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The effects of the interaction between irrigation and fertilization systems on the growth and productivity of tomato crop

*Alaa Jamalaldeen Shreef Mohamed1,2, Osama Osman Ali *1, Yassir Mohamed Ibrahim2, Mohmed Abdallah Mohmed Abdalhi1,*

1. Department of Agricultural Engineering, Faculty of Agricultural technology and Fish sciences, Al-Neelain University, Khartoum, Sudan
2. Department of Agricultural Engineering, Faculty of Agriculture, University of Nile Valley, Sudan

E-mail address: osamaosman076@gmail.com

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ABSTRACT

The study investigates the integrative effects of modern drip and traditional furrow irrigation techniques, and nitrogen fertilization strategy on tomato farms production under water-limited conditions in arid region northern Sudan. The research employs in a split-plot with a factorial subplot in a randomized completely block design with three replications, drip irrigation and furrow irrigation assigned as main plot treatments, and four N fertilizer application rates (0%, 60%, 80% and 100%) as subplots. The study tested the irrigation techniques performance, growth parameters, yield components and nutrient use efficiency. The analysis of irrigation techniques performance across irrigation methods shows a significant advantage for modern drip irrigation technique over furrow irrigation with the highest values of Christiansen Uniformity (CU = 87.6%) and Distribution Uniformity (DU = 78%). The study results reveal significant impacts of average discharge, CV(Coefficient of Variation), CU and DU at 0.05 level of significant. Their results ranged from 3.45 l/h - 5.23 l/h, 3.03 - 6.33, 60.33% - 87.6% and 60.6% - 78%. The integration of SDI with 80% NFR in drip irrigation and FI with 100% NFR in furrow obtained maximum tomato yield as 25.73 fruit/plant and 12.40 fruit/plant and saved 20% of nutrient use. In other hand, considering the agronomy components and yield components, the most preferable integration may assigned to SDI with 80% NFR in drip irrigation and FI with 80% NFR in furrow for their high yield, better agronomy components, enhancement of yield components and increased nutrient use efficiency. The study presented profitable water and nutrient combination strategies, adoption of these strategies is a beneficial in water and nutrient -limited conditions in arid or similar regions.

KEYWORDS

Tomato yield; Nitrogen fertilizer rates; Surface drip irrigation; furrow irrigation; water-use efficiency; Nutrient-use efficiency.

1. Introduction

Efficient use of water resources has become a critical challenge for agriculture in Sudan, Where rapid population growth is increasing pressure on already limited water supplies. Ensuring food security under these condition requires producing more food with less water by improving water productivity (Ismail, *et al*., 2015).

This challenge is especially evident vegetable production system, which depend on a continuous and reliable water supply throughout the growing season. Anticipated changes in regional water availability, particularly those associated with the Grand Ethiopian Renaissance Dam (Recent discussions regarding the Grand Ethiopian Renaissance Dam highlight that changes in up stream water regulation may influence the timing and variability of water flow to down stream countries including Sudan) (Magee, T. 2018) , further highlight the urgent need to adopt improved irrigation strategies that enhance water-use efficiency (Tesfaye et.al., 2021; Berhane & Melesse,2022) .

In many agricultural regions of Sudan, competition over freshwater resources between agriculture, domestic use, and other economic sectors is intensifying. As a result, irrigation management is shifting form maximizing crop yield per unit of land to maximizing yield per unit of water consumed. Improving water productivity is therefore essential for sustaining irrigated agriculture under increasing water scarcity (Pereira et al., 2020; FAO,2020).

Modern irrigation technologies such as drip irrigation can substantially enhance water-use efficiency by minimizing surface losses and delivering water directly to the crop root zone (Dagdelen et al., 2021), resulting in better uniformity and reduced water waste.

