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Effect of Foliar Fertilizer and Irrigation Levels on Carrot Productivity

Ciza A. [a*] and Silungwe F. R [b]

[a] *Department of Civil and Water Resources Engineering, Sokoine University of Agriculture, Tanzania.*

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Carrot (*Daucus carota L.)* productivity is still low in Tanzania due to inadequate management. There is dearth of information from the literature on the best management practices with respect to irrigation water (IW) and fertilizer levels for optimal carrot production. Consequently, farmers have limited access to means of boosting carrot productivity levels. Thus, a study was conducted to evaluate the effect of various levels of irrigation for carrots using drip irrigation and their interaction with carbonate foliar fertilizer (Lithovit standard) on the growth, yield, and sugar content of carrots at the School of Engineering and Technology (SoET) research field, Sokoine University of Agriculture (SUA) in Morogoro region, Tanzania. Crop water requirement (ET_c) was calculated using established procedures upon which water application levels were based. Foliar fertilizer was applied at levels of 1 (F_1), 1.5 (F_2), and 2 (F_3) g/L/plant, while irrigation levels applied were 60 (I_1), 80 (I_2), and 100 (I_3) percent of ET_c. The experiment was a 3x3 factorial with treatment combinations F_1I_1, F_1I_2, F_1I_3, F_2I_1, F_2I_2, F_2I_3, F_3I_1, F_3I_2, and F_3I_3 conducted over two seasons during 2020/2021 and 2021/2022. The highest yield of 30.9 t ha^{-1} of carrots was obtained under 100% ET_c, and the lowest yield of 15.1 t ha^{-1} was obtained under the 60% ET_c. Carrots under a deficit irrigation water level of 20%, i.e., 80% ET_c were found to have the highest content of sugar. On the other hand, the highest yield of 26.1 t ha^{-1} of carrots was obtained under the 2 g/L/plant fertilizer level, and the lowest yield of 17.9 t ha^{-1} of carrots was obtained under the 1 g/L/plant fertilizer level. Carrots under the 1.5

**Corresponding author: E-mail: cizaalexandre729@gmail.com;*

g/L/plant fertilizer level were found to have the highest content of sugar. Therefore, for optimum growth and yield, full irrigation in combination with foliar fertilizer application at a level of 2 g/L/plant is recommended for carrots under Morogoro conditions. However, for high sugar content, irrigation at 80% ET_c in combination with foliar fertilizer application at a level of 1.5 g/L/plant is recommended.

Keywords: Carrots; foliar fertilizer; drip irrigation; sugar content; carrot yield; carrot growth.

1. INTRODUCTION

Carrots (*Daucus carota L.*) are one of the important and major root vegetables used for different purposes in the daily human diet [1]. It is rich in beta-carotene, which enhances resistance to blood and eye diseases, and a large amount of carrots in the diet has a favorable effect on the nitrogen balance [2, 3].

Due to the importance of the crop for human existence, increased production to maximize yield is inevitable. However, in most parts of sub-Saharan Africa (SSA), carrot yield has persistently been low due to limited information on appropriate agronomic factors such as irrigation water level [4] and rate of carbonate foliar fertilizer (lithovit standard) application [5]. Elsewhere, carrot yield has reportedly been increased under improved management. Gutezeit (2001) reported that carrot growth, quality, and yield were positively affected by a 75% irrigation level in Germany. On the other hand, El-nasr and Ibrahim [6] reported that the carbonate foliar fertilizer application at a level of 3 ml/L/plant significantly enhanced the growth, yield, and root quality of carrots in Egypt. In Tanzania, this carbonate foliar fertilizer under irrigation system has been tested for other crops such as paddy and maize where it increased the yields [7]. However, limited information is found on carrot production for the best management practices in managing carbonate foliar fertilizer levels and irrigation water (IW).

