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EFFECT OF DIFFERENT LEVELS OF SUSTAINED DEFICIT IRRIGATION ON THE GROWTH, NUTRIENT ELEMENT ACCUMULATION AND WATER USE EFFICIENCY OF TOMATO (*Solanum lycopersicum* L.)

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ABSTRACT

Experiments were carried out under rain shelter to investigate the effect of deficit irrigation on the growth, nutrient element accumulation and water use efficiency of tomato. Tomato of the MT I variety were transplanted in poly bags and subjected to four (4) different irrigation levels. The irrigation levels included soil water potential values of 33 Kpa (full irrigation at 100 % field capacity) as control and deficit treatments of 68, 53 and 39 % of field capacity (FC), corresponding to soil water potential values of 1319.60, 890.24 and 511.89 Kpa respectively. Deficit irrigation treatments were imposed from 2 to 14 weeks after transplanting (WAT) and data collected on plant height, total leaf area, plant dry weight, leaf water potential, stomatal conductance, net photosynthetic rate, nutrient element accumulation and yield water use efficiency. The results showed that deficit irrigation treatments significantly reduced all parameters studied. There was a significant, positive linear relationship between leaf area, dry weight, leaf water potential, net photosynthetic rate and irrigation levels. Deficit treatments of 68, 53 and 39 % FC reduced leaf water potential by 56, 50 and 35 % and yield water use efficiency by 38, 22 and 10 % respectively over the control. The effect on the water use efficiency suggests that sustained deficit irrigation may not be a useful strategy for water conservation in tomato production under prevailing conditions.

Keywords: Tomato, leaf area, dry weight, leaf water potential, net photosynthetic rate and irrigation levels

INTRODUCTION

Plants are constantly subject to a variety of abiotic challenges in their natural environment which often impede their productivity. Water scarcity is among the most prevalent of such abiotic challenges and has been adjudged to be one of the most important constraints to crop production, especially in arid and semi arid regions [1]. In Sub-Sahara Africa, water scarcity has been implicated as one of the factors responsible for low crop productivity [2]. It is important to point out that agriculture is not just the major victim of water scarcity but also a major contributor, largely due to inefficient and wasteful use of water [3, 4]. As a result the management of agricultural water use has become a major focus in the effort to conserve water and stem waste [5]. The implementation of deficit irrigation is among steps being taken in this direction.

Deficit irrigation is a water conservation technology that is reported to be capable of improving both crop and water productivity. [6] had reported water savings of up to 30 % in their work on tomato and potato production under deficit irrigation. They showed that the deficit treatment caused the transduction of stress signals from the root to the shoot, leading to a reduction in stomatal aperture and an increase in the photosynthetic water use efficiency. Similar findings were made by [7] and [8]. In addition to its water conservation role, deficit irrigation has also been reported to be particularly valuable for the improvement of quality parameters. [8, 9, 10] had reported significant increases in the quality of tomato fruits after deficit treatment. There are however variable report on the effect of deficit irrigation on the growth and yield of crops. Whereas [6] found no significant adverse effect of deficit treatment on the yield of tomato, [11] submitted that tomato fruit yield was consistently higher with adequate irrigation compared to deficit treatments. In view of the value of deficit irrigation practice in water conservation and its implication for the sustainability of ecosystems and food production, it is pertinent that it be deployed in the production of different crops. However, due to the fact that it is difficult to extrapolate result from one region or crop to others as a result of regional variability in environmental and agronomic practices [12, 7], it is necessary that the specific practice as it relate to a particular crop, region and climatic conditions be scrupulously determined. It is in this line that this work was carried out to determine the most effective sustained deficit irrigation level for tomato production under hot and humid low land conditions.