Water and nutrient availability are tow of the most important factors affecting crop growth and production. Their efficient management is not only essential for high crop productivity but also for protecting environmental quality. Fertigation-the application of soluble fertilizer through the irrigation system -has emerged as a key precision agriculture technique capable of synchronizing nutrients and water supply, improving nutrient uptake, and reducing losses (Reddy et al., 2020; Zhang et al., 2022). Integrating fertigation with drip irrigation has proven particularly effective for vegetable crops particularly under water-limited conditions.

Tomato (Solanum lycopersicum) is one of the most widely grown and economically important vegetable crops globally, valued for its nutritional content and health benefits. Tomatoes are rich sources of vitamin C, B-carotene, and lycopene, a powerful antioxidant associated with disease prevention (Ahmed et al., 2021; Wang et al .,2020) .

Due to its high economic value and sensitivity to water and nutrient management, tomato production in Sudan requires optimized irrigation and fertilization practices to improve both yield and fruit quality under conditions of increasing water scarcity.

Despite the importance of integrated irrigation and fertilization management, limited research in Sudan has examined the combined effects of irrigation methods and fertilizer application rates on tomato growth, yield, fruit quality, and resource-use efficiency. Understanding these interactions is essential for developing practical recommendations that support sustainable tomato production.

Therefore, the main objective of this study was to investigate the interactive effects of two irrigation methods (surface drip and furrow irrigation) and four fertilizer rates on tomato vegetative growth, yield, quality, and resource-use efficiency.

The specific objectives were to:-

1- Evaluate the effects of irrigation systems and fertigation treatments on tomato growth, fruit yield, and quality.
2- Compare the performance of furrow and surface drip irrigation systems under different nitrogen fertilization levels and assess their interaction.
3- Identify the optimal combination of irrigation method and fertilizer application rate for maximizing tomato productivity and resource -use efficiency.

2. Materials and Method

2.1. *Description of the study area*

The field experiment was conducted during the winter season of 2021/2022 at the Saharij Project for Agricultural and Animal Production, located in the River Nile State, Sudan.

The site is situated at 17°40′ N latitude, 33°20′ E longitude, and an elevation of 334 m above me an sea level. The region is classified as arid, characterized by large fluctuations in temperature, relative humidity, and solar radiation throughout the season. Climatic data for the study period were obtained from the ElHudyba Meteorological Station and are summarized in Table (1).

The soil at the experimental site is predominantly sandy loam, with a high sand content (68%) and relatively low clay content (26.7%). Composite soil samples were collected using an auger from two soil layers (0-30 cm and 30–60 cm) to assess the physico- chemical properties.

. Laboratory analysis indicated that the soil is moderately alkaline, non-saline, and non-sodic, with medium available phosphorus and low organic carbon content.

These characteristics reflect the typical soil conditions of arid northern Sudan, where efficient water and nutrient management is essential for sustaining crop production.

Table 1. The climate data in study area obtained from El-Hudyba Meteorological Station for the experiment season.

Solar Rad. ($MJ/m^2/d$)	RH%	Sun shine ($MJ/m^2/d$)	Wind speed $m{\cdot}s^{-1}$	Temperature, °C		Month
				Max	Min	
19.2	10.0	224.6	53.0	31.8	17.5	Des.
19.9	10.0	224.6	47.0	27.2	12.1	Jan.
22.2	10.3	198.7	34.0	31.7	14.1	Feb.
24.2	31.0	10.3	9.72	35.7	17.4	March
25.8	26.0	10.6	8.28	39.5	21.4	April
26.0	18.0	10.7	8.8	42.5	25.5	May
24.3	28.0	9.8	9	42.0	26.8	June
21.7	59.0	8.0	10.44	38.1	26.7	July

2.2. Experimental treatments and design

The experiment consisted of two irrigation methods surface drip irrigation (SDI) and furrow irrigation (FI) combined with four nitrogen fertilizer application rates of 0%, 60%, 80%, and and 100% of the recommended dose. The 0% N treatment represented the control, as it received no nitrogen addition, while the other treatments (60%, 80%, 100%) were considered fertilization levels. The study was conducted over a four month period from December 2021 to March 2022. A total of 24 treatment combinations were obtained from the factorial arrangement of the two irrigation systems and four nitrogen fertilizer rates, with three replications for each irrigation method. The experimental layout followed a split plot design within a Randomized Complete Block Design design within a Randomized Complete Block Design (RCBD). Irrigation method was assigned to the main plots, while nitrogen fertilizer rate was allocated to the subplots.

