CARROT PRODUCTIVITY UNDER VARIOUS LEVELS OF IRRIGATION AND FERTILIZATION

ABSTRACT

Carrot (*Daucus carota L.*) is normally grown under irrigation system. In Tanzania, carrot productivity is still low, mainly due to poor agronomic practices as a result of limited information on optimal levels of irrigation water that enhance crop production. Thus, a study was conducted to evaluate the interactions between various irrigation levels under drip irrigation and soil-based NPK fertilizer for optimal growth, yield, and sugar content of carrots in Morogoro, Tanzania. The crop water requirement was calculated in terms of crop evapotranspiration (ET_c) as the product of ET_o, Kc, and the ground cover reduction factor (K_r). Soil-based fertilizer was applied at a level of 150 kg NPK ha^{-1}, while irrigation levels applied were 100, 80, and 60% of ET_c. It was found that the growth, yield, and sugar content of carrots were affected differently at various irrigation water (IW) application levels. The growth parameters of carrots improved consistently to optimum IW levels. Further, the highest average yield of 0.37 tons ha^{-1} of carrots was obtained under 100% of IW, and the lowest average yield of 0.216 tons ha^{-1} was obtained at 60% of IW in both seasons. The 60 and 80% IW level yields did not differ significantly ($p>0.05$). Carrots grown at a deficit irrigation water level of 80% were found to have the highest content of sugar. Therefore, for optimal growth and yield, an irrigation level of 100% is recommended for carrots. However, for high sugar content, an irrigation level of 80% is recommended.

Key words: Drip irrigation, carrot yield, carrot growth, reference evapotranspiration, NPK fertilizer

1. INTRODUCTION

Carrots are one of the most consumed vegetables in the world owing to their delicious flavour and high carotene content, which has a number of health benefits [18]. Despite their importance, carrot production remains low in most parts of sub-Saharan Africa (SSA) due to various challenges exacerbated by a lack of information on crop water requirements (ET_c) and their respective levels, which would improve carrot production.

Crop water requirements play a key role in irrigation arrangement, designing, and water management in irrigated agriculture [32]. In agreement with this, the literature is rich in studies on ET_c and its effects, especially for common crops such as maize[2], wheat [25], and paddy rice [32]. However, limited information is found on carrots, especially for the part of SSA. Although the crop is normally grown under irrigation, very limited information is found on how best the drip irrigation system can be used for irrigated carrot production in SSA and its respective irrigation water requirements. Such kinds of information have assisted in improving carrot production elsewhere; for instance, [31] reported that the water requirement to achieve carrot production is 460.6 mm in Chile. Conversely, [10] stated that 97% of ET_c promoted the yield of carrots in Brazil. While these studies may not necessarily benefit Tanzanian carrot farmers directly, there is limited information as to which irrigation water level can enhance carrot production in Tanzania. As a result, the levels of irrigation water applied are either insufficient or excessive for good quality carrots [30].

In addition, both irrigation and fertilizer have positive or negative effects on plant development. For instance, [16] reported that 75% of ET_c combined with 150 kg N ha^{-1} enhanced the yield of carrots in Germany. [1] stated that full irrigation in interaction with 120 kg N ha-^{1} enhanced the growth and yield of carrots in Egypt. In Tanzania, there is a dearth of information on the interaction between the irrigation water and fertilizer levels and their effects on carrot production [13]. There is a need to provide information on crop water requirements for carrots as the crop has gained an increasing demand, hence the need for higher production. Given that the price of carrots has increased internationally by about 50 dollars per ton [26], and dwindling fresh water resources, there is a need to increase its production using an efficient and more precise means of irrigation that saves water. Therefore, this study was aimed at determining the ET_c by applying various amounts of water to the carrot crop using drip irrigation and assessing their influences in combination with fertilizer levels on the growth, quality, and yield of carrots. The study evaluated: (1) the effect of various water application and soil-based fertilizer levels on the growth, yield, and quality of carrots; and (2) the effect of the interaction between water application and soil-based fertilizer levels on the growth, yield, and quality of carrots.