2. Materials and Methods

2.1. Experimental design and crop establishment

Experiment was set up under rain shelter at the Faculty of Agriculture, University Putra, Malaysia with coordinates 02°N 59.476′ 101°E 2.867′, 51 m altitudes. Average night and day time temperature was 23.75±0.95 and 30.92±0.64, average relative humidity was 74.37±3 and average light intensity (PAR) under shelter was 395.76±8.1. The soil used for the experiment consisted of a 1:1:1 (v/v) mixture of topsoil, coarse sand and peat. Soil field capacity was determined with the pressure plate (membrane) method [13]. The physical and chemical properties of the soil mixture are presented in Table 1. Planting materials were raised in the nursery using tomato, MT 1 variety seeds and two weeks old seedlings were transplanted into polybags containing 7.7 kg of soil. N:P:K:Mg + TE (12:12:17:2+TE) fertilzer was applied by side dressing at transplanting and at 2 and 6 WAT at the rate of 2 t ha-1. Deficit irrigation treatments were imposed at 2 week after transplanting (2 WAT) with full irrigation (100 % FC) as the control and (68 % FC), (53 % FC) and (39 % FC) as the deficit treatments. Watering was done daily using the weight differential, water balance method [14]. Pots were weighed each day and the amount of water required to bring soil moisture to the required deficit regime was supplied. There were three pots per treatment per replication and each pot had one plant. The experiment was set up in a randomized complete block design (RCBD).

Table 1: Physical and chemical properties of experimental soil media

Soil properties	Analytical values
Field Capacity (%)	23.20±1
pH	5.6
CEC($Cmol_c$ kg^{-1})	0.48±0.3
N (%)	0.38±0.11
P (mg g^{-1})	0.36±0.04
K (mg g^{-1})	9.84±0.61
Ca (mg g^{-1})	62.64±1
Mg (mg g^{-1})	15.57±0.61
Na (mg g^{-1})	3.04±0.01
C (%)	2.21±0.8
S (%)	0.006±0.01

1.1 Plant height

Plant height was measured with a meter tape at 2, 4. 6 and 8 WAT. The height of two tagged plants was taken from the base of the soil level to the tip of the apical leaf. Height readings are the averages of two tagged plants.

1.2 Total leaf area

Total leaf area was measured after fruit harvest (12 WAT), using a leaf area meter (model LI – 3100 Li-Cor Inc. Lincoln, Nebraska, USA). Entire leaves of the plant was lopped and fed into the leaf area meter to obtain the total leaf area of the plant. Total leaf area readings are the averages of three plants per treatment per replication.

1.3 Dry weight

Plants for dry weight determination were harvested at 12 WAT. Shoot and root were measured with a weighing balance, after drying for 72 hours in an oven at 70 °C. Thereafter total plant biomass and shoot:root ratio were conputed.

1.4 Gaseous exchange parameters

Measurement of stomatal conductance and net photosynthetic rate (Pn) was done on a cloudless day at 8 WAT using a portable photosynthetic system, model Li-6400 (Li-Cor Inc., Lincoln, Nebraska, USA). Reading was taken on the youngest fully matured leaf as described by [15].

1.5 Leaf water potential

Leaf water potential was measured at 8 WAT using a pressure bomb (model SKPM 1400 Skye Instrument Limited, UK). Readings were taken between 11:00 AM and 2:00 PM, on the youngest fully matured leaf.

1.6 Water use efficiency

Yield water use efficiency (YWUE) was determined as the ratio of total fruit yield to total irrigation water applied as described by [16]Yasmeen (2011).

$$YWUE = \frac{fruit\ yield\ (g)}{total\ irrigation\ (m^3)}$$

1.7 Nutrient content

Root and shoot (leaves and stem) samples were prepared for nutrient analysis by drying in the oven at 70 °C for 72 hours. For sample digestion, 0.25 g of the dried sample was weighed into 100 ml digestion tube and 5 ml of H_2SO_4 added. This was left to stand for 2 hours and then transferred to the digestion block in the fume hood. Ten (10) ml of 30 % H_2O_2 was then added and the sample heated at 450 °C for 25 minutes. After digestion tubes were left to cool to room temperature and the volume made up to 100 ml with distilled water. The digested samples were then analyzed for K, Ca, Mg, Mn, Fe and Zn using the atomic absorption spectrophotometer, (model 3110, PerkinElmer) and N and P using the autoanalyzer, (Quickchem IC+FIA 8000 series, LACHAT Instruments).

1.8 Statistical analysis

Data were analyzed with ANOVA procedure in the SAS package for RCBD using the statistical software version 9.4 developed by the SAS Institute (2002-2012). Treatment means were compared using Tukey (HSD) at 5 % ($P \leq 0.05$) significant level. Correlation analysis was used to determine strength and nature of relationship between parameters studied. All statistical tests were carried out at 95 % confidence level and differences at $P \leq 0.05$ were deemed to be significant.

