mm depth in the buckets filled with sandy loam on the 24th of July, 2020. Germination of the tomato started with 80% of water application on the 29th July, 2020 (5 days after planting). The quantities of water applied to the tomato plants in the buckets as the four treatments at 2 days irrigation interval were 100% of the water requirement (1 liter), 80% of the water requirement (0.80 liters), 60% of the water requirement (0.60 liters) and 50% of water requirement (0.50 liters).

The plant growths were determined weekly for 5 weeks 14 days after planting for the two varieties of the tomato plant irrigated with magnetized water and non-magnetized water. First, the growth was determined by measuring the height of the plant from the soil base in the bucket to the terminal bud using a tape rule. Next, the diameter of the stem (stem thickness) of the tomato plants was measured carefully 30 mm above the soil base using a vernier caliper. The diameters of the stem of the tomato plants were measured three (3) times, 19 days, 49 days and 71 days after planting. The pictorial view of the tomato plant 6 weeks after planting is shown in Figure 4.

Figure 4. Pictorial view of the tomato plant 6 weeks after planting

Determination of yield of the tomatoes

The tomato fruit was harvested 82 days after planting on the 13th of October, 2020. All the tomato fruits were harvested including the ripped and unripped two varieties of tomato plants because of the lock-down and order by the government that people should stay at home to prevent the spread of Covid-19 in 2020. The yield of the tomato was determined based on the weight of the tomato fruits harvested from each treatment. The tomato fruits from each treatment were weighed on a weighing balance and recorded.

Determination of nutritional qualities and concentration of heavy metals in the tomatoes

The protein, carbohydrate, crude fibre, moisture content, iron, ash, vitamin A and vitamin C contents of the tomato fruits were determined using the standard methods given by AOAC (2000). The concentrations of some selected heavy metals were determined from the tomato fruits irrigated with magnetized water or non-magnetized water to know if the magnetized water increased the uptake of heavy metals from the soil that could be above the permissible limit. The Chromium, Copper, Iron, Lead, Manganese, Nickel and Zinc were determined using the standard methods given by APHA (2005) and AOAC (2000).

Statistical analysis by paired t-test for the growth, stem diameter and yield of the tomato

Paired t-test was used to check if the effect of magnetized water were significant on the growth, stem diameter (stem girth) and yield of the tomato. First, the mean difference between the results of magnetized water and the control results was determined. Then, the mean, the standard deviation, the standard error and the t-test values were determined using Equations (1), (2), (3) and (4), respectively as given by (Montgomery, 1998; Yusuf *et al.*, 2022). The data of the yield of tomato for the computation of the paired t-test was presented in Table 3.

$$\bar{d} = \frac{\sum d}{n} \quad (1)$$

$$\delta = \sqrt{\frac{\sum d^2 - n(\bar{d})^2}{n-1}} \quad (2)$$

$$\delta_{Er} = \frac{\delta}{\sqrt{n}} \quad (3)$$

$$t_{cal} = \frac{\bar{d}}{\delta_{Er}} \quad (4)$$

Where $\bar{d}$ is the mean of the difference from the data x_1 and x_2, Σd is the summation of d, n is the number of observations, δ is the standard deviation, δ_{Er} is the standard error and t_{cal} is the calculated value of the t-test ($\alpha = 0.05/2 = 0.025$).

Table 3. Mean height of tomato plant ('Roma VF' variety) for computation of the Paired t-test

Tomato plant height MW (T_1)	Tomato plant height NMW(T_0)	$d = T_1 - T_0$	d^2
58	42	16	256
230	192	38	1,444
303	265	38	1,444
825	722	103	10,609
983	894	89	7,921
n = 5		**∑d = 284**	**∑d² = 21,674**

T0 and T1:were defined in Figure 2

$$\bar{d} = \frac{284}{5} = 56.8 \quad (1)$$

$$\delta = \sqrt{\frac{21{,}674 - 5(56.8)^2}{5-1}} = 37.225 \quad (2)$$

$$\delta_{Er} = \frac{37.225}{\sqrt{5}} = 16.648 \quad (3)$$

$$t_{cal} = \frac{56.8}{16.648} = 3.412 \quad (4)$$

Similarly, T_2 versus T_0 and others were calculated using the same method with the Equations (1) to (4).