The treatments were arranged as follows:

1. Surface drip irrigation (SDI) with 0% of nitrogen fertigation rate, NFR (traditional fertilization);
2. Surface drip irrigation (SDI) with 60% of nitrogen fertigation rate (NFR);
3. Surface drip irrigation (SDI) with 80% of nitrogen fertigation rate (NFR);
4. Surface drip irrigation (SDI) with 100% of nitrogen fertigation rate (NFR), control;
5. Furrow irrigation (FI) with 0% of nitrogen fertigation rate, NFR (traditional fertilization);
6. Furrow irrigation (FI) with 60% of nitrogen fertigation rate (NFR);
7. Furrow irrigation (FI) with 80% of nitrogen fertigation rate (NFR);
8. Furrow irrigation (FI) with 100% of nitrogen fertigation rate (NFR), control.

Prior to planting, the field was prepared by ploughing with a mounted disk plough at a depth of 0.25 m. The land was left fallow for two weeks to allow soil settling, then leveled using a general -purpose blade. Ridging was done at 0.75 m spacing, and tomato seedlings were transplanted at 0.50 m spacing, following standard recommendations of the State Ministry of Agriculture.

All plots, regardless of irrigation method, received daily irrigation during the first seven days after transplanting to ensure uniform establishment. Thereafter, irrigation scheduling was imposed based on 100% of crop evapotranspiration (ETc), with water applied every 2 days under SDI and every 7 days under FI. The total applied water for each treatment was recorded and computed according to the crop water requirement.

The selected nitrogen fertilizer rates (0%, 60%, 80% and 100%) were chosen based on previous studies conducted in arid regions, which reported that tomato growth and yield respond strongly to moderate reductions in nitrogen supply.

Several researchers indicated that nitrogen reductions between 20-40% do not significantly reduce tomato yield under efficient irrigation systems such as drip irrigation (Mahajan & Singh, 2006; Pandey et al., 2019; Xu et al., 2021). Therefore, the 100% rate represented the full recomm ended dose (control), 80% was selected to test the potential of reducing nitrogen by 20%, & 60% was selected to examine a stronger reduction of 40%. The 0% treatment served as a baseline to evaluate the crop response in the absence of nitrogen fertilizer and to quantify the relative contribution of nitrogen to yield and growth.

These four levels were chosen to provide a clear understanding of the yield response curve and to identify the optimum nitrogen rate under each irrigation method.

2.3. Crop water requirement

The crop water requirement (CWR) of tomato was estimated to compensate for the amount of water lost through evapotranspiration (ETc). The ETc was calculated using the standard FAO method, which combines the reference evapotranspiration (ETo) and the crop coefficient (Kc) according to Equation (1).

$$ETc = ETo * Kc \qquad (1)$$

Where:

ETc = crop evapotranspiration (mm/day)

ETo = reference evapotranspiration (mm/day)

Kc = crop coefficient

The reference evapotranspiration (ETo) was calculated using the FAO-modified Penman Monteith equation (Allen et al., 1998), based on monthly climatic data (temperature, relative humidity, sunshine hours, and wind speed) obtained from the El Hudyba Meteorological Station (Table 1). The ETo was computed using the CROPWAT 8.0 software following Equation (2):

$$ETo = \frac{0.408(Rn-G)+\gamma\frac{900}{T+273}U2(es-ea)}{\Delta+\gamma(1+0.34U2)} \qquad (2)$$

Where:

