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(RESEARCH ARTICLE)

Growth and yield responses of tomato to irrigation in screenhouse-potted soil amended with varying levels of poultry manure

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Abstract

The need for production of high value crops has increased over the years, hence the need to more appropriately determine irrigation water levels in water-scarce scenarios. The Aim of this research was to 1) determine the effect of deficit irrigation on growth and yield of tomato, and 2) determine how poultry manure amendments of soil would interact with irrigation to influence the observed growth and yield responses. There were two irrigation levels namely 0.75 and 1.5 l per plant per week, combined with 0, 34 and 68 g/plant poultry manure, in a 2 x 3 factorial design with three replicates. Growth and yield parameters were measured till maturity. Data were analysed through RTANOVA in a GLM at $\alpha=0.05$. Results showed that the combination of 0.75 l irrigation water per plant per week with 34 g poultry manure per plant significantly increased number of leaves, branches and collar diameter. At low levels of irrigation (0.75 l/plant/week) the highest number of flowers (196) is produced under fertilization with 68 g poultry manure per plant, with a reproductive success rate of 18.37%. When the irrigation rate doubles, the highest number of flowers (126 /plant) is produced in plants fertilized with 34 g/plant poultry manure, with a reproductive success rate of 42.06%., representing the best combination of treatments for maximum fruit yield; doubling manure rates to 68 g/plant results in increased flower abortion and reduced reproductive success.

Keywords: Crop ecophysiology; Irrigation; Drought stress; Tomato; Reproductive success

1. Introduction

Global population has been growing consistently, from the earliest available data, through the era of the green revolution (over 3 billion people) to the present, where it stands at 7.8 billion people and is forecast to grow at a rate of 0.1% by 2100 [1]. Although this population growth rate is slowing down globally, it is still predicted to continue growing in Africa beyond the present century [2]. As a result, the demand for food to feed the increasing population has increased [3,4].

Concurrent with global population growth is increasing anthropogenic climate change. Among the causes of climate change are deforestation of land for agriculture and urban development [5]. These activities have increased over time, tracking the increase in global population growth. Deforestation has been shown to alter regional climate indicators such as greenhouse gases, temperature and precipitation patterns and rates [5,6,7]. In consequence, climate change and abiotic stress are inextricably linked. According to Pereira [8], abiotic stressors include extreme levels of light, radiation (UV-B and UV-A), temperature, water, chemical factors, soil or sediment salinity due to excessive Na+, deficient or in excess of essential nutrients, gaseous pollutants etc. Of these stressors, water levels in the soil are the most impacted due to changes in precipitation patterns associated with climate change.

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Changes in precipitation patterns lead to three main types of abiotic stress; drought, waterlogging and submergence stress, all of which have been shown to have negative implications for non-adapted plants [9,10] while adapted plants could thrive or perform moderately at minimum. Therefore knowledge on how specific plants respond to stressors is still relevant to food production, especially for production of short duration high value horticultural crops.