Results

Growth and stem diameter of the tomato plant

The growths of the tomato plants after germination, measured 14 days after planting for 5 weeks are presented in Tables 4 and 5. The growth rate in term of the heights of the plant 42 days after planting for 'Roma VF' variety at 100%, 80%, 60% and 50% water application was 983 mm, 938 mm, 1,029 mm and 906 mm, respectively for tomato plant irrigated with magnetized water while the corresponding heights of tomato plant irrigated with non-magnetized water were 894 mm, 957 mm, 864 mm and 877 mm and shown in Table 4. From Table 5, the growths of the tomato plant for 'UC 82B' variety at 42 days after planting with magnetized water for 100%, 80%, 60% and 50% water application were 983 mm, 954 mm, 977 mm and 906 mm, respectively while the corresponding heights for tomato plants irrigated with non-magnetized water were 866 mm, 903 mm, 828 mm and 775 mm. Magnetized water increased the growth rate of the tomato plants more than the tomato irrigated with non-magnetized water for 'Roma VF' and 'UC 82B' varieties. The results of statistical analysis by Paired t-test to know the effect of the magnetized water or magnetization of irrigation water on the growth of tomato plants for the two varieties are presented in Table 6.

The stem thickness (diameter of the stem) of the tomato plant for 'Roma VF' variety is presented in Table 7 and the results of statistical analysis by Paired t-test are presented in Table 8. The stem diameter of the tomato plant irrigated with magnetized water 71 days after planting for 100%, 80%, 60% and 50% water application were 79.7 mm, 75.4 mm, 60.2 mm and 40.2 mm, respectively but the corresponding heights of the tomato plant irrigated with non-magnetized water were 57.2 mm, 50.6 mm, 49.7 mm and 31.6 mm as shown in Table 7.

Table 4. Mean height of tomato plant ('Roma VF' variety) irrigated with magnetized and non-magnetized water

Day after planting (days)	Height of tomato plant irrigated with MW (mm)				Height of tomato plant irrigated with NMW (mm)			
	100%	80%	60%	50%	100%	80%	60%	50%
14	58	59	133	112	42	72	60	55
21	230	226	239	231	192	206	224	214
28	303	315	363	323	265	292	311	276
35	825	796	813	722	722	770	734	703
42	983	938	1,029	906	894	957	864	877

MW = Magnetized water, NMW = non-magnetized water
100% = Irrigation applied at 100% of available water, 80% = Irrigation applied at 80% of available water
60% = Irrigation applied at 60% of available water, 50% = Irrigation applied at 50% of available water

Table 5. Mean height of tomato plant ('UC 82B' variety) irrigated with magnetized water and non-magnetized water

Day after planting (days)	Height of tomato plant irrigated with MW (mm)				Height of tomato plant irrigated with NMW (mm)			
	100%	80%	60%	50%	100%	80%	60%	50%
14	93	46	50	47	48	59	49	16
21	249	233	239	229	206	230	217	238
28	289	298	291	345	289	314	299	319
35	812	782	814	722	690	764	721	668
42	983	954	977	906	866	903	828	775

MW, NMW, 100%, 80%, 60% and 50% were defined in Table 4.

Table 6. Value of t-test for the growth of the tomato plant

Treatment	Degree of freedom	Calculated value of t	Table value of t at $\alpha \leq 0.05$	Effect of the treatment on the growth of tomato plant
'Roma VT' variety				
T_1 versus T_0	4	3.412	2.776	Significant
T_2 versus T_0	4	0.801	2.776	Not Significant
T_3 versus T_0	4	2.236	2.776	Not Significant
T_4 versus T_0	4	4.298	2.776	Significant
'UC 82B' Variety				
T_1 versus T_0	4	2.781	2.776	Significant
T_2 versus T_0	4	0.703	2.776	Not Significant
T_3 versus T_0	4	1.704	2.776	Not Significant
T_4 vs T_0	4	1.993	2.776	Not Significant

Table 7. Mean stem diameter of tomato plant ('Roma VF' variety) irrigated with magnetized water and non-magnetized water

Day after planting (days)	Stem diameter of tomato plant irrigated with MW (mm)				Stem diameter of tomato plant irrigated with NMW (mm)			
	100%	80%	60%	50%	100%	80%	60%	50%
19	39.0	33.2	30.1	29.0	37.4	30.2	30.2	20.0
49	63.3	58.7	56.2	40.2	50.6	49.7	42.3	40.7
71	79.7	75.4	60.2	40.2	57.2	50.6	49.7	31.6

MW, NMW, 100%, 80%, 60% and 50% were defined in Table 4

Table 8. Values of t-test for the stem diameter of the tomato plant ('Roma VT' variety)