Δ = slope of vapor pressure curve (kPa/°C)
Rn = net radiation at crop surface (MJ/m²/day)
G = soil heat flux density (MJ/m²/day)
T = air temperature at 2 m (°C)
e_s = saturation vapor pressure (kPa)
e_a = actual vapor pressure (kPa)
$e_s - e_a$ = vapor pressure deficit (kPa)
U_2 = wind speed at 2 m height (m/s)
γ = psychrometric constant (kPa/°C)

Tomato crop coefficients (Kc) used in this study were:

0.45 at the initial stage, 0.75 during the development stage,
1.10 at mid-season, and 0.65 during the late season, as recommended by Panigrahi et al. (2010). These values were applied across the growing period to compute daily crop water requirements under the two irrigation systems.

2.4. Surface drip and furrow irrigation methods

Nitrogen fertilizer was applied using two different application methods according to the irrigation system. In the drip irrigation treatments, nitrogen was supplied through fertigation, where the required amount of urea was dissolved in water and injected into the irrigation line using at each irrigation event according to the scheduled fertigation rates (0%, 60%, 80%,and 100% of the recommended dose).

In the furrow irrigation treatments, nitrogen fertilizer was applied manually to the soil surface (broadcasting) along the plant rows before irrigation and incorporated lightly into the topsoil to reduce volatilization losses.

The total nitrogen dose was split into three equal applications at 20, 40 and 60 days after transplanting in both irrigation systems.Both surface drip irrigation (SDI) and traditional furrow irrigation (FI) systems were used in the study. In the SDI system, a pressure regulated layout was installed to ensure uniform water distribution across the experimental plot, which measured 15 m × 30 m (0.045 ha). Lateral lines were spaced to maintain optimal coverage, and pressure-compensating emitters were fixed at 50 cm intervals, providing a discharge rate of 4 L/h. Each lateral contained 24 emitters, with a total of 216 emitters per drip plot, and one emitter was alloc ated per plant. Irrigation water in the drip system was applied at 2day intervals, matching crop evapotranspiration demands and maintaining soil moisture near field capacity.

For the furrow irrigation method, water from the same storage tank used in the drip system was directed to supply control pipelines, and discharge rates were calibrated volumetrically. A siphon was installed to regulate water flow from the water course into the farm ditch.

Furrows were constructed at a uniform length of 15 m, and irrigation was scheduled every 7 day, following conventional surface irrigation practices in the region.

Both systems received identical irrigation water quality, and all fertigation treatments (60%, 80% , and 100% NFR) in the drip system were applied by injecting soluble urea fertilizer directly into the irrigation water. Under furrow irrigation, fertilizer was applied using traditional broadcasting methods for the corresponding NFR treatments

2.5. Hydraulics of drip irrigation system

A set of hydraulic parameters was evaluated to assess the performance of the surface drip irrigation system. These parameters included emitter discharge variation, emission uniformity, and the emitter discharge coefficient of variation. All measurement were conducted following internationally recognized standards for drip irrigation performance evaluation.

2.5.1 Emitter discharge rate variation

Emitter discharge rate variation (Q_{var}), was calculated using the equation (3) of Burt *et al*. (1997):

$$Q_{\text{var}} = \frac{q_{\max} - q_{\min}}{q_{\max}} \quad (3)$$

Where: q_{max} is the maximum emitter discharge rate and q_{min} is the minimum emitter discharge rate.

2.5.2 Emission uniformity

Coefficient of uniformity (CU %) was calculated by the equation suggested by Abd El-Wahed *et al*. (2015). Emission uniformity (EU%) is most important for evaluating system performance, it is measure the uniformity of emitters discharge in drip irrigation system. Emission uniformity was calculated using the equation (4) suggested by Ortega *et al.* (2002):

$$EU\% = \frac{q_{25\%}}{\bar{q}} * 100 \quad (4)$$

Where: EU: Emission uniformity%; $q_{25\%}$: mean of the lower quarter of emitters discharge (L/h); q: mean of the emitters discharge (L/h). For a point source of drip irrigation system installed in uniform topography recommended value of EU ranges from 85-90%. General criteria for EU values are 90% or greater (excellent), 80 to 90% (good), 70 to 80% (fair), 60 to 70% (poor) and less than 60% (unacceptable), (ASAE, 1988).