Among the fruit vegetables most demanded across the world is tomato (*Lycopersicon esculentum* L.). Its global production stands at 160 million tons, with just over 1 million tons produced in Cameroon as of 2018. However, in several production zones output has reached a peak during the main cropping seasons due to limited arable land for rain fed production. Farmers are now looking to off-season irrigated production, which in the tropics implies production in the dry season, when land would have been freed from other crops. The off-season crop is often more profitable, as few farmers have the resources for irrigated agriculture. However, irrigated production faces a number of challenges, amongst which is determining the appropriate amounts of irrigation water to apply. Inadequate irrigation above or below mean annual precipitation in the production zone could result to water deficit- or drought stress [10], [11] or waterlogging stress [12] both of which limit growth and yield of susceptible crops. Drought stress and tolerance responses are species-specific and genetically coded [13] but the end results are often a reduction in crop growth and yield levels. In the tropics, drought stress can be expected in the dry season due to very low- or absence of precipitation. In addition, high atmospheric temperatures directly translate to the soil, which in turn affects soil water content and availability to plant because the heat is dissipated from the soil surface down the soil profile, especially in dark-colored soils. On the other hand, excess soil water in off-season can occur due to excessive irrigation, and hence waterlogging stress would occur. Waterlogging alters soil chemistry, making soils anoxic such that plant roots can't respire [12,14]. Chemical components are formed which could be directly toxic to plant roots. Irrespective of the stressor, the mechanisms of tolerance are centered around stress avoidance and resource re-allocation [15,16] which, in less adapted plants would ultimately result in reduction in growth and yield. Drought and waterlogging make nutrients bound in the soil and unavailable for plants, and these nutrients, especially nitrates, are central to production of compatible osmolytes responsible for stress tolerance. It has been reported that healthier plants are more resistant to stress [17]. Therefore, a possibility is investigating whether augmenting this nutrient deficit by soil amendments would make the plants healthier and hence more tolerant to drought stress. One of the more available soil amendments whose use is increasingly popular in Cameroon is poultry manure. It is rich in nitrates, and has additional benefits of increasing soil organic matter content and water holding capacity. In the current research, we investigated the effect of variations in irrigation water levels as moderated by fertilization with poultry manure, on growth and yield of tomato in screenhouse. The objectives were 1) to determine the growth and yield performance of tomato under deficit irrigation, and 2) to determine how poultry manure amendments of soil would affect the observed growth and yield responses to irrigation water variations. The results are significant for improving tomato fruit production in screenhouses and in the field during the off-season.

2. Material and methods

2.1. Study area

The screen house used for the experiment is located within the SOWEFCU (South West Farmers' Cooperative Union) premises in Kumba, Meme Division, Cameroon. The coordinates of the site are as follows: 04.628°58"N latitude and 009.444°98"E longitude, at an altitude of about 237 m asl. Kumba falls within the Cameroon Agro-ecological Zone IV characterized by monomodal rainfall, with one dry- and one rainy season. Mean annual temperature stands at 25 °C and the total average rainfall in the subdivision is about 2200 mm (IRAD- Barombi, Unpublished data), and the natural vegetation is equatorial forest. Agriculture is the backbone of the economy, and tomato is an emergent crop in the area.

2.2. Pre-planting soil analysis

Pre-planting soil analysis was done to determine the suitability of the soil for the experiments. These analyses were done in the Plant and Soil Laboratory of the University of Dschang, using standard methods. Results of this analysis are presented in Table 1. The soil was sandy clay, slightly acidic, rich in organic matter, with suitable levels of exchangeable cations (Table 1). We concluded it has suitable characteristics for growth of tomato under controlled conditions.

Table 1 Characteristics of soils used for the experiment.

Soil Property	Value	Soil Property	Value
Texture	Sandy Clay	Exchangeable cations (me/100g)	
pH (water)	5.55	Calcium	3.8
pH (KCl)	5.15	Magnesium	1.4
Organic Matter		Potassium	0.05
Organic carbon (%)	2.17	Sodium	0.09
Organic matter (%)	3.83	Total	5.34
Total nitrogen (g/kg)	2.0	Exchangeable acidity (me/100g)	
C/N ratio	11	H+ Al (EA)	0.1
		Cation Exchangeable capacity (CEC)	
		Effective CEC	5.45
		S/CECE (%)	97.5
		CEC pH 7	35.2
		Base saturation (%)	15.5
		Available Phosphorous (mg/kg)	18.9

KCl = potassium chloride, me = milliequivalent, CEC = cation exchange capacity

2.3. Nursery operations and seedling transplant

Seeds of the tomato variety Cobra F1 26 were planted and nursed on nursery beds of about 2m by 1m and 30cm high. In the nursery, the seedlings were shaded against direct impact of solar radiation. They were kept weed free and watered regularly. Seedlings were transplanted into pots in the screenhouse at 3 weeks old. Transplanting was done in the evening in order to avoid transplanting shock. The seedlings were watered immediately after being transplanted.