In addition, interaction between fertilizer and irrigation water application plays an important role in the production of carrots [8]. According to Kifle et al. [9], various studies have been conducted, but these studies have mainly concentrated on carrot production and productivity. As a result, it remains unclear as to which fertilizer rate in combination with irrigation water level produces the best quantity and quality of carrots. For instance, Quezada et al. [10] reported that the growth, yield, and quality parameters of carrots are significantly enhanced by foliar application of potassium under full irrigation, while the application of foliar fertilizer in combination with a 75% water application level positively affected the growth of carrots [11]. These studies point to the need for full investigation on the interactions between irrigation levels and the rates of fertilizer application and their effects on the growth, yield, and quality of carrots. There is a need to provide Tanzanian farmers with the information to know at what rate of fertilizer application and irrigation level the yield, quality, and growth of carrots would be enhanced as the increase in demand dominates the current production. In Tanzania, the average per capita daily carrot consumption is approximately 50 g, while the recommended daily consumption is at least 80 g [12, 13]. This indicates that the production of carrots is still low mainly due to poor agronomic practices and a lack of information on optimal levels of irrigation and of fertilizer application that enhance crop production, therefore prompting increased production under irrigation and fertilization systems.

2. MATERIALS AND METHODS

2.1 Description of the Soil and Irrigation Water in the Study Area

The soil texture in the experimental area was sandy clay and the pH of the irrigation water was 7.8. Tables 1 and 2 in results show the details of the physical and chemical properties of the soil and irrigation water.

2.2 Experimental Design

A factorial arrangement of treatments was laid out in a split-plot design. Two factors, factor 1 being three irrigation levels (100, 80, and 60% ET_c), and factor 2, being three carbonate foliar fertilizer (lithovit standard) levels (1, 1.5, and 2 g/L/plant), were investigated in a 3 x 3 factorial with three replications. There were a total of 9 treatment combinations (plots). Each subplot measured 1.5 m × 2 m in size and was separated from the next by a 0.5 m buffer zone.