Treatment with	Degree of freedom	Calculated value of t	Table value of t at $\alpha \leq 0.05$	Effect of the treatment on the growth of tomato plant
T_1 versus T_0	2	2.034	4.303	Not Significant
T_2 versus T_0	2	1.888	4.303	Not Significant
T_3 versus T_0	2	1.942	4.303	Not Significant
T_4 versus T_0	2	1.838	4.303	Not Significant

Yield of the tomato fruits

The yields of the tomato for 'Roma VF' and 'UC 82B' varieties harvested once, 82 days after planting were presented in Table 9, and the results of statistical analysis of the t-test of the effect of magnetized water on the yield were presented in Table 10. The mean yield of tomatoes with 'Roma VF' variety irrigated with magnetized for 100%, 80%, 60% and 50% water application were 315 g, 170 g, 170 g and 155 g, respectively while the corresponding values for the 'Roma VF' variety irrigated with non-magnetized water were 160 g, 125 g, 169 g and 125 g. The yields of the tomato irrigated with magnetized water were all higher than those irrigated with non-magnetized water at all levels of water applied. For the 'UC 82B' variety, only the yield of tomato plant irrigated with magnetized water with 100% water application was higher at 150 g than the tomato irrigated with non-magnetized water with 100% water application with 115 g. The yields of tomato irrigated with non-magnetized water for 80%, 60% and 50% produced higher yields than those irrigated with magnetized water, as shown in Table 9. The effect of magnetization of irrigation water for growing tomatoes was not statistically significant on the yield of the two varieties of tomatoes as shown in Table 10.

Table 9. Mean yield of tomato ('Roma VF' and 'UC 82B' varieties) irrigated with magnetized water and non-magnetized water (corrected version of the results with red colour with too low yield)

AW_P (%)	Tomato yield irrigated with MW (g)		Tomato yield irrigated with NMW (g)	
	'Roma VF' variety	'UC 82B' variety	'Roma VF' variety	'UC 82B' variety
100	315	180	150	115
80	170	155	125	210
60	170	210	160	255
50	155	130	125	185

AW_P = Percentage of available water applied during the irrigation
MW = Magnetized water, NMW = non-magnetized water

Table 10. Values of t-test for the yield of the tomatoes

Treatment	Degree of freedom	Calculated value of t	Table value of t at $\alpha \leq 0.05$	Effect of the treatment on the growth of tomato plant
'Roma VT' variety	3	1.790	3.182	Not Significant
'UC 82B' variety	3	0.949	3.182	Not Significant

Nutritional values and concentrations of heavy metals in the tomato fruits

The nutritional qualities of the tomato were assessed based on the percentage contents of Vitamin A, Vitamin C, carbohydrate, protein, crude fat, fibre and the concentrations of the heavy metals in the tomato fruits harvested from the tomato plants irrigated with magnetized and non-magnetized water. The percentage of Vitamin A, Vitamin C, carbohydrate, protein, crude fat, fiber and moisture content are presented in Tables 11 and 12 for the 'Roma VF' variety and 'UC 82B' variety, respectively. The tomato fruit irrigated with 50% of the water requirement for 'Roma VF' variety and the tomato fruits irrigated with 80% and 50% of water requirements for 'UC 82B' variety were mistakenly disposed of before the time of the nutritional analysis was done for the tomato and results were not included in the Tables 11, 12, 13 and 14. Based on the results presented in Tables 11 and 12 for the nutritional values, the values of Vitamin C with the tomato plant irrigated with magnetized water for 100%, 80% and 60% were 116.40, 116.20 and 112.10 mg/kg, respectively. In comparison, the corresponding values for the control (non-magnetized water) with 100%, 80%, 60% and 50% water application were 110.10, 97.62, 111.60 and 88.76 mg/kg, respectively. Vitamin C and Vitamin A contents were higher for the tomato plants irrigated with magnetized water than for tomato plants irrigated with non-magnetized water (control), as shown in Table 11. Tomato is a vegetable fruit and an essential source of Vitamin C and magnetization of irrigation water increased the Vitamins A and C contents of the tomato for the varieties as shown in Tables 11 and 12. The carbohydrate and protein contents of tomatoes irrigated with magnetized water and non-magnetized water had almost the same values for the two varieties of tomatoes.

The concentrations of the heavy metals in the tomato fruits are presented in Tables 13 and 14 for the 'Roma VF' variety and 'UC 82B' variety, respectively. Magnetization of irrigation usually increases the uptake of some elements from the soil. Still, it did not increase the uptake of the heavy metals more than the tomato irrigated with non-magnetized water. Therefore, the values of the heavy metals (Cr^{2+}, Cu^{2+}, Fe^{2+}, Mn^{2+}, Ni^{2+} and Zn^{2+}) assessed from the tomato fruits below the permissible limits of FAO/WHO except for the concentration of Lead (Pb^{2+}) that were above the permissible limits of FAO/WHO for the two varieties as shown in Tables 13 and 14.