2.5.3 Emitter discharge coefficient of variation

The emitter discharge coefficient of variation (CV) and the statistical uniformity were calculated using ASAE EP458 (1996) to evaluate drip system in the field. The calculated uniformity values require the determination of mean emitter discharge rate $\bar{q}$, and standard deviation of emitter discharge rates S_q, which were calculated using the equations 5 and 6 respectively.

$$\bar{q} = \frac{\sum_{i=1}^{n} q_i}{n} \quad (5)$$

Where: q_i : individual emitter discharge observed (L/h).

$$S_q = \sqrt{\frac{\sum_{i=1}^{n} q_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} q_i\right)^2}{n-1}} \quad (6)$$

Where: q_i : individual emitter discharge observed (L/h); N: Number of observations in each lateral.

Coefficient of variation (CV) defined as the ratio of the standard deviation of flow to the mean flow for a sample number of emitters. It is a statistical parameter expressed as the emitters discharge coefficient of variation, which was calculated using the equation (7) as follows:

$$CV = \frac{S_q}{\bar{q}} \qquad (7)$$

2.6. Water productivity

Water productivity (WP) was calculated as the ratio of the crop yield to the total seasonal irrigation water applied (m3/ha) using the following formula equation (8) below:

$$CWP = \left(\frac{kg}{m^3}\right) = \frac{weight\ of\ \ matter\ \left(kg\,/ha\right)}{ETc\ \ \left(m^3/ha\right)} \qquad (8)$$

2.7. Agronomic practices

Tomato is sensitive plant to the pest, diseases and weeds. In order to overcome that the risks, standard agronomic practices, including weeding, pest control, and disease management, were uniformly applied to all treatments according to guided by Main Vegetable Research Centre AAU. Spraying of pride @ 15 g/ 15-liter water was done to control the insect and thrips. Nitrobenzene was sprayed @ 20ml/ 15-liter water for proper flowering of tomato crop. Profenophos and Acephate was sprayed @ 10ml/ 15-liter water for control the insect. Trenching of Dermet (50% chloropyrifos) @ 1ml/ 1iter of water for control plant from termites. 22 tin powder was used protect tomato as fungicide. Four times, weeding was carried out manually to control weed competition.

2.8. Data collection

Data on tomato growth and yield parameters were collected at different growth stages throughout the experiment. To avoid edge effects, plant samples were taken randomly from the middle rows of each subplot.

Measured vegetative growth parameters included:

Plant height (cm)

Stem diameter (mm)

Number of leaves per plant

Number of branches per plant Leaf area (mm^2)

These measurements were averaged for each treatment before statistical analysis.

Yield and yield components were also recorded, including:

Fruit length (cm).

Fruit width (cm).

Number of fruits per plant.

Fresh fruit weight (ton/ha).

Dry fruit weight (ton/ha).

Tomato fruits were harvested manually at maturity to prevent damage, and all yield components were measured and recorded for each treatment

2.9. Statistical analysis

All collected data were statistically analyzed using SAS software (Version 9, SAS Institute, Cary, NC, USA). Analysis of variance (ANOVA) was performed to determine the effects of irrigation system, nitrogen fertilizer rate, and their interaction on all measured parameters within the Randomized Complete Block Design (RCBD).

Significant differences among treatment means were determined using the Ftest, and mean separation was carried out using the Least Significant Difference (LSD) test at 0.01 and 0.05 probability levels. Statistical significance was classified as:

ns: non-significant ($P > 0.05$)

*: significant ($P \leq 0.05$)

**: highly significant ($P \leq 0.01$)

All analyses were applied consistently across growth, yield, and water productivity parameters.