2. MATERIALS AND METHODS

2.1 Description of the study area

The field experiment was carried out at the School of Engineering and Technology (SoET) research field (grid zone 350 213.19 E, 9 243 788.94 N, 37M; 512 m above sea level) as shown in Figure 1. The SoET is part of the Sokoine University of Agriculture (SUA) and is situated 3 km from the town center within Morogoro Municipality, Tanzania.

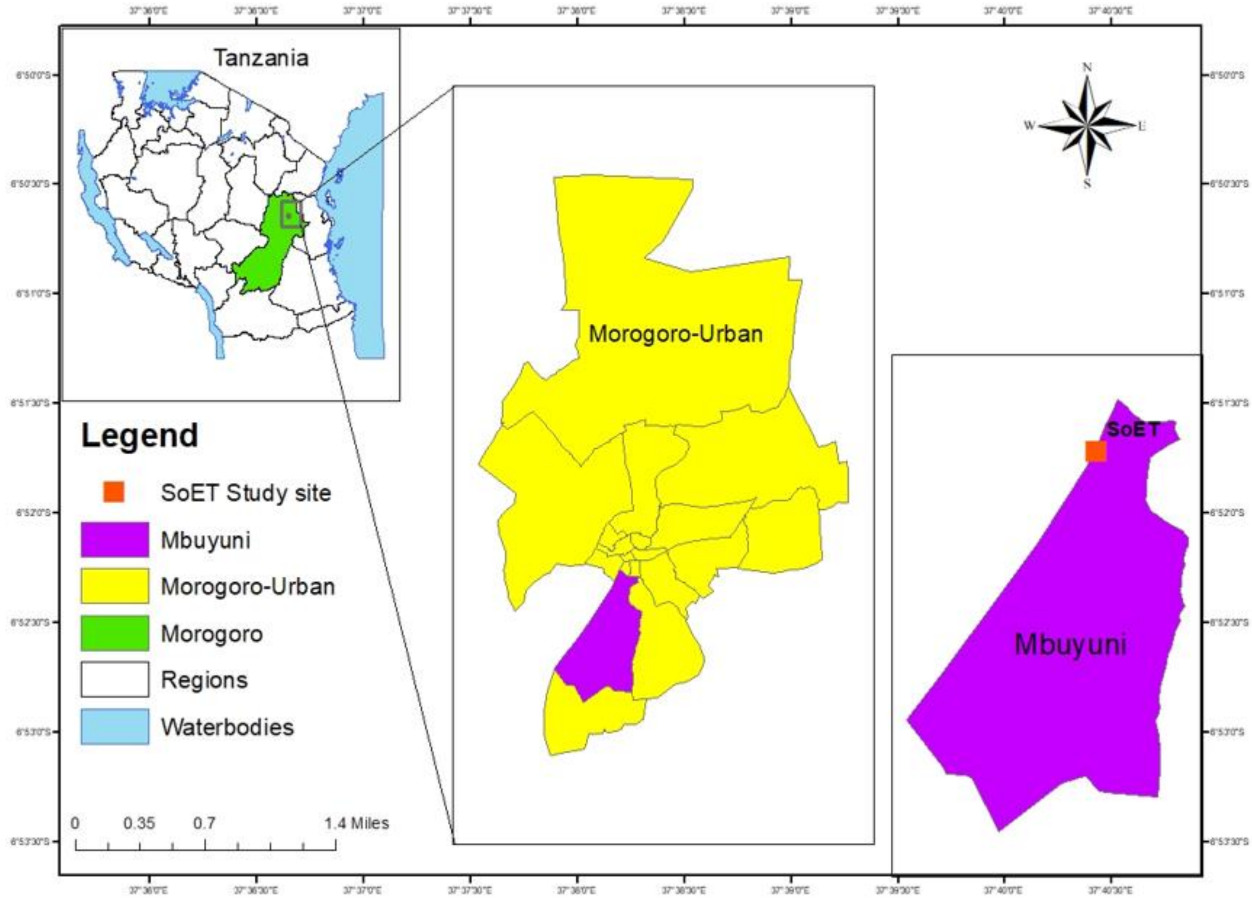

Figure 1: Map showing the location of the study site

2.2 Experimental Design

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

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% of readily available water (I_{100}) application level, was 2 liters per hour (L h^{-1}). The discharges of the other emitters corresponding to water application levels of 80% and 60% of ET_c (I_{80} and I_{60}) were attained based on the 2 L h^{-1} 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. To achieve the desired spacing of 10 cm between plants, thinning has been done two weeks following the crop emergence, 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_{100}), 380.67 mm (I_{80}), and 285.498 mm (I_{60}) in season one, while in season two it was 233.64 mm (I_{100}), 186.92 mm (I_{80}), and 140.19 mm (I_{60}).