Table 11. Nutritional values of the tomato fruit ('Roma VF' variety) to 2 decimal places instead 3 d.p

Parameters in the tomato fruit	Tomato fruit irrigated with MW				Tomato fruit irrigated with NMW			
	100%	80%	60%	50%	100%	80%	60%	50%
Moisture content (%)	88.70	90.42	88.56	-	89.26	88.63	90.02	90.00
Crude fat (%)	0.37	0.49	0.42	-	0.46	0.31	0.39	0.43
Fibre (%)	0.72	0.72	0.42	-	0.78	0.55	0.49	0.54
Ash (%)	3.70	4.03	3.66	-	2.67	3.50	2.75	2.40
Protein (%)	3.79	2.86	4.01	-	3.70	2.88	2.64	4.11
Carbohydrate (%)	97.28	98.51	97.44	-	96.88	95.87	96.29	97.47
Vitamin A (mg/kg)	0.87	0.82	0.75	-	0.68	0.76	0.64	0.60
Vitamin C (mg/kg)	116.40	116.20	112.10	-	110.10	97.62	111.60	88.76

MW = Magnetized water, NMW = non-magnetized water

Table 12. Nutritional values of the tomato fruit ('UC 82B' variety)

Parameters in the tomato fruit	Tomato fruit irrigated with MW				Tomato fruit irrigated with NMW			
	100%	80%	60%	50%	100%	80%	60%	50%
Moisture content (%)	90.83	-	89.07	-	89.36	89.25	88.68	90.38
Crude fat (%)	0.36	-	0.42	-	0.43	0.45	0.60	0.52
Fibre (%)	0.66	-	0.42	-	0.54	0.59	0.64	0.66
Ash (%)	2.84	-	2.61	-	3.51	3.24	4.16	3.48
Protein (%)	2.91	-	3.18	-	3.79	2.09	2.97	2.57
Carbohydrate (%)	97.61	-	95.87	-	97.59	95.62	97.05	97.61
Vitamin A (mg/kg)	0.84	-	0.69	-	0.67	0.75	0.65	0.60
Vitamin C (mg/kg)	116.20	-	112.30	-	110.20	98.00	111.00	88.76

Table 13. Concentration of heavy metals in the tomato fruit ('Roma VF' variety)

Conc. heavy metals in the tomato fruit	FAO/WHO (mg/kg)	Tomato fruit irrigated with MW				Tomato fruit irrigated with NMW			
		100%	80%	60%	50%	100%	80%	60%	50%
Chromium (mg/kg)	2.30	0.403	0.541	0.324	-	0.349	0.487	0.358	0.430
Copper (mg/kg)	73.00	0.592	0.843	0.548	-	0.840	0.745	0.742	0.664
Iron (mg/kg)	425.50	2.187	0.758	0.980	-	1.243	1.452	0.897	1.501
Lead (mg/kg)	0.30	2.430	2.005	1.246	-	1.002	1.240	1.008	0.986
Manganese (mg/kg)		1.552	1.860	2.055	-	2.544	2.345	1.756	1.652
Nickel (mg/kg)	63.00	0.326	0.528	0.436	-	0.547	0.428	0.522	0.380
Zinc (mg/kg)	100.00	0.261	0.243	0.248	-	0.450	0.345	0.320	0.302

Table 14. Concentration of heavy metals in the tomato fruit ('UC 82B' variety)

Conc. heavy metals in the tomato fruit	FAO/WHO 2001 (mg/kg)	Tomato fruit irrigated with MW				Tomato fruit irrigated with NMW			
		100%	80%	60%	50%	100%	80%	60%	50%
Chromium (mg/kg)	2.30	0.346	-	0.467	-	0.298	0.314	0.422	0.347
Copper (mg/kg)	2.00	0.486	-	0.497	-	0.651	0.750	0.740	0.678
Iron (mg/kg)	1.00	1.576	-	0.997	-	0.984	1.027	1.752	2.050
Lead (mg/kg)	0.50	2.054	-	1.552	-	0.755	0.984	1.026	1.320
Manganese (mg/kg)	5.00	2.455	-	2.097	-	2.025	1.548	1.755	0.902
Nickel (mg/kg)	63.00	0.428	-	0.278	-	0.406	0.505	0.249	0.415
Zinc (mg/kg)	1.50	0.264	-	0.262	-	0.400	0.259	0.310	0.252