3. Results and Discussion

3.1 Evaluation of Irrigation system performance

The analysis of the drip irrigation system showed that the measured discharge variation (CV), coefficient of uniformity (CU), and distribution uniformity (DU) values were within acceptable ranges, indicating efficient and consistent water delivery. These parameters apply only to pressurized irrigation systems and therefore were not measured for the furrow irrigation system, as CU, DU, and CV are not typically used to evaluate surface irrigation performance.

For the furrow system, performance assessment was based on field observations, crop response, and water application behavior rather than emitter based uniformity indicators.

The differences between the two systems in this study therefore reflect:

(1) The measured hydraulic performance of the drip system.

(2) The practical field performance of the furrow system under the same experimental conditions

These results agree with previous studies reporting that drip irrigation generally achieves higher uniformity and more precise water distribution due to localized application and reduced infiltration variability (Mukherjee et al., 2023).

Table 2. Drip irrigation system performance parameters.

DU	CU	CV	Sd	Average discharge	Lateral line Location
70.6a	85.6a	3.72b	1.19c	3.45c	1
60.6a	82.3ab	3.9b	1.63c	4.21abc	2
69a	67.6b	6.33a	2.22a	3.46c	3
78a	87.6a	3.03b	1.19c	4.11bc	4
74.3a	60.33ab	3.91b	1.91ab	4.83ab	5
69.6a	80.1ab	4.17b	2.14a	5.23a	6
12.1	16.8	0.134	0.49	1.039	L.S.D.
10.5	13.2	17.6	15.9	13.5	C.V

Means having the same alphabetical letter (s) are not significantly differ at 0.05 level according to least significant difference test.

3.2 Tomato crop agronomy components

This study examined the interactive effects of irrigation method and nitrogen fertilizer rate on key vegetative growth parameters of tomato, including plant height, stem diameter, number of leaves, number of branches, and leaf area. Both irrigation system and nitrogen rate had statistically significant effects ($P \leq 0.05$) on all agronomic characteristics, indicating a strong interaction between water application method and nutrient management under arid climatic conditions.

3.2.1 Plant height

Plant height was significantly affected by both irrigation method and nitrogen fertilizer rate (Table 3). The tallest plants (71.93 cm) were recorded under furrow irrigation with 60% NFR, while the highest corresponding value under drip irrigation was 60.93 cm at 80% NFR. Plant height ranged from 23.16 to 71.93 cm across all treatments.

These results align with Ebstu and Muluneh (2025), who reported tomato plant height values between 24.7 and 83 cm. The significant interaction between irrigation method and nitrogen rate suggests that moderate nitrogen application levels enhance tomato vegetative growth, although the response differs between irrigation systems. Similar trends were reported by Usoh et al. (2017), Sharma and Kispotta (2016), and Sampathkumar and Pandian (2010), confirming the combined influence of irrigation and nitrogen on tomato growth.

Table 3. Effect of irrigation systems and fertilizer rate on vegetative growth of tomato plant.

Plant leaf area (mm)	Number of branch/plant	Number of leave/plant	Stem diameter(mm)	Plant height (cm)	Fertilizer rate%	Irrigation systems
34.6	9.33	46.66	3.18	23.16	0	Drip irrigation
29.78	18.2	120.6	11.63	47	60	
31.71	33.13	82.13	22.04	60.93	80	
32.03	27.04	98.6	12.3	43.7	100	
10.41	8.86	18.26	2.93	45.46	0	Furrow irrigation
30.41	18.46	33.73	3.31	71.93	60	
28.42	26.2	46.21	3.36	33.6	80	
23.08	20.22	83.13	3.2	33	100	

3.2.2 Stem diameter

Stem diameter was significantly influenced by irrigation method and nitrogen rate (Table 3). The highest value (22.04 mm) was obtained under SDI with 80% NFR, while furrow irrigation record ed comparatively lower and more uniform values (2.93 3.36 mm). Even though the 80% NFR produced the highest stem diameter in both irrigation systems, drip irrigation consistently produced thicker stems.