2.3 Crop water requirements

The reference crop evapotranspiration (ET_o) was determined using the Penman-Monteith equation [5] with the aid of INSTAT plus (v3.6) software [34]. Climatic data were obtained from the Tanzania Meteorological Agency for the Sokoine University of Agriculture meteorological station.

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: [11].

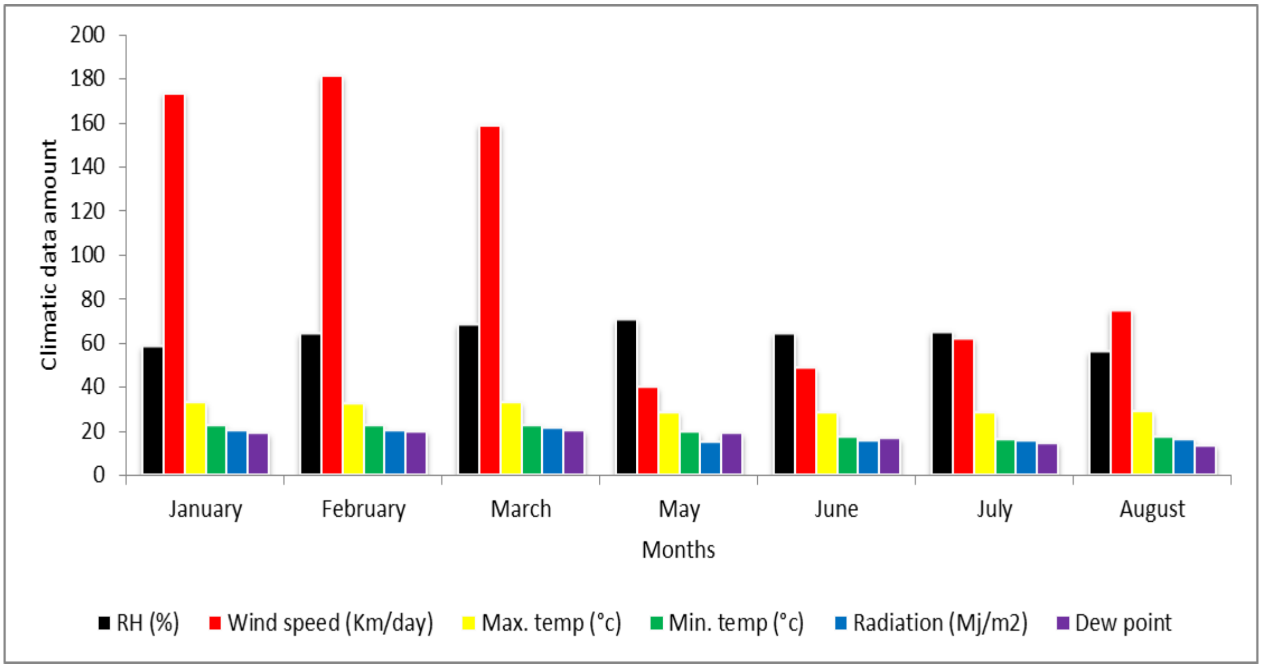

Figure 2: Mean monthly climatic data during the experiment

2.4 Crop growth parameters

The plant growth parameters that were gathered include plant height, number of leaves per plant, and the length of leaves. 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. 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.

2.5 Yield parameter

Yield data was obtained after harvesting. The same carrots that have been used to take data for the plant growth parameters were also used for the determination of fresh root weight by using a weighing scale balance. The obtained weights were recorded in kilograms.

2.6 Root growth parameters

The same carrots that have 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 starting from the shoulder to the end of the tap root. The shoulder and core diameter of roots were measured at 0.5 cm from the top of the shoulder using a vernier caliper, and measurements were recorded in mm.

2.7 Quality parameter

The total soluble solids were measured using a hand-held refractometer (0–30% Brix) and recorded in percentage.