2.4. Treatments and experimental design

The treatment consisted of three rates of poultry manure (PM) and two rates of irrigation, combined in a 2x3 factorial design. The treatments were replicated three times. The three manure treatments (0 g/plant, 34 g/plant and 68 g/plant, respectively of poultry manure) in combination with two irrigation treatments, I2 and I1 (0.75 l and 1.5 l per plant per week respectively) were assigned to a total of 18 experimental units. Within the screenhouse, the pots were spaced 60 cm x 50 cm apart, and randomised. The manure doses were used based on studies conducted by [27], and irrigation volumes computed from the mean annual rainfall in the region, with the higher irrigation volume (1.5 l per plant per week) corresponding to mean annual rainfall of 2500 mm for the region, while the lower irrigation level depicted a 50% deficit irrigation scenario. Deficit irrigation would occur naturally in rain fed systems under predicted decrease in rainfall or during the dry season; in irrigated systems it is a management option in the predicted scenarios of freshwater scarcity for crop production. Seedlings were transplanted at three weeks old, when they were 10-12 cm tall, and showed no visible signs of disease.

2.5. Conditions within the screenhouse

The screenhouse measured 16m by 4m. It was constructed with wood and the roof was covered with a transparent polythene to avoid rainwater altering the treatments. The walls were covered with a mesh, estimated to have adequate light transmission quality and ambient CO_2 levels. The experimental pots were placed on tables measuring 4 by 1.5m and 60 cm high. The walls were screened with mesh to keep out predators. During the experiment, temperature within the screenhouse ranged from 24.5 to 41.5 ºC with a relative humidity range of 49 to 80.5% at midday.

2.6. Irrigation

Two rates of irrigation were used, 0.75 l/plant/week (I2) and 1.5 l of water/plant/week (I1). The crops were irrigated three times a week (split irrigation), with volumes of 0.25 l and 0.5 l of water respectively. The crops were irrigated over a period of two months.

2.7. Manure application

Poultry manure was applied two weeks after transplanting. This was done at three rates: 0 g/plant, 34 g/plant and 68 g/plant respectively as per the different treatments.

2.8. Weed and pest control

Hand weeding was regularly carried out. Insect pests were controlled by spraying Kumfu 5%WP, a systemic insecticide at a rate of 0.5 g/liter using a hand sprayer. Cacaocides 2010 75WP was applied at a rate of 5g per 5 litres of water to prevent diseases caused by fungi.

2.9. Staking

The plants were staked at about three weeks after transplanting to prevent lurching and breaking of stems under the weight of the fruits, thereby keeping the fruits off the ground. This was also done for the purpose of achieving uniform coverage during spraying and facilitating harvesting (Figure 2).

Figure 2 Tomato plants in screenhouse after staking

2.10. Data collection and analysis

2.10.1. Growth parameters

Plant height

This was measured using a meter rule graduated in cm, from the soil level to the point of terminal growth. The average height of the plant per treatment was obtained by adding up the heights of plants and dividing this sum by the number of plants measured.

Number of Leaves

This data was obtained by counting the number of leaves per plant. The average number of leaves per plant was obtained by adding up the total number of leaves per treatment and dividing this total by the number of plants per the treatment.

Leaf length and leaf width

This data was obtained using a meter rule. Leaf length was recorded as the distance from the base of the petiole to the tip of the leaf, and the width across three points on the leaf. The average leaf length and width was obtained by dividing the sum of leaf lengths and widths by the number of leaves measured.

Leaf area

This was obtained using the following formula of Blanco and Fagoletti [26]:

$$LA=0.708W^2-10.44W+82.4 \quad \text{……………………………………..Eqn 1}$$

Where L=leaf length, W=leaf width and LA=Leaf area

2.10.2. Yield

Yield parameters measured included number of flowers per plant, number of fruits per plant, and reproductive success. Number of flowers and fruits were counted cumulatively. The reproductive success was determined based on the number of flowers and fruits formed as follows:

$$\text{Reproductive Success}=\frac{\text{Number of Fruits}}{\text{Number of Flowers}}*100 \text{………………………..Eqn 2}$$

2.10.3. Data analysis

Data were subjected to GLM ANOVA with rank transformation, following negative tests for normality and homogeneity of variance. Main and interaction effects were analysed and means separated through Tukey HSD test at $\alpha = 0.05$, using the Minitab Version 17 statistical package. Correlation between main effects, growth and yield parameters was tested using Spearman Rank Correlation.