This may be attributed to the ability of SDI to maintain soil moisture near field capacity, improve -ing aeration and nutrient uptake. These results agree with Meric et al. (2011) and Hassanli et al. (2009), who found enhanced vegetative growth under drip irrigation due to uniform water distribution and reduced evaporation losses.

3.2.3 Number of leaves per plant

The number of leaves per plant showed significant variation across treatments (Table 3). The hig-hest value (120.6 leaves/plant) occurred in SDI with 60% NFR, followed by 98.6 leaves/plant un der the drip control (100% NFR). In furrow irrigation, the maximum number of leaves (83.13 lea ves/plant) was observed under the control treatment.

The superior performance of SDI is likely due to its ability to supply precise and continuous water and nutrients directly to the root zone. Similar findings were reported by Musabekov et al. (2022) and Absanto et al. (2025), who attributed increased leaf production under drip irrigation to efficient nutrient delivery and improved moisture distribution**.**

3.2.4 Number of branches per plant

The number of branches per plant was significantly influenced by the interaction of irrigation method and nitrogen rate (Table 3). Drip irrigation generally produced more branches, with the highest value (33.13 branches/plant) under SDI with 80% NFR. In contrast, furrow irrigation produced fewer branches across all treatments, likely due to moisture stress resulting from uneven water distribution and percolation losses.

Both irrigation methods achieved their highest branch numbers at 80% NFR, indicating that this rate optimizes vegetative growth. These results agree with Shashidhara et al.(2007), who reported higher branch numbers under drip irrigation compared to furrow irrigation.

3.2.5 Plant leaf area

Leaf area was significantly higher under drip irrigation than under furrow irrigation (Table 3), ranging from 29.78 to 34.6 mm² under SDI and 10.41 to 30.41 mm² under FI. An unexpected observation was that SDI with 0% NFR produced a relatively high leaf area (34.6 mm²), whereas the same rate under FI yielded the lowest leaf area (10.41 mm²).

This contrast may be explained by the improved moisture conservation and micro- environment created under SDI even without nitrogen addition. Higher leaf area values are associated with enhanced nutrient uptake, biomass accumulation, and photosynthetic activity. These results are consistent with Bajracharya & Sharma (2005) and Pramanik & Patra (2016).

3.3 Tomato yield and Quality components

This section evaluates the effects of irrigation methods and nitrogen fertilizer rates on tomato yield components, including fruit size, number of fruits per plant, fresh and dry fruit weight, and overall yield productivity. Significant differences were observed among treatments, demonstrate-ing the strong influence of water–nutrient interactions on crop performance.

3.3.1 Number of fruits per plant

The number of fruits per plant differed significantly across treatments. Drip irrigation consistent-ly produced more fruits than furrow irrigation.

SDI + 80% NFR: 25.73 fruits/plant (highest)
FI + 100% NFR: 12.40 fruits/plant
Lowest fruit count: FI + 0% NFR
The increase under SDI can be attributed to efficient fertigation and better root-zone moisture stability. Similar results were reported by Sampathkumar & Pandian (2010) and Anwar et al. (2020).

Table 4. Effect of combined of fertilizer application and irrigations systems on tomato yield components.

Number of fruit/plant	Fruit width (mm)	Fruit length (mm)	Fertilizer rate%	Irrigation System
0.73	11	14.33	0	Drip irrigation
10.73	15.33	19.333	60	
25.73	22.33	22	80	
6.62	29.4	31.44	100	
2.66	27	29	0	Furrow irrigation
8.6	30.66	32.66	60	
10.6	31.66	33.66	80	
12.40	16.22	18.55	100	