2.8 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 [9].

3. RESULTS AND DISCUSSION

3.1 Soil and irrigation water analysis

Tables 1 and 2 show the characteristics of soil and of irrigation water. According to the categorization suggested by [14], the soil texture was sandy clay. Sandy clay soil is suitable for vegetable production but needs regular watering and fertilizing to ensure healthy development [21]. According to [29], the sodium adsorption ratio (SAR) was low. Irrigated water with low SAR is safe with regard to causing sodicity [36].

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 high
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

3.2 Effect of different Water Application Levels on the Growth, Yield, and Quality Parameters of Carrots

3.2.1 Plant height

Irrigating carrots with full irrigation resulted in the highest plant height in season one (44.59 cm) and season two (42.14 cm), while 60% water application level resulted in the shortest plant height in season one (37.82 cm) and season two (38.1 cm) (Table 3). However, during the first season, the plant heights were not significantly different ($p>0.05$) between the 80 and 100% water application levels, but both differed significantly ($p<0.05$) from the 60% water application level. In the second season, plant heights differed significantly among the three water application levels. Results (Table 3) show that the carrot height was positively influenced by the availability of water at the proper timing and amount, therefore, the plant height increased under full irrigation. However, in season one, the plant height was positively affected by irrigation water levels more than in season two. The difference between seasons may be related to temperature and evapotranspiration, as also pointed out by [37].

Table 3**:** Effect of different water application levels on the growth and yield parameters of carrots

Water level	**Plant height (cm)**	**Number of leaves**	**Leaf length (cm)**	**Root fresh weight (kg)**	**Root length (cm)**	**Root core diameter (mm)**	**Root shoulder diameter (mm)**	**TSS (%)**
				First season				
60%	37.82 a	10 a	10.86 a	0.616 a	15.15 a	15.3 a	24.27 a	8.994 a
80%	42.39 b	11 b	11.62 b	0.756 a	16.6 ab	17.39 a	29.28 b	9.978 b
100%	44.59 b	12 c	12.57 c	0.990 b	17.17 b	21.76 b	33.48 c	8.441 a
LSD(5%)	2.553	0.268	0.588	0.194	1.616	2.115	3.755	0.696
				Second season				
60%	38.1 a	9 a	9.81 a	0.554 a	14.36 a	14.96 a	24.07 a	8.5 a
80%	40.16 b	10 b	10.64 ab	0.703 a	15.8 ab	16.72 b	28. 51 b	8.8 b
100%	42.14 c	11 c	11.08 b	0.874 b	17.02 b	18.21 c	30 c	8.1 c
LSD(5%)	1.409	0.558	1.152	0.1656	1.761	0.962	0.934	0.275

TSS: Total Soluble Solids, LSD: Least Significance Difference.

Means followed by the same letter (s) in the same column are not significantly different according to DMRT.

3.2.2 Number of leaves

Full irrigation resulted in high number of leaves per plant in season one (12) as well as in season two (11). The lowest number of leaves per plant in the first season (10) as well as in the second season (9) was obtained from the 60% water application level (Table 3). The number of leaves differed significantly ($p<0.05$) among the three irrigation water levels in season one as well as in season two. These results under full irrigation might be due to better nutrients utilization using adequate soil moisture. A similar observation was also made by [20], who found that full irrigation resulted in the highest number of leaves per plant than 80, 60, 40, and 20% water application levels.

3.2.3 Leaf length

Results in Table 3 show that full irrigation produced the maximum length of leaves in season one (12.57 cm) as well as in season two (11.08 cm). Likewise, the 60% water application level recorded the minimum length of leaves in the first season (10.86 cm) as well as in the second season (9.81 cm). Further, the leaf lengths differed significantly ($p<0.05$) among the three water application levels in season one. In season two, leaf lengths under the 60 and 80%; 80 and 100% water application levels did not differ significantly ($p>0.05$); however, leaf lengths significantly differed ($p<0.05$) between the 60 and 100% water application levels.

These results could be attributed to better water application during the vegetative stage, which helped the crop to utilize the nutrients and make the plant more efficient in attaining its potential photosynthetic activity that enhanced the length of leaves. In connection with this, [37] reported that the length of leaves increases if optimal irrigation water and nutrition are applied during the vegetative stage.