Discussion

Water is essential for tomato production, and the quantity of water applied below the water requirement of the tomato plant during irrigation affects the growth rate, stem diameter and yield of the tomato as shown in Tables 4, 5, 7 and 9. Magnetization of irrigation water increased the growth rate of the tomato plants for both the 'Roma VF' variety and 'UC 82B' variety as shown in Tables 4 and 5. The growth rate results were in agreement with the study of Fakhri *et al*. (2018) that magnetized water increased the germination rate of tomato seeds and enhanced better growth of the tomato plant. In addition, the results of high growth rate and bigger stem diameter of tomato plant irrigated with magnetized water were in agreed with the results obtained by Yusuf and Ogunlela (2015) that magnetization of irrigation increased the growth rate and stem diameter of tomato plant. Kareem (2018) also stated that magnetized water increased the growth rate, saved irrigation water and reduced the effect of water shortage (deficit irrigation) on plant growth. The effect of magnetization of irrigation water was statistically significant on the growth of the tomato plant for the 'Roma VF' and 'UC 82B' varieties when 100% of water requirement was supplied, also significant at 50% water requirement for 'Roma VF' variety but not significant for 80% 60% and 50% as shown in Table 6.

Magnetizing irrigation water is a promising technology to improve crop yield, especially in some developing countries where fertilizers to improve soil fertility are rarely available. Table 9; increased the yield of the tomato for the 'Roma VF' variety at 82 days when the tomato fruits were all harvested. The result obtained for 'UC 82B' variety revealed that magnetization of irrigation water only increased the yield at 100% water requirement. However, 80%, 60% and 50% water requirements produced higher of tomato fruits when harvested 82 days after planting. The results of the yield obtained in this study were in agreement with the results of Kareem (2018) that magnetized water increased the water use efficiency (water productivity) by 78%. In addition, it increased the yield of tomatoes by 52.68%. Surendran *et al*. (2016) also reported that magnetized water enhanced the growth rate and increased the yield of cowpea. However, the effect of magnetized water was not significant on the yield for the varieties as presented in Table 10.

In Tables 11 and 12 for the nutritional values of the tomato fruits, it was observed that magnetized water increased Vitamin A and Vitamin C. This was in agreement with the results Yusuf and Ogunlela (2016) that magnetization irrigation water increased the Vitamin A and C contents of tomatoes. Furthermore, Rawabdeh (2014) reported that magnetized water increased the uptake of some essential elements (N, P and K) compared to plants irrigated with non-magnetized water. Therefore, this could also improve the tomato's protein, Vitamins A and C contents.

The nutritional quality of the tomato could be affected by the concentration of heavy metals in the fruits. Tables 13 and 14 show that the magnetization of irrigation water did not increase the concentrations of Chromium, Copper, Iron, Manganese, Nickel and Zinc compared to the tomato irrigated with non-magnetized water. The concentrations of heavy metals in the tomato that could cause cancer and other diseases in men were below the permissible limits of FAO/WHO (2001). The concentrations of Lead (Pb^{2+}) in the two varieties of tomato irrigated with magnetized water and non-magnetized water were above the permissible limits of FAO/WHO. The result was in agreement with Yusuf and Ogunlela (2016) that magnetized water increased the concentration of Lead in the tomato.

Conclusions

Magnetization of irrigation water increased the growth rate of the tomato plant. Magnetized water increased the stem diameter and the growth rate and development of the tomato plant at various levels of water application (100%, 80%, 60% and 50% water requirement applied) compared to tomato plants irrigated with non-magnetized water. Magnetized water for irrigating tomato plant increased the yield of 'Roma VF' variety tomatoes by 110.00%. Furthermore, it increased the yield of the 'UC 82B' variety by 56.62% when the water requirement was fully supplied during the irrigation. In addition, tomato plants irrigated with magnetized water had higher yields under deficit irrigation at 80%, 60% and 50% water requirements applied. Magnetized water also increased the Vitamin A and Vitamin C contents of tomatoes. It did not increase concentrations of heavy metals (Chromium, Copper, Iron, Manganese, Nickel and Zinc) in the tomato fruits. Still, it slightly increased the concentration of Lead (Pb^{2+}) in the tomato fruits. From this study, it is recommended that further studies should be carried out to determine the uptake of Lead (Pb^{2+}) and its concentration in tomatoes irrigated with magnetized water.

Authors' Contributions

All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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