3.3.2 Tomato fruits length and width parameters

The results in (Table 4) shows that the fruits length and width parameters were affected by both irrigation systems and different fertilization application. The fruits length and width varied from 14.33 mm to 33.66 and 11 mm to 31.66 mm respectively, in both irrigation methods. The highest fruits length and width were 33.66 mm and 31.66 mm obtained in FI with 80% NFR treatment, while the lowest results were obtained in SDI with 0% NFR treatment (Table 4). The furrow system was achieved a better results in the terms of fruits length and width parameters, that may be due to the larger wetted layers, and increased the available soil moisture in the root zone, which encourages the tomato plants to absorb sufficient water and consequently increase the photosynthesis activity. The obtained results are in close agreement with these obtained by (Mukherjee *et al*., 2023), who concluded that growth and yield were significantly influenced by the surface irrigation.

Table 5. Effect of irrigation systems and fertilizer rate% interaction on fresh weight and dry weight (ton/ha) of tomato plant

dry weight (ton/ha)	fresh weight (ton/ha)	Fertilizer rate%	Irrigation system
1.12	19.13	0	Drip irrigation
1.21	23.9	60	
1.21	31.94	80	
2.11	36.87	100	
2.13	31.94	0	Furrow irrigation
1.99	33.13	60	
2.23	45.54	80	
1.24	24.99	100	

3.3.3 Tomato fruits fresh and dry weight

The influence of nitrogen fertilizer and irrigation systems on fruits fresh and dry weight was presented in table 5. The furrow irrigation system was recorded the maximum values of fresh and dry weight in FI with 80% NFR treatment as 45.54 ton/ha and 2.23 ton/ha respectively. While minimum values of 19.13 ton/ha and 1.12 ton/ha were obtained with treatment SDI with 0% NFR treatment of drip irrigation.

The maximum values followed by the control treatment in drip system of SDI with 100% NFR. It means that, average fresh and dry weight has the same trend such as fruits length and width parameters for the different treatments (El-Adl, 2009). More nutrient availability, especially near the root zone might have increased the translocation of photosynthates to the storage organ of tomato crop resulting in an increased weight of tomato crop. The low weight in furrow irrigation might be due to less availability of nutrients for crop growth (Pawar *et al*., 2002; Kukal *et al*., 2014; Ranjitha, *et al*., 2018).

4. Conclusion

This study demonstrated that irrigation method and nitrogen fertilizer rate interact significantly to influence tomato growth, yield, and water productivity under arid climatic conditions in northern Sudan. Across all measured parameters, surface drip irrigation (SDI) consistently outper formed traditional furrow irrigation (FI), primarily due to improved moisture distribution, reduce d evaporation losses, and the ability to apply nutrients through fertigation.

4.1 Agronomic Response

Vegetative growth parameters such as plant height, stem diameter, number of leaves, and leaf area were all superior under SDI across most fertilizer treatments. The improved performance can be attributed to stable soil moisture levels and optimized nutrient availability, which enhance root activity and photosynthesis.
These findings align with Meric et al. (2011) and Absanto et al. (2025).

4.2 Yield Response

The highest fruit number, size, fresh weight, and dry matter were consistently achieved under SD I with 80% NFR, demonstrating that moderate nitrogen rates produce optimal physiological responses when combined with efficient irrigation. Excess nitrogen (100% NFR) did not yield further improvement, supporting the argument that balanced nitrogen supply is more beneficial than high quantities under arid conditions.

4.3 Water Use Efficiency

The study highlights that SDI significantly enhances crop water productivity, aligning with global findings that drip irrigation is more appropriate in water limited environments (Hassanli et al., 2009; Zwart & Bastiaanssen, 2004).
Fertigation allowed precise nutrient delivery, reducing losses and improving nutrient use efficien cy by up to 20% compared with FI.

4.4 Practical Implications

The results suggest that adopting SDI with 80% NFR can:
maximize tomato yield improve water and nutrient efficiency reduce fertilizer waste
support sustainable agriculture in arid and semi-arid regions.
Such integration is especially important as water scarcity increases, emphasizing the need for efficient water–nutrient management strategies.

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