3.2.4 Fresh root weight

The highest fresh root weight in the first season (0.99 kg) as well as in the second season (0.874 kg) was recorded under full irrigation, while the lowest fresh root weight in the first season (0.616 kg) as well as in the second season (0.554 kg) was obtained under the 60% water application level (Table 3). Further, the fresh root weight did not differ significantly ($p>0.05$) between the 60 and 80% water application levels, but both were significantly different from the full irrigation in both seasons at a level of 65.23%. These results could be attributed to the availability of optimal water level, which increased root size, resulting in a higher fresh root yield. This is in agreement with [31], who found that full irrigation produced the highest fresh root weight of carrots compared to deficit irrigation.

3.2.5 Root length

Full irrigation resulted in the maximum length of roots in the first season (17.17 cm) as well as in the second season (17.02 cm). Likewise, the minimum root length in the first season (15.15 cm) as well as in the second season (14.36 cm) was recorded under the 60% water application level (Table 3). Further, the root lengths under the 60 and 80%; 80 and 100% water application levels did not differ significantly ($p>0.05$), but significantly differed ($p<0.05$) between the 60 and 100% water application levels in both seasons. A possible explanation for this could be that the enhanced root lengths under full irrigation were due to the intake of appropriate nutrients from the irrigation water that resulted in improved root growth. These results mirror those by [22], who found that the root lengths of carrots were positively correlated with the amount of water level applied.

3.2.6 Root core and shoulder diameter

Results (Table 3) show that the root core diameter was not significantly different ($p>0.05$) between the 60 and 80% water application levels, but both differed significantly ($p<0.05$) from that under full irrigation in season one. In season two, root core diameter differed significantly among the three water application levels. On the other hand, the root shoulder diameter differed significantly ($p<0.05$) among the three water application levels in both seasons.

The maximum root core diameter of 21.76 mm for season one and 18.21 mm for season two was obtained under full irrigation, while the minimum root core diameter of 15.3 mm for season one and 14.96 mm for season two was obtained under the 60% water application level. Likewise, the maximum root shoulder diameter in season one (33.48 mm) and season two (30 mm) was obtained under full irrigation, while the minimum root shoulder diameter in season one (24.27 mm) and season two (24.07 mm) was obtained under the 60% water application level.

These results under full irrigation could be due to the absorption of sufficient irrigation water during the growing period that enabled lower soil strength, nutrient absorption, and an appropriate physical environment for better root growth, resulting in increased root volume as pointed out by [7].

3.2.7 Total soluble solids (TSS)

As shown in Table 3, the highest TSS in season one (9.978%) and season two (8.8%) were obtained under the 80% water application level, while the lowest TSS in season one (8.441%) and season two (8.1%) were obtained under full irrigation. Further, the TSS did not differ significantly ($p>0.05$) between the 60 and 100% water application levels, but both were significantly different from those under the 80% water application level in season one. In season two, TSS significantly differed ($p<0.05$) among the three water application levels.

The fact that the less watered carrots had higher TSS content in their roots is more of a physiological aspect that could be explained on the basis of redistribution of plant photosynthesate toward the roots due to the water deficit, which led to decreased water content as well as increased sugar content. A similar observation has also been made by [15], who reported that higher irrigation water levels reduce TSS on carrot roots.

3.3 Effect of soil-based NPK Fertilizer on the Growth, Yield, and Quality Parameters of Carrots

3.3.1 Plant height

Results (Table 4) show that the plant heights under the 1.5 and 2 g per plant fertilizer levels did not differ significantly ($p>0.05$), but both were significantly different ($p<0.05$) from those under the 1 g per plant fertilizer level in season one. However, in season two, plant heights were significantly different ($p<0.05$) among the three fertilizer rates. The maximum plant heights in season one (44.16 cm) as well as season two (42.21 cm) were obtained under the 2 g per plant fertilizer level, while the shortest plant heights in the first season (38.43 cm) and the second season (37.57 cm) were obtained under the 1 g per plant fertilizer level.

These results reflect the role of potassium and nitrogen as essential elements in metabolism and a variety of other processes necessary for plant growth including plant height and its development. The findings are consistent with those of [6]. Another study by [4] found that increasing NPK fertilization rate resulted in increased carrot height.