3. Results

3.1. Growth responses

Table 2 shows analysis of variance results of the main and interaction effects on growth parameters. All growth variables measured varied significantly over time ($p<0.0001$). Irrigation levels significantly influenced number of leaves and branches of tomato as well as collar diameter. Manure levels significantly affected all growth variables ($p<0.0001$) except plant height ($p>0.05$). The interaction between irrigation and manure levels had a significant effect on the RLA only (Table 2).

Table 2 Analysis of variance results on statistical significance of irrigation and fertilization effects on growth of tomato in screenhouse.

Factor	Height	No. Leaves	Collar diameter	No. Branches	LA
Time	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Irrigation	0.778	**0.012**	**0.000**	**0.001**	0.227
Fertilizer level	0.072	**0.000**	**0.000**	**0.000**	**0.000**
Time*irrigation	0.864	0.491	0.122	0.173	0.944
Time*fertilizer level	**0.000**	**0.000**	0.326	**0.000**	**0.000**
Irrigation*fertilizer level	0.398	0.966	0.724	0.337	**0.002**
Time*irrigation*fertilizer level	0.457	0.865	0.874	0.998	0.147

Values represent levels of significance. P-Value less than 0.05 indicate statistical variation in the effect of the measured factor on the response variable

Increasing irrigation significantly increased all growth variables measured, except the LA. Increasing irrigation volume from 0.75 l per plant to 1.5 l per plant increased mean number of leaves from 8.8 to 10.78 per plant and collar diameter from 0.48 to 0.85 cm, almost a doubling effect (Table 3). Increasing poultry manure rate on the other hand did not influence plant height, but number of leaves, collar diameter and number of branches all increased as fertilization levels increased from 0 to 34 g poultry manure per plant (Table 3).

Table 3 Growth responses of tomato to irrigation and fertilization with poultry manure, in screenhouse

Irrigation (l/plt/week)	Height (cm)	No Leaves	CD (cm)	No Branches	LA (cm2)
0.75	41.28a	8.88a	0.48a	0.90a	52971a
1.50	41.89a	10.78b	0.85b	1.33b	58993a
Fertilizer (g/plt)					
0.00	39.94a	7.24a	0.48a	0.53c	18025a
34.00	41.76a	11.33b	1.03b	1.57b	91423b
68.00	43.14a	11.01b	0.49a	1.26a	58498c

Values represent means. Means separated through RT ANOVA with Tukey HSD test at α=0.05. Means with the same letter within the column for each main effect are not statistically different. CD = collar diameter; LA = leaf area, plt = plant

With respect to interaction effects, the combination of 1.5 l irrigation water per plant with 34g poultry manure per plant resulted in 12.26 leaves, 1.56cm collar diameter and 1.72 branches with a leaf area of 103096 cm^2 per pot, which considered together, represent the best set of growth parameters across treatments. This effect was statistically similar to that of combining 1.5 l irrigation water with 68g poultry manure per plant (Table 4).

Table 4 Growth responses of tomato to interaction between irrigation and poultry manure levels in screenhouse

Irrigation (l/plt/week)	Fertilizer level (g/plt)	Height	No. leaves	CD	No Branches	LA
0.75	0.00	39.85a	6.81b	0.46c	0.36c	12178c
0.75	34.00	40.96a	**10.40a**	**0.50ab**	**1.42a**	79750a
0.75	68.00	43.21a	9.48a	0.47bc	0.92b	66986a
1.50	0.00	40.04a	7.68b	0.50ab	0.71c	23873c
1.50	34.00	42.56a	**12.26a**	**1.56a**	**1.72a**	103096a
1.50	68.00	43.07a	**12.39a**	**0.51a**	**1.57ab**	50010b

Values represent means. Means separated through RT ANOVA with Tukey HSD test at α=0.05. Means with the same letter within the column for each interaction effect are not statistically different. CD = collar diameter; LA = leaf area, plt = plant.

3.2. Reproductive responses

Analysis of variance results of main and interaction effects on reproductive parameters are presented on Table 5. Number of flowers, fruits and reproductive success changed significantly over time ($p<0.0001$). Manure level, and all interaction effects except that between irrigation and time, significantly affected reproductive parameters ($p<0.0001$). The levels of irrigation did not have a significant effect on reproductive success ($p>0.05$ for all parameters).