2 Results

2.1 Plant height

The plant height of tomato was significantly ($P \leq 0.05$) affected by deficit treatment under hot and humid lowland conditions. Results revealed significant reduction of height from 4 to 8 WAT

(Figure 1). At 4 WAT only plants subjected to 39 % FC deficit treatment were affected as their height was reduced by 28 % compared to the control. However, at 6 WAT all deficit treatments reduced plant height, suggesting that effect of deficit was not only dependent on the severity but also on the duration. Difference in height between plants treated with 39, 53 and 68 % FC and the control were 35, 19 and 18 % respectively. The deficit induced reduction in plant height persisted at 8 WAT for the 39 and 53 % FC deficit irrigation treatments. However, height of plants treated with 68 % FC was not significantly lower than that of the control (100 % FC) at 8 WAT, indicating a tendency for conditioning under prolonged, moderate stress.

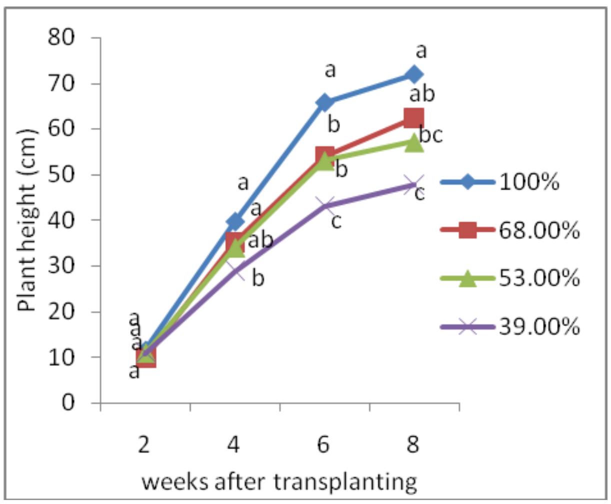

Figure 1: Effect of different levels of sustained deficit irrigation on the plant height of tomato at 2, 4, 6 and 8 weeks after transplanting

3.2. Total leaf area

Deficit irrigation had a significant ($P \leq 0.05$) effect on the total leaf area of tomato. The result showed that there was a linear relationship (R2=0.88) between irrigation level and total leaf area (Figure 2). Tomato plants subjected to full irrigation (control) gave the highest tota leaf area, followed by 68, 53 and 39 % FC in that order. Leaf area at full irrigation (control) was 3,166.2 cm2, which was more than that of plants irrigated with 39 and 53 % FC by 59 and 55 % respectively. The 69 % FC treatment also gave leaf area values that were 51 and 46 % respectively higher than that of the 39 and 53 % treatments.

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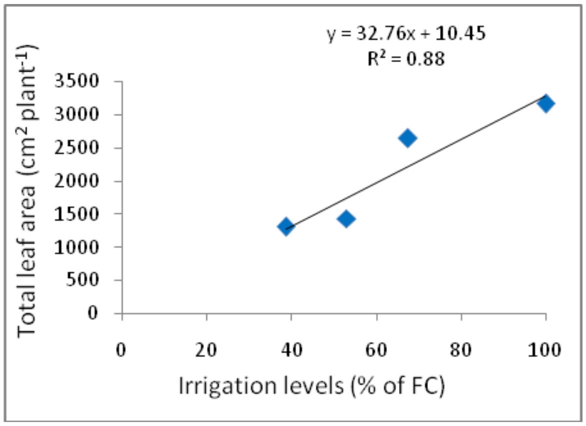
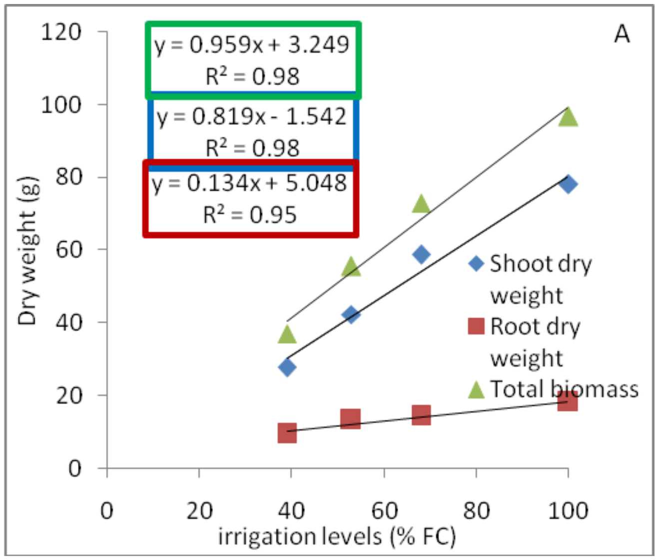