Table 4: Effect of different rates of soil-based NPK fertilizer on the growth and yield parameters of carrots

Fertilizer level	**Plant height (cm)**	**Number of leaves**	**Leaf length (cm)**	**Root fresh weight (kg)**	**Root length (cm)**	**Root core diameter (mm)**	**Root shoulder diameter (mm)**	**TSS (%)**
First season								
1	38.43 a	10 a	11.07 a	0.671 a	15.59 a	16.33 a	27.06 a	8.702 a
1.5	42.2 b	11 b	11.72 b	0.726 a	16.22 a	18.01 ab	28.21 ab	8.956 a
2	44.16 b	12 c	12.26 b	0.965 b	17.11 a	20.11 b	31.76 b	9.756 b
LSD(0.05)	2.48	0.268	0.588	0.194	1.616	2.115	3.755	0.696
Second season								
1	37.57 a	9 a	9.57 a	0.555 a	15.47 a	15.05 a	26.24 a	6.922 a
1.5	40.63 b	10 ab	10.87 b	0.690 a	15.74 a	16.47 b	27.79 b	8.811b
2	42.21 c	11 b	11.08 b	0.886 b	16.07 a	18.38 c	28.55 b	9.656 c
LSD(0.05)	1.409	0.558	1.152	0.1656	1.761	0.962	0.934	0.275

TSS: Total Soluble Solids, LSD: Least Significance Difference.

Means followed by the same letter (s) in the same column are not significantly different according to DMRT.

3.3.2 Number of leaves

As indicated in Table 4, the number of leaves differed significantly ($p<0.05$) among the three fertilizer levels in season one. In season two, the number of leaves under the 1 and 1.5 g per plant and 1.5 and 2 g per plant fertilizer levels did not differ significantly ($p>0.05$). However, there was a significant difference ($p<0.05$) between the 1 and 2 g per plant fertilizer levels. Applying the 2 g per plant fertilizer level resulted in the maximum number of leaves per plant in season one (12) as well as season two (11). The minimum number of leaves per plant was obtained from the 1 g per plant fertilizer rate in season one (10) as well as season two (9).

These results are in agreement with those found by [33] and [23]. This study clearly implies that the increment in fertilization rate directly increased the number of leaves. A study by [12] reported that the highest fertilization rate resulted in the highest number of leaves per plant in two seasons.

3.3.3 Leaf length

Table 4 shows that the leaf length did not differ significantly ($p>0.05$) between the 1.5 and 2 g per plant fertilizer rates, and that both differed significantly ($p<0.05$) from the 1 g per plant fertilizer rate in both seasons. Applying the fertilizer at a rate of 2 g per plant resulted in the maximum length of leaves in season one (12.26 cm) as well as in season two (11.08 cm). Likewise, the 1 g per plant fertilizer rate recorded the minimum length of leaves in the first season (11.07 cm) as well as in the second season (9.57 cm).

These results under the highest fertilizer level could be related to the fact that a high NPK fertilizer level eliminates problems like fixation and immobilization of nutrients by entering the cells rapidly and fulfilling the nutrient demand of the growing plant, resulting in enhanced length of the leaf. Similar observations were also made by [22] and [35].

3.3.4 Fresh root weight

Fresh root weights did not differ significantly ($p>0.05$) between the 1 and 1.5 g per plant fertilizer levels but both differed significantly ($p<0.05$) from those under the 2 g per plant fertilizer level in both seasons. The highest fresh root weight in the first season (0.965 kg) as well as in the second season (0.886 kg) were recorded under the 2 g per plant fertilizer level, while the lowest fresh root weight in the first season (0.671 kg) as well as in the second season (0.555 kg) were obtained under the 1 g per plant fertilizer level.

The findings (Table 4) reveal that the values of fresh root weight increased when fertilizer rates were increased up to the 2 g per plant fertilizer rate. This is consistent with the findings of [4], who found that increasing nitrogen and potassium fertilizer levels gradually and expressively improved root production.