Table 5 Analysis of variance results on statistical significance of irrigation and fertilization effects on yield of tomato in screenhouse.

Factor	No. flowers	No. fruits	Reproductive success
Time	0.000	0.000	0.000
Irrigation	0.234	0.499	0.729
Manure level	0.000	0.000	0.000
Time*irrigation	0.908	0.994	0.751
Time*manure level	0.000	0.000	0.000
Irrigation*manure level	0.000	0.000	0.000
Time*irrigation*manure level	0.000	0.000	0.000

Values represent levels of significance. P-Value less than 0.05 indicate statistical variation in the effect of the measured factor on the response variable

Doubling irrigation rate did not significantly change any of the reproductive parameters measured (Table 6). Increasing manure rate from 0 to 34g/plant increased number of flowers from 157 to 248, with a further increase to 284 as fertilizer rate doubled to 68 g/plant. Average fruit numbers increased by a factor of 5.7 from 12 to 68 fruits per plant as manure rates increased from 0 to 34 g/plant and this is reflected on the reproductive success (Table 6). A further doubling of fertilizer from 34 to 68g/plant did not significantly change the number of fruits or reproductive success, but number of flowers increased significantly.

Table 6 Reproductive responses of tomato to irrigation and fertilization with poultry manure, in screenhouse

Irrigation (l/plant/week)	No Flowers	No Fruits	Reproductive success
0.75	373a	51a	13.67a
1.50	316a	75a	23.73a
Fertilizer			
0.00	157c	12b	7.64a
34.00	248b	68a	27.42b
68.00	284a	46a	16.20b

Values represent means. Means separated through RT ANOVA with Tukey HSD test at α=0.05. Means with the same letter within the column for each main effect are not statistically different

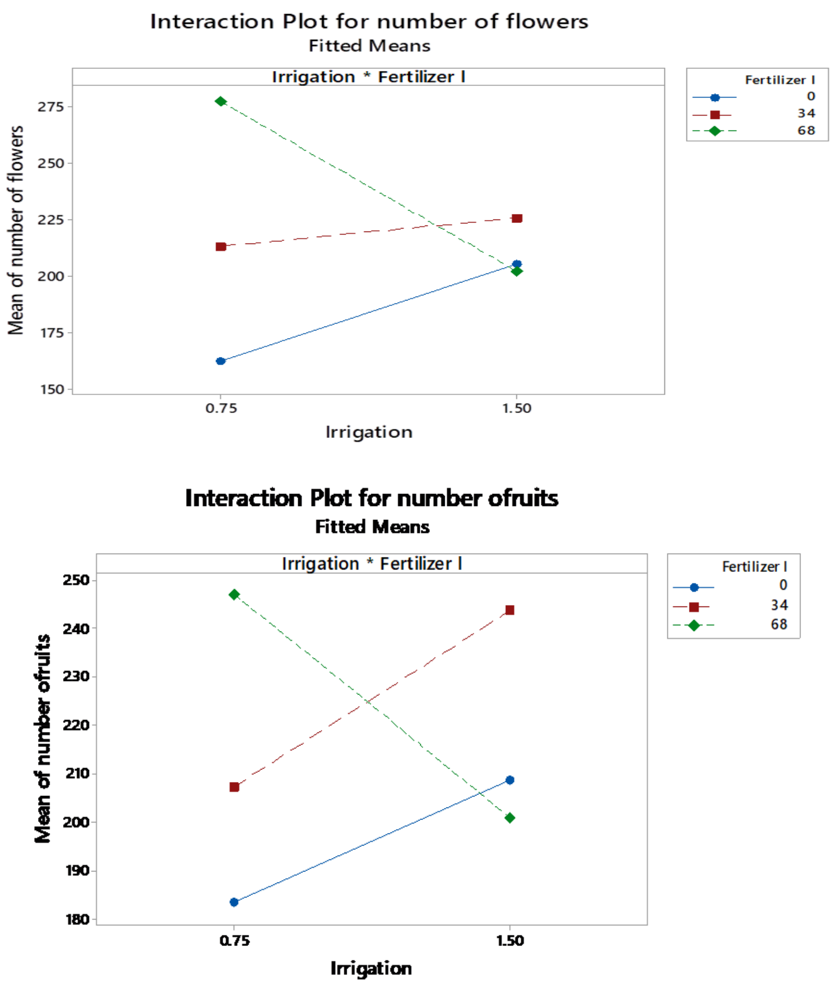

Figure 1 Effect of interaction of irrigation and fertilization with poultry manure on number of flowers (A) and number of tomato fruits (B) in Screenhouse.