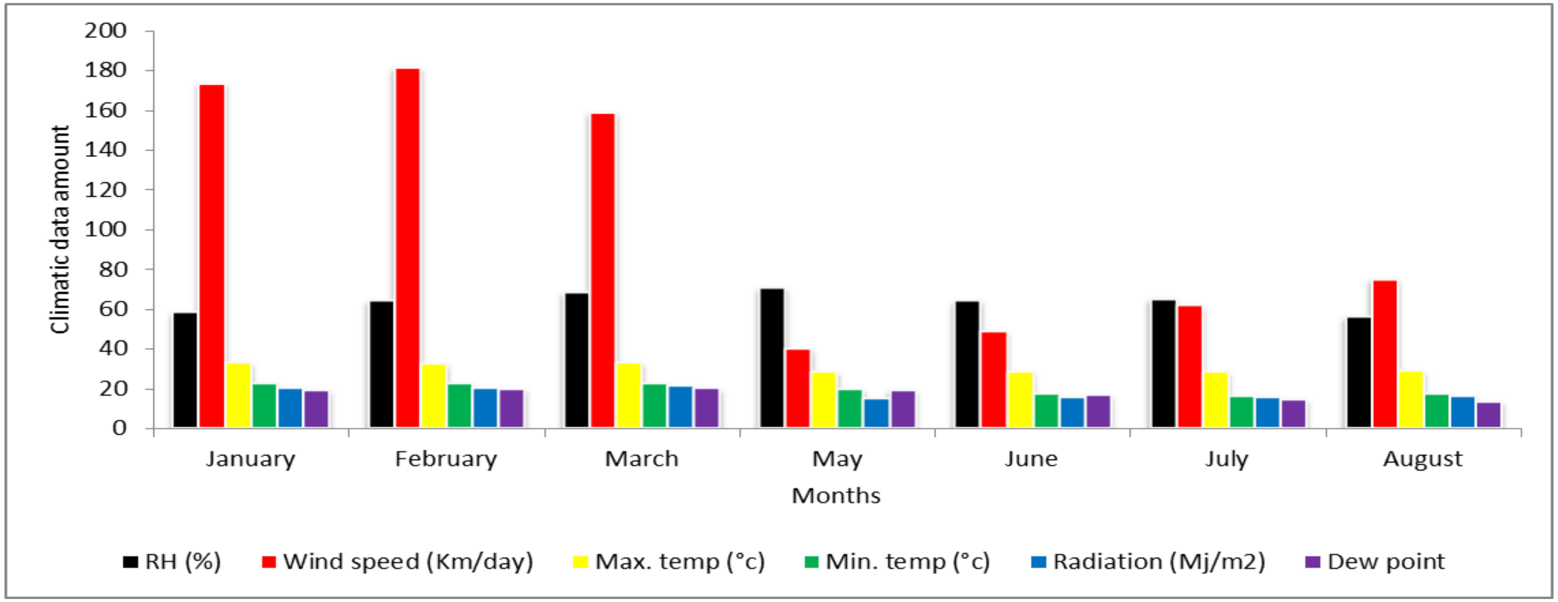

Fig. 1. Mean monthly climatic data during the experiment

Drip irrigation system was used for the irrigation of carrots, with gate valves installed at the head of each lateral feeding the whole plot. The discharge of one emitter corresponding to full irrigation, i.e., 100% ET_c (I_3), was 2 litres per hour (L/h). The discharges of the other emitters corresponding to water application levels of 80 and 60% ET_c (I_2 and I_1) were attained based on the 2 L/h discharge by measuring the discharge from an emitter using graduated cylinders and adjusting the valves. The measurements were taken at three positions (at the beginning, middle, and end) of the lateral. Thinning has been done two weeks after the emergence of the crop to attain the required spacing of 10 cm between plants, which gave 45 plants per sub-plot with a row spacing of 20 cm. No control for zero irrigation was applied because the experiment took place during the dry season. The applied water depth was 475.83 mm (I_3), 380.67 mm (I_2), and 285.498 mm (I_1) in season one, while in season two it was 233.64 mm (I_3), 186.92 mm (I_2), and 140.19 mm (I_1).

2.3 Crop Water Requirements

The reference crop evapotranspiration (ET_o) was determined using the Penman-Monteith equation [14] with the aid of INSTAT plus (v3.6) software [15].

The crop water requirement was determined as follows:

$$ET_c = ET_o \times K_c \qquad (1)$$

Where,

ET_c: Crop evapotranspiration (mm day^{-1})

ET_o: Reference evapotranspiration (mm day^{-1})

K_c: Crop coefficient

Source: [16].

2.4 Crop Growth, Yield, and Root Parameters

The plant growth parameters like plant height, the number of leaves per plant, and the length of leaves were measured. From each treatment, the height of 5 tagged carrot plants was measured using a ruler from the ground level to the top of the root shoot. The obtained measurements were recorded in cm. On the same plants, the length of leaves was measured from the bulb neck to the tip of the leaf using a ruler. The number of fully expanded leaves was counted and recorded as the number of leaves per plant.

The yield data was obtained after harvesting. The obtained weights were recorded in tons/ha.

For the root growth parameter study, the same carrots that had been used to take data for the plant growth parameters were also used for the determination of the root growth and quality of carrots. The root length was determined using a vernier caliper. The shoulder and core diameter of roots were measured at 0.5 cm from the top of the shoulder using also a vernier caliper, and measurements were recorded in mm.

2.5 Quality Parameter

Quality parameter like the total soluble solids, i.e., sugar level in carrots was measured using a hand-held refractometer (0–30% Brix) and recorded in percentage.

2.6 Statistical Analysis

Analysis of variance (ANOVA) on the data collected was done using Genstat statistical software. The mean separation was carried out using Duncan's multiple range test (DMRT) at the 0.05 probability level [17].

3. RESULTS AND DISCUSSION

3.1 Soil and Irrigation Water Analysis

Tables 1 and 2 show the results of soil and irrigation water tests in the study area. According to the classification suggested by [18], the soil texture was sandy clay. Sandy clay soil is suitable for vegetable production but needs regular watering and fertilizing to ensure healthy development [19]. According to Park et al. [20], the sodium adsorption ratio (SAR) was low. Irrigated water with low SAR is safe with regard to sodicity hazard [13].

3.2 Effect of Different Irrigation Levels on the Growth, Yield, and Quality of Carrots

3.2.1 Plant height

Carrots irrigated at 100% ET_c produced the highest plant height in the first season (43.27 cm) and second season (40.92 cm) compared to 60% and 80% ET_c, while 60% ET_c resulted in the least plant height in the first season (37.4 cm) as well as the second season (37.42 cm) (Table 3). However, during the first season, the plant heights for 80% and 100% ET_c were not significantly different at the 5% level, but both differed significantly ($p<0.05$) from the 60% ET_c. In the second season, plant height differed significantly ($p<0.05$) among the three irrigation levels.