Figure 2: Effect of different levels of sustained deficit irrigation on the total leaf area of tomato

3.3. Plant dry weight

Plant biomass is an important measure of productivity and could serve as a useful indicator of the nature and extent of response to stress. In this study, sustained deficit irrigation had a significant ($P \leq 0.05$) effect on the dry weight of tomato. The result revealed that there was a significant linear relationship (Figure 3 A and 3B) between irrigation level and shoot dry weight (R2=0. 98), root dry weight (R2=0.95) and total biomass (R2=0.98). It also signified that the effect of stress was more pronounced on the shoot than the root dry weight. The regression equation revealed that for every 1 unit increase in the level of deficit, shoot dry weight declined by 0.82 g while root dry weight reduced by 0.13 g.

Tomato plants irrigated with 39 % FC deficit treatment reduced dry weight by 65, 48, 32 and 62 % and by 53, 35, 28 and 49 % for shoot dry weight, root dry weight, total biomass and shoot:root ratio respectively over the control and 68 % FC deficit treatments. Irrigation with 53 % FC deficit also reduced dry weight by 50, 27, 26 and 42 % for shoot dry weight, root dry weight, shoot:root ratio and total biomass respectively over the control. The 68 % FC and the full irrigation (control) treatments are not significantly different in their effect on the dry weight.



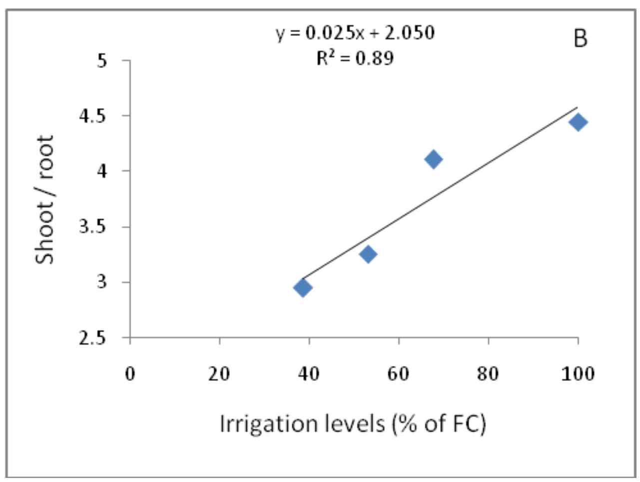


Figure 3: Effect of sustained deficit irrigation on the dry weight (A) and shoot:root ratio (B) of tomato.

3.4. Net photosynthetic rate (Pn)

Deficit irrigation had a significant ($P \leq 0.05$) effect on the net photosynthetic rate of tomato. The result showed that there was a linear relationship (R2=0.82) between irrigation level and Pn (Figure 4). Tomato plants subjected to full irrigation (control) gave the highest Pn, followed by 68, 53 and 39 % FC in that order. Pn at full irrigation (100 % FC) was 21.77 µmol CO2 m-2 s-1, which was more than that of plants irrigated with 39 and 53 % FC by 44 and 33 % respectively.

The 69 % FC treatment also gave leaf area values that was 41 and 30 % respectively higher than that of the 39 and 53 % treatments.

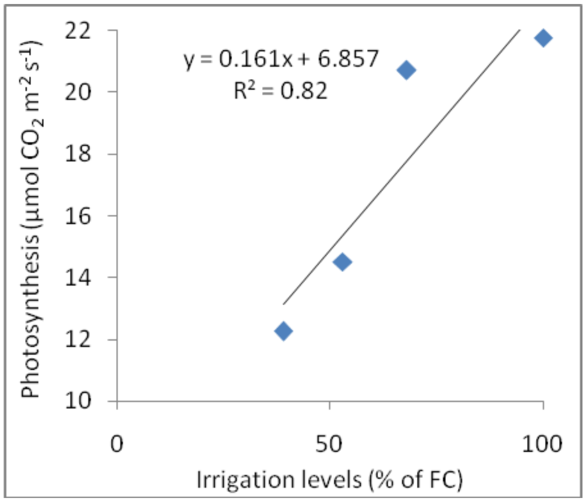


Figure 4: Effect of sustained deficit irrigation on the net photosynthetic rate of tomato

3.5. Stomatal conductance (gs)

The result of this study showed that treatment with sustained deficit irrigation significantly ($P \leq 0.05$) affected the stomatal conductance