Manure and irrigation interact in the field to produce the observed results. At low levels of irrigation (0.75l/plant) corresponding to mean annual precipitation of 1250mm per year, the highest number of flowers (196) is produced under fertlilization with 68g poultry manure per plant, corresponding to a reproductive success rate of 18.37 (Table 7). When the irrigation rate doubles, the highest number of flowers (126/plant) is produced in plants fertilized with 34 g/plant poultry manure, corresponding to a reproductive success rate of 42.06% (Table 7). The best combination of treatments for maximum fruit yield therefore is irrigation at 1.5l/plant under fertilization with 34 g poultry manure per plant (Table 7; Figure 1).

Table 7 Reproductive responses of tomato to interaction between irrigation and poultry manure levels in screenhouse.

Irrigation (l/plant/week)	Fertilizer level	No Flowers	No Fruits	Reproductive success
0.75	0.00	55c	0b	0b
0.75	34.00	122b	15b	12.30b
0.75	68.00	196a	36a	18.37a
1.50	0.00	102b	12b	11.76b
1.50	34.00	126b	53a	42.06a
1.50	68.00	88b	10b	11.36b

Values represent means. Means separated through RT ANOVA with Tukey HSD test at α=0.05. Means with the same letter within the column for each interaction effect are not statistically different

Table 8 Correlation of irrigation and poultry manure levels with growth and yield parameters of tomato grown in screenhouse.

	Time	I	ML	Height	No. Leaves	CD	No. Branches	No. Flowers	No. Fruits	LA
Irrigation	0.000									
	1.000									
Manure level	0.000	0.000								
	1.000	1.000								
Height	**0.924**	0.000	0.034							
	0.000	0.998	0.481							
No. Leaves	**0.726**	0.072	**0.242**	0.805						
	0.000	0.139	**0.000**	0.000						
CD	**0.774**	**0.155**	0.030	0.793	0.682					
	0.000	**0.001**	0.531	0.000	0.000					
No. Branches	**0.459**	**0.111**	**0.246**	0.558	0.742	0.520				
	0.000	**0.022**	**0.000**	0.000	0.000	0.000				
No. Flowers	**0.215**	-0.022	**0.194**	**0.328**	**0.429**	**0.308**	0.447			
	0.000	0.657	**0.000**	**0.000**	**0.000**	**0.000**	0.000			
No. Fruits	**0.472**	0.037	**0.147**	**0.547**	**0.461**	**0.474**	0.296	0.260		
	0.000	0.442	**0.002**	**0.000**	**0.000**	**0.000**	0.000	0.000		
RLA	**0.650**	0.007	0.162	0.785	0.793	0.654	0.665	0.570	0.467	
	0.000	0.887	0.001	0.000	0.000	0.000	0.000	0.000	0.000	
RS	**0.396**	-0.013	**0.180**	**0.479**	**0.417**	**0.393**	0.237	0.359	0.876	0.436
	0.000	0.790	**0.000**	**0.000**	**0.000**	**0.000**	0.000	0.000	0.000	0.000

Top value within cell is ρ, the Spearman Rank Correlation Coefficient. The bottom value within the cell is p, the level of significance. Correlations exist when p<0.05. I = Irrigation, ML = Manure rate, CD = collar diameter, LA = Leaf area, RS = reproductive success

Results of correlation analysis (Table 8) show that manure levels were a better determinant of growth and reproduction than levels of irrigation, although the correlations are weak for both parameters. There was a significant positive correlation of all growth and yield parameters with time (p<0.0001). Irrigation correlated positively with collar diameter and number of branches only, while manure levels correlated positively with most growth and yield parameters (Table 8).