It is evident that the plant height increased gradually as irrigation water levels increased up to full irrigation. This could be attributed to the favorable soil moisture for proper plant growth associated with the rapid increase and expansion of plant cells that play vital roles in the biological and physiological processes of carrot plants, resulting in an increase in the plant height. This is in agreement with the findings by Ludong [21], who reported that the height of carrots increased with increasing levels of irrigation water.

3.2.2 Number of leaves

Irrigating carrots at 100% ET_c produced the highest number of leaves in the first season (10.6) as well as in the second season (10.4) compared with the other treatments. The lowest number of leaves per plant was obtained from the 60% ET_c in both seasons (Table 3). The number of leaves per plant was not significantly different ($p>0.05$) between the 60% and 80% ET_c, but both differed significantly ($p<0.05$) from the 100% ET_c in the first season. However, in the second season, the number of leaves per plant differed significantly ($p<0.05$) among the three irrigation levels.

From the results, it is evident that irrigation levels of 60 and 80% decreased the number of leaves per plant. This could be due to the effect of water deficit which decreased the photosynthetic capacity that led to decreased leaf stomata conductance due to stomata closure as pointed out by [22].

3.2.3 Leaf length

Results in Table 3 show that irrigating carrots at 100% ET_c resulted in the maximum length of leaves in the first season (11.34 cm) as well as in the second season (10.54 cm). Likewise, the 60% ET_c recorded the minimum length of leaves in the first season (10.66 cm) as well as in the second season (9.53 cm). Further, the leaf lengths were not significantly different ($p>0.05$) among the three irrigation levels in the first season. However, in the second season, the three irrigation levels differed significantly ($p<0.05$) in relation to leaf length. The increase in the leaf length as irrigation level increased up to 100% ET_c could be attributed to the better utilization of nutrients using adequate soil moisture. These results are in agreement with those found by Jahan [23], who reported an increase in the leaf length of carrots as irrigation level increased up to full irrigation.

Table 1. Physical and chemical properties of the soil in the study area

Soil properties	Values	Description
pH 1:2.5 in H_2O	6.12	Medium acidic soil
Total Nitrogen (%)	0.11	Low
Extractable Phosphorus (mg kg^{-1})	0.28	Low
EC_e (dS/m)	0.16	Normal
Potassium (Cmol kg^{-1})	0.208	Medium
Particle size distribution (%)		
Clay	39.76	Sandy clay
Sand	54.56	
Silt	5.68	

Table 2. Irrigation water quality

Parameters	Results	Description
Ph	7.8	Normal
Sodium (me L^{-1})	9.95	Slight to moderate
EC_w (dSm^{-1})	1.013	Medium
Phosphorus (mg L^{-1})	0.04	Non-problem
SAR (meq L^{-1})	1.33	Low
Bicarbonate (meq L^{-1})	0.38	Good
Carbonate (meq L^{-1})	1.38	Medium
Nitrogen (mg L^{-1})	0.03	Normal

Table 3. Effect of different water application levels on the growth, quality, and yield of carrots

Water level	Plant height (cm)	Number of leaves	Leaf length (cm)	Fresh root weight(t/ha)	Root length (cm)	Root core diameter (mm)	Root shoulder diameter (mm)	TSS (%)
				First season				
60%	37.4a	9.6 a	10.66a	16.7 a	14.25a	13.19 a	23.77 a	8.15a
80%	41.54 b	9.9 a	10.76a	21.9 b	16.07b	16.53 b	26.82 b	8.5a
100%	43.27b	10.6 b	11.34a	30.9 c	17.07 b	18.83 c	29.08 c	8.11a
LSD(5%)	2.185	0.366	0.716	1.3	1.008	1.728	1.816	0.499
				Second season				
60%	37.4 a	8.7 a	9.53 a	15.1 a	13.82 a	12.8 a	23.39 a	6.38 a
80%	38.83 b	9.7 b	10.06 b	21.2 b	15.36 b	14.03 b	25.90 b	7.67b
100%	40.92 c	10.4 c	10.54 c	28.4 c	16.94 c	15.98 c	27.13 b	6.34 a
LSD(5%)	0.606	0.378	0.325	1.19	1.02	1.025	2.073	1.107

TSS: Total Soluble Solids, LSD: Least Significance Difference, DMRT: Duncan's Multiple Range Test. Means followed by the same letter (s) in the same column are not significantly different according to DMRT

3.2.4 Fresh root weight

The highest fresh root weight in the first season (30.9 t ha^{-1})) as well as in the second season (28.4 t ha^{-1}) was recorded under the 100% ET_c, while the lowest fresh root weight in the first season (16.7 t ha^{-1}) as well as in the second season (15.1 t ha^{-1}) was obtained under the 60% ET_c. Fresh root weight was significantly different ($p<0.05$) among the three irrigation levels in both seasons (Table 3).

The reduced fresh root weight under the 60% ET_c could be due to the soil water stress that caused the carrot plants to absorb inadequate nutrients essential for root growth. In connection with this, Li et al. [24] reported that drought stress throughout the entire growth period of carrots caused a more severe reduction in the root production.

3.2.5 Root length

Full irrigation resulted in the maximum length of roots in the first season (17.07 cm) as well as in the second season (16.94 cm), while the minimum root length in the first season (14.25 cm) as well as in the second season (13.82 cm) was recorded under the 60% ET_c. Further, the root length was not significantly different ($p>0.05$) between the 80 and 100% ET_c, but both differed significantly ($p<0.05$) from that under the 60% of ET_c in the first season. However, in the second season, the root length differed significantly ($p<0.05$) among the three irrigation levels (Table 3).

The increased root length due to higher water application levels could be due to availability of sufficient moisture which helped in rapid cell elongation leading to longer root formation. This is consistent with findings by Afrin et al. [25] and Ahmad et al. [26], who reported that root length of carrots was higher with higher amount of water level.

3.2.6 Root core and shoulder diameters

The maximum root core diameter of 18.83 mm in the first season and 15.98 mm in the second season were obtained under the 100% ET_c, while the minimum root core diameter of 13.19 mm in the first season and 12.8 mm in the second season were obtained under the 60% ET_c. Likewise, the maximum root shoulder diameter in the first season (29.08 mm) and in the second season (27.13 mm) were obtained under the 100% ET_c and the minimum root shoulder diameter in the first season (23.77 mm) and in the second season (23.39 mm) were obtained under the 60% ET_c (Table 3). Further, the root core diameter differed significantly ($p<0.05$) among the three irrigation levels in the first as well as the second season. On the other hand, the root shoulder diameter followed the same trend as that of the root core diameter in the first season in terms of statistical significance but during the second season the root shoulder diameter under the 80 and 100% ET_c did not differ significantly ($p>0.05$).

Deficit irrigation (60 and 80% ET_c) produced the lowest values in root core and shoulder diameters for carrots. This could be due to the effect of prolonged water stress, with consequent reduction in overall growth. In confirmation of this, Reid and Gillespie [27] reported that water deficits cause water stress in plants, prevent plant and root growth, and reduce the absorbing areas and capacities of plant roots.

3.2.7 Total Soluble Solids (TSS)

As shown in Table 3, the highest TSS in the first season (8.5%) and the second season (7.67%) were obtained under the medium water application level (80% ET_c), while the lowest TSS in the first season (8.11%) and the second season (6.34%) were obtained under full irrigation. Further, the TSS were not significantly influenced by irrigation levels in the first season. However, in the second season, the TSS under the 60 and 100% ET_c differed significantly ($p<0.05$) from those under the 80% ET_c.

The abundance of TSS content in the roots of the lesser irrigated carrot plants is more of a physiological characteristic that could be explained by plant photosynthesate redistribution into the roots as a result of the water deficit, which resulted in lower water content but increased sugar content. A similar observation has also been made by Fikselová et al. [28], who reported that increased moisture has a negative influence on TSS content on carrot roots.

3.3 Effects of Foliar Fertilizer on the Growth, Yield, and Quality of Carrots

3.3.1 Plant height

Spraying foliar fertilizer at a level of 2 g/L/plant resulted in the most plant height in the first season (43.27 cm) and the second season (41.14 cm), while the foliar fertilizer level of 1 g/L/plant resulted in the least plant height in the first season (37.55 cm) as well as the second season (36.18 cm). The plant heights under 1.5 and 2 g/L/plant fertilizer levels were not significantly different at the 5% level in the first season, but both differed significantly ($p<0.05$) from the 1 g/L/plant fertilizer level. However, in the second season, plant height differed significantly ($p<0.05$) among the three fertilizer levels. The results (Table 4) show that carrot height consistently increased with fertilizer rate. The application of higher fertilizer rates has the potential to fulfill the requirements of the plant for nutrients than lower fertilizer rates. This observation was also made by Badr et al. [29], who reported that the highest level of foliar feeding produced the most carrot height compared to the lowest fertilizer level. In their study, Alhariri and Boras [30] reported that foliar application of up to 1.5 g/L/plant fertilizer significantly enhanced carrot growth by increasing carrot height. A study by El-nasr and Ibrahim [6] reported that spraying carrot plants with foliar fertilizer at a level of 3 ml/L/plant produced the highest values of plant height compared to control treatment (without foliar application) in two seasons.

3.3.2 Number of leaves

As shown in Table 4, the number of leaves per plant followed the same trend as that of plant height in the two seasons in terms of statistical significance. Spraying foliar fertilizer at a level of 2g/L/plant produced the highest number of leaves per plant in the first season (10.4) as well as in the second season (10.08) compared with the other treatments. The lowest number of leaves per plant was obtained from the 1 g/L/plant fertilizer level in both seasons.

In agreement with this, El-Helaly [31] stated that the use of high foliar feeding levels improved the number of leaves on carrots compared to low fertilizer levels. Badr (2010) reported that among the different fertilizer levels (0.5, 1, 1.5 and 2 ml/L/plant), 2 ml/L/plant produced the highest number of leaves.

3.3.3 Leaf length

Spraying foliar fertilizer at a level of 2 g/L/plant resulted in the maximum length of leaves in the first season (11.37 cm) as well as in the second season (10.39 cm). Likewise, the 1 g/L/plant fertilizer level recorded the minimum length of leaves in the first season (10.47 cm) as well as in the second season (9.45 cm). Further, the leaf lengths were not significantly different ($p>0.05$) between the 1 and 1.5 g/L/plant fertilizer levels in the first season as was the case for the 1.5 and 2 g/L/plant fertilizer levels but the 1 g/L/plant fertilizer level was significantly different ($p<0.05$) from the 2 g/L/plant fertilizer level. In the second season, the leaf lengths under the 1.5 and 2 g/L/plant fertilizer levels were not significantly different ($p>0.05$) but both differed significantly ($p<0.05$) from the 1 g/L/plant fertilizer level (Table 4).

Foliar nutrition using a high fertilizer level can eliminate problems like fixation and immobilization of nutrients by penetrating the stomata of the leaf, entering the cells rapidly and fulfilling the nutrient demand of the growing plant, resulting in enhanced length of the leaf [32]. This is in agreement with the findings of Anub [11], who reported that an increased application level of foliar feeding to carrots enhanced the length of the leaves.

Table 4. Effect of different rates of foliar fertilizers on the growth and yield parameters of carrots

Fertilizer level	Plant height (cm)	Number of leaves	Leaf length (cm)	Fresh root weight (t/ha)	Root length (cm)	Root core diameter (mm)	Root shoulder diameter (mm)	TSS (%)
				First season				
1	37.55 a	9.4 a	10.47 a	19.8 a	15.53 a	13.09 a	22.6 a	8.27b
1.5	41.39 b	10.2 b	10.92 ab	23.6 ab	15.71 a	17.28 b	28.15 b	8.88 c
2	43.27 b	10.4 b	11.37 b	26.1 b	16.16 a	18.18 b	28.92 b	7.6 a
LSD(0.05)	2.185	0.366	0.716	1.3	1.008	1.728	1.816	0.499
				Second season				
1	36.18 a	9.2 a	9.45 a	17.9 a	15 a	11.49 a	20.38 a	6.36a
1.5	39.85 b	9.7 b	10.29 b	22.9 b	15.42 a	15.11 b	27.53 b	8.25b
2	41.14 c	10.08 c	10.39 b	24.03 b	15.7 a	16.21 c	28.51 b	5.78 a
LSD(0.05)	0.606	0.378	0.325	1.19	1.02	1.025	2.073	1.107

3.3.4 Fresh root weight

The highest fresh root weight in the first season (26.1 t/ha) as well as in the second season (24.03 t/ha) were recorded under the 2 g/L/plant fertilizer level, while the lowest fresh root weight in the first season (19.8 t/ha) as well as in the second season (17.9 t/ha) were obtained under the 1 g/L/plant fertilizer level. Fresh root weight followed the same trend as that for leaf length in terms of statistical significance in both seasons (Table 4). The fresh root weight consistently increased with increasing fertilizer levels. In their study, Shibairo et al. [33] reported that higher fertilizer levels directly increased the root fresh weight by producing heavier roots than the lower rates.

3.3.5 Root length

Results (Table 4) indicate that the root length was not significantly influenced by the levels of fertilizer application in both seasons. Nevertheless, the highest level of 2 g/L/plant resulted in the maximum length of root in both seasons, while the minimum root length was recorded under the 1 g/L/plant fertilizer level in both seasons. This positive effect on the root length due to increased fertilizer levels could be attributed to the favorable fertilizer nutrients for proper plant growth associated with rapid increase and expansion of plant cells that play vital roles in the biological and physiological processes of carrot plants, resulting in an increase of the root length. A similar observation was also made by Badr and Helmy (2011), who reported that higher fertilizer levels produced longer roots than the lowest fertilizer levels.

3.3.6 Root shoulder and core diameters

Results (Table 4) indicate that the root shoulder diameter did not differ significantly ($p>0.05$) between the 1.5 and 2 g/L/plant fertilizer levels in the first as well as the second seasons but both differed significantly ($p<0.05$) from that under the 1 g/L/plant fertilizer level. On the other hand, the root core diameter did not differ significantly ($p>0.05$) between the 1.5 and 2 g/L/plant fertilizer levels in the first season, but during the second season, the root core diameter differed significantly ($p<0.05$) among the three fertilizer levels. The maximum root core diameter of 18.18 cm in the first season and 16.21 mm in the second season was obtained under the 2 g/L/plant fertilizer level, while the minimum root core diameter of 13.09 mm in the first season and 11.49 mm in the second season was obtained under the 1 g/L/plant fertilizer level. Likewise, the maximum root shoulder diameter in the first season (28.92 mm) and the second season (28.51 mm) was obtained under the 2 g/l/plant fertilizer level. The minimum root shoulder diameter in the first season (22.6 mm) and the second season (20.23 mm) was obtained under the 1 g/l/plant fertilizer level. These results are in agreement with those of Badr et al. [29]. Other studies Arshad et al. [34], El-nasr and Ibrahim [6], and Sharangi and Paria [35] reported that higher fertilizer levels directly increased the root core and shoulder diameters than the lower fertilizer levels.

3.3.7 Total Soluble Solids (TSS)

The highest TSS in the first season (8.88%) and the second season (8.25%) were obtained under the 1.5 g/L/plant fertilizer level, while the lowest TSS in the first season (7.6%) and the second season (5.78%) were obtained under the 2 g/L/plant fertilizer level. Further, the TSS were significantly influenced by fertilizer levels in the first season. However, TSS under the 1 g/L/plant fertilizer level did not differ significantly ($p>0.05$) from that under the 2 g/L/plant fertilizer level during the second season (Table 4). The highest fertilizer level (2 g/L/plant) resulted in decreased sugar levels in the carrots. This is an intriguing result as it tends to suggest that there is an optimal level of fertilization for TSS accumulation. In confirmation of this, Evers [36], Mbatha [37], and Noella et al. [38] reported that less fertilized treatments had a greater tendency to increase sugar content in carrots than the most fertilized treatments.

3.4 Effect of the Interaction between Irrigation Water and Foliar Fertilizer Levels on the Growth, Yield, and Quality of Carrots

3.4.1 Plant height

The interaction between full irrigation × 2 g/L/plant fertilizer level produced the highest plant height in the first season (46.43 cm) as well as in the second season (43.08 cm) compared to other interactions, while 60% ET_c × 1 g/L/plant fertilizer level resulted in the least plant height in the first season (33.83 cm) as well as in the second season (34.49 cm). Further, the plant height under the 60% ET_c × 1 g/L/plant fertilizer level differed significantly ($p<0.05$) with other combinations in both seasons (Table 5). The height of carrots increased consistently with fertilizer and irrigation water increments, up to 2 g/L/plant in combination with full irrigation. This could mean that the nutrients from irrigation water (full irrigation) in combination with the nutrients from foliar feeding enhanced photosynthesis which resulted in better plant growth. The findings are in harmony with those by Batra [39] and Prabhakar [40], who reported that the increase in irrigation water and fertilizer levels resulted in increased carrot height.