3.3.5 Root length

Results (Table 4) show that the root length was not significantly affected by the rate of fertilizer application. Nevertheless, the highest rate of 2 g per plant resulted in the maximum length of root in season one (17.11 cm) as well as in season two (16.07 cm). The minimum root length in season one (15.59 cm) as well as in season two (15.47 cm) was recorded under the 1 g per plant fertilizer rate.

The increase in root length could, however, be associated with the increased nutrient use efficiency of both macro and micro nutrients from the NPK high level. This is logical as the macro and micro nutrients contribute to cell division and elongation, which in turn increases the root length of the carrots. This is in line with the results of [17], [23], [27].

3.3.6 Root core and shoulder diameter

Table 4 shows that root shoulder and core diameters under the 1.5 g per plant fertilizer level were not significantly different ($p>0.05$) from those under the 1 and 2 g per plant fertilizer levels, but those under the 1 g per plant fertilizer level were significantly different from those under the 2 g/plant fertilizer level in season one. However, in season two, the root core diameter was significantly different ($p<0.05$) among the three fertilizer rates, but root shoulder diameter did not significantly differ ($p>0.05$) between the 1.5 and 2 g per plant fertilizer rates, but both were significantly different from the 1 g per plant fertilizer rate. The maximum root core diameter in the first season (20.11 mm) as well as in the second season (18.38 mm) was obtained under the 2 g per plant, while the minimum root core diameter in the first season (16.33 mm) as well as in the second season (15.05 mm) was obtained under the 1 g per plant fertilizer level. Likewise, the maximum root shoulder diameter in the first season (31.76 mm) as well as in the second season (28.55 mm) was obtained under the 2 g per plant fertilizer level, while the minimum root shoulder diameter in the first season (27.06 mm) as well as in the second season (26.24 mm) was obtained under the 1 g per plant fertilizer level.

The increase in the root core and shoulder diameters under the highest fertilizer rate could be attributed to the adequate nutrients distributed by NPK soil-based fertilizer to enhance soil structure and allow shoulder and core of carrot roots to easily expand, as also stated by [35] and [6].

3.3.7 TSS

Results (Table 4) show that the TSS did not differ significantly ($p>0.05$) between the 1 and 1.5 g per plant fertilizer rates, but were both significantly different from those under the 2 g per plant fertilizer level in season one. However, TSS were significantly different ($p<0.05$) among the three fertilizer rates in season two. The maximum TSS in season one (9.756 %) and season two (9.656%) were obtained under the 2 g per plant fertilizer rate, while the lowest TSS in the first season (8.702%) and the second season (6.922%) were obtained under the 1 g per plant fertilizer rate.

The improvement in the TSS in roots as a result of a high fertilizer rate could be related to the mode of action of macro nutrients in enhancing the photosynthetic activity and enzymes of carbohydrate transformation. This is in agreement with the findings by [24] and [28], who found that TSS increased as potassium, nitrogen, and phosphorus levels increased.

3.4 Effects of the Interaction between Water Application and Soil-Based NPK Fertilizer Levels on the Growth of Carrots

3.4.1 Plant height

Results (Table 5) show that the highest water application level combined with the highest fertilizer rate resulted in a higher plant height. Such interaction differed significantly ($p<0.05$) in season one but wasn't as clearly defined in season two. The maximum plant height in season one (49.22 cm) and season two (44.19 cm) was obtained under full irrigation in combination with the 2 g per plant fertilizer level, while the minimum plant height in season one (35.5 cm) and season two (34.74 cm) was obtained under the 60% water application level × 1 g per plant fertilizer level. This could be attributed to favourable soil moisture levels for enhanced translocation of nutrients to promote photosynthesis, regulate temperature, and keep cells turgid, resulting in better plant growth. [8] reported that the highest water application level favored by the transformation of organic matter derived from inorganic fertilizer owing to the optimal level of soil moisture resulted in plant height enhancement.

Table 5: Effects of the interaction between water application and soil-based NPK fertilizer levels on the plant height

Fertilizer levels	**1 g**	**1.5 g**	**2 g**
Water levels	Plant height		
	First season		
60%	35.5 a	37.84 ab	40.11 abcd
80%	37.97 abc	46.04 ef	43.15 de
100%	41.83 bcde	42.71 cde	49.22 f
LSD (5%)	4.296		
	Second season		
60%	34.74 a	39.15 bc	40.43 bcd
80%	37.88 b	40.6 cd	42.01 de
100%	40.11 bcd	42.13 de	44.19 e
LSD (5%)	2.44		

TSS: Total Soluble Solids, LSD: Least Significance Difference.