4. Discussion

The aims of this research were to determine the growth and yield performance of tomato under deficit irrigation, and how poultry manure amendments of the potted soil would interact to modify these responses. This is essential because due to climate change, crop production increasingly faces a future in which deficit irrigation would be more common, and so how crop growth can be adapted to these scenarios is essential to future food security. In the current study, growth parameters indicate that tomato plants in screenhouse suffered effects of drought stress under the deficit irrigation scenario, with number of leaves, number of branches, leaf area and collar diameter measuring almost half of the values recorded under the current mean annual rainfall scenario. The reduction in growth parameters under drought is typically due to combined effects of reduced transpiration to improve water use efficiency, reduced photosynthesis, reduced cell elongation due to diversion of photosynthate to drought survival mechanisms and away from growth, as has been explained by several authors [11,18]. Biomass, transpiration, stomatal conductance and leaf growth have been shown to reduce in tomato plants subjected to deficit irrigation in greenhouse [18,19]. This is consistent with findings in the current study where all growth parameters were significantly lower in the water deficit scenario. As irrigation water doubled to 1.5 l per plant per week which is equivalent to the mean annual rainfall of 2500 mm in the region, the stress is alleviated and growth attributes double from the values measured under the deficit irrigation scenario. We found further, that augmenting the soil with poultry manure would improve the growth of plants under the deficit irrigation scenario, to levels statistically similar with growth under the control irrigation scenario. Waraich et al. [17] have shown how improved mineral nutrition enhances the plants ability to grow better even under stress conditions, by 'maintaining charge balance, electron carriers, structural components, enzyme activation, and providing osmoticum for turgor and growth'. Our findings are consistent with those of [20] who reported that although growth of potato decreased by about 50% under deficit irrigation, this could be ameliorated through nitrogen fertilization. Nitrogen is a major component of poultry manure, which is readily available to local farmers in Cameroon. Therefore in a future with expected decline in freshwater resources for crop production, deficit irrigation equivalent to 1200 mm (50% less than normal) coupled with poultry manure rates of 34 g/plant would still maintain growth of tomato plants.

Furthermore, increasing irrigation from the deficit levels to normal did not significantly improve flowering, fruiting and reproductive success, contrary to findings by [19], but increasing fertilization with poultry manure has almost a doubling effect on these parameters. It has been reported [21] that yield of greenhouse tomato increases with increase in both irrigation and fertilization levels. It is unclear why reproductive parameters responded to fertilization, but not irrigation levels in the current experiment, but it is possible that the 0.75 l /plant/week irrigation treatment represent a mild deficit irrigation scenario, under which plants are still expected to do well, as has been reported by [22]. Thus our results suggest under deficit irrigation, reproduction would still continue, further enhanced by fertilization. We also found a threshold for fertilization with poultry manure. At lower levels of irrigation there is apparently some degree of drought stress in the plant. To scavenge for free radicals and stabilize proteins, the nitrogen and other nutrients in plants are diverted from reproduction. Therefore, plants supplied with more poultry manure have excess to spare for growth and reproduction and hence are better adapted to withstand the stress and have excess resources to channel into flower and fruit formation. Indeed, vegetative and reproductive structures require large quantities of nitrates for protein synthesis and related processes necessary for growth and reproduction [23]. Nitrogen supplementation has also been shown to up regulate production of compatible osmolytes and antioxidants necessary to scavenge for reactive oxygen species, stabilize membranes and enhance photosynthesis and other key physiological functions during abiotic stress [24].

When irrigation levels are increased, the stress is alleviated and so moderate amounts of nitrates and other nutrients are needed for flower and fruit formation. We observed in the current study that increasing nitrate concentration through poultry manure of 64 g/plant under well watered conditions would stimulate excessive vegetative growth and flower abortion, leading to reduced reproductive success. These results are similar to those reported for pepper, a member of the same Solanaceae family [25].

5. Conclusion

In a future in which precipitation is predicted to vary significantly, with projected decreases in freshwater for crop production, tomato production will still be possible at deficit irrigation levels equivalent to 50% of current precipitation rates, if the soils are amended with poultry manure at a rate of 34 g/plant. These results are significant for future food security in the region.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare that there is no conflict of interest.

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