3.4.2 Number of leaves

Results (Table 6) show that the number of leaves per plant under the full irrigation × 2 g/L/plant fertilizer level differed significantly ($p<0.05$) with other combinations in the first season. However, in the second season, the 60% ET_c × 1 g/L/plant fertilizer level differed significantly ($p<0.05$) with other combinations. Application of full irrigation in combination with 2 g/L/plant fertilizer level produced the highest number of leaves in the first season (11.27) as well as in the second season (10.51), while the lowest number of leaves in the first season (8.93) as well as in the second season (8.16) was obtained under the 60% ET_c × 1 g/L/plant fertilizer level. A similar explanation as that advanced for the case of plant height for the full irrigation x 2 g/L/plant fertilizer level combination would seem to be the case for the number of leaves produced [41].

3.4.3 Leaf length

The maximum leaf lengths in the first season (11.56 cm) as well as in the second season (11.25 cm) were obtained under the full irrigation in combination with the 2 g/L/plant fertilizer level. Likewise, the minimum leaf lengths in the first season (9.72 cm) as well as in the second season (9 cm) were obtained under the 60% ET_c × 1 g/L/plant fertilizer level (Table 7). The leaf lengths were not significantly different ($p>0.05$) among various interactions in the first season. However, in the second season, the full irrigation × 2 g/L/plant fertilizer level differed significantly ($p<0.05$) from other combinations. A similar explanation as that given for the plant height and number of leaves could be advanced for the case of the length of leaves [42-44].

Table 5. Effects of the interaction between water application and foliar fertilizer levels on the plant height

Fertilizer levels	1 g	1.5 g	2 g
Water levels	**Plant height**		
	First season		
60%	33.83 a	38.49 b	39.87 bc
80%	39.11 b	42 bc	43.50 cd
100%	39.7 bc	43.69 cd	46.43 d
LSD (5%)	3.784		
	Second season		
60%	34.49 a	38.29 c	39.5 d
80%	35.74 b	39.91 de	40.85 ef
100%	38.31 c	41.37 f	43.08 g
LSD (5%)	1.105		

Table 6. Effects of the interaction between water application and foliar fertilizer levels on the number of leaves

Fertilizer levels	1 g	1.5 g	2 g
Water levels	**Number of leaves**		
	First season		
60%	8.93 a	9.93 bc	9.97 bc
80%	9.47 ab	10.17 bc	10.14 bc
100%	10.03 bc	10.5 c	11.27 d
LSD (5%)	0.635		
	Second season		
60%	8.16 a	8.88 b	9.31 bc
80%	9.16 bc	9.75 cd	10.43 de
100%	10.36 de	10.43 de	10.51 e
LSD (5%)	0.65		

Table 7. Effects of the interaction between water application and foliar fertilizer levels on the leaf length of carrots

Fertilizer levels	1 g	1.5 g	2 g
Water levels		**Leaf length First season**	
60%	9.72 a	10.85 ab	11.41 b
80%	10.48ab	10.66 ab	11.14 b
100%	11.22ab	11.24 ab	11.56 b
LSD (5%)	1.241		
		Second season	
60%	9 a	10.09 cde	9.5 abc
80%	9.47 ab	10.28 de	10.42 de
100%	9.87 bcd	10.51 e	11.25 f
LSD (5%)	0.563		

4. CONCLUSION

Spraying foliar fertilizer at a level of 2 g/L/plant enhanced the growth and yield of carrots compared to other fertilizer levels in two seasons. However, 1.5 g/L/plant fertilizer level resulted in the highest sugar content in the roots. On the other hand, full irrigation increased carrot production in both seasons. However, carrots under a level of 80% ET_c were found to have the highest content of sugar. Therefore, for optimum growth and yield, full irrigation and foliar fertilizer application at a level of 2 g/L/plant is recommended for carrots under Morogoro conditions. On the other hand, for high sugar content, deficit irrigation at 80% ET_c in combination with foliar fertilizer application at a level of 1.5 g/L/plant is recommended.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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