3.4.2 Number of leaves

As shown in Table 6, the number of leaves followed the same trend as that of the plant height in both seasons in terms of statistical significance. The maximum number of leaves in season one (12.97) and season two (11.37) were produced under full irrigation in combination with the 2 g per plant fertilizer rate, while the minimum number of leaves in season one (9.83) and season two (9.47) were produced under the 60% water application level × 1 g per plant fertilizer level.

The increased number of leaves under full irrigation and 2 g per plant fertilizer rate might be due to the availability of more nutrients from irrigation water and NPK fertilizer that possibly increased the rate of cell division and elongation, leading to the production of more plant leaves, as stated by [3].

Table 6: Effects of the interaction between water application and soil-based NPK fertilizer levels on the number of leaves

Fertilizer levels	**1 g**	**1.5 g**	**2 g**
Water levels	Number of leaves		
	First season		
60%	9.83 a	10.5 bc	10.77 c
80%	10.23 ab	10.93 c	11.57 d
100%	10.5 bc	11.6 d	12.97 e
LSD (5%)	0.585		
	Second season		
60%	9.47 a	9.47 a	9.96 ab
80%	9.8 ab	10.3 abc	10.67 bcd
100%	10.1 abc	11.03 cd	11.37 d
LSD (5%)	0.967		

TSS: Total Soluble Solids, LSD: Least Significance Difference.

Means followed by the same letter (s) in the same column are not significantly different according to DMRT.

3.4.3 Leaf length

Table 7 shows that the leaf length did not differ significantly ($p>0.05$) between the 60% water application level × 1.5 g per plant, 60% water application level × 2 g per plant, and 80% water application level × 1 g per plant fertilizer levels in season one. In season two, the length of leaves differed significantly between the 60% water application level × 1 g per plant and the full irrigation × 2 g per plant fertilizer rates. The maximum length of leaves in season one (13.55 cm) and season two (11.85 cm) was obtained under full irrigation in combination with the 2 g per plant fertilizer rate. The minimum length of leaves in season one (10.38 cm) and season two (8.79 cm) was obtained under the 60% water application level × 1 g per plant fertilizer rate.

The maximum leaf length under full irrigation and the 2 g per plant fertilizer rate could be attributed to the physiochemical and biological improvements that happened in the soil, such as favourable temperature and moisture levels and nutrient accessibility that occurred in the carrot plant. For this reason, photosynthesis and stomatal conductance increased and the leaves became longer, as also observed by [19].

Table 7: Effects of the interaction between water application and soil-based NPK fertilizer levels on the leaf length of carrots

Fertilizer levels	**1 g**	**1.5 g**	**2 g**
Water levels	Length of leaves		
	First season		
60%	10.38 a	10.91 ab	11.27 ab
80%	11.25 ab	11.65 bc	11.95 bc
100%	11.57 bc	12.59 cd	13.55d
LSD (5%)	1.019		
	Second season		
60%	8.79 a	10.25 ab	10.37 ab
80%	10.03 ab	10.85 ab	11.03 ab
100%	9.88 ab	11.52 b	11.85 b
LSD (5%)	1.996		

TSS: Total Soluble Solids, LSD: Least Significance Difference.

Means followed by the same letter (s) in the same column are not significantly different according to DMRT.

4. Conclusion

The application of the 2 g per plant fertilizer level enhanced the growth, quality, and yields of carrots compared to other fertilizer levels in two seasons. Full irrigation is best for carrot production in both seasons compared to other water application levels. Carrots under an IW level of 80% were found to have the highest content of sugar. The interaction between full irrigation in combination with 2 g per plant fertilizer rate enhanced the growth, yield, and quality parameters of carrots compared to other combinations. Therefore, for optimum growth and yield, an IW level of 100% and 2 g per plant fertilizer rates are recommended for carrots. For high sugar content, an IW level of 80% is recommended. Application of irrigation water and fertilizer under or over these levels seems to be an uneconomical and wasteful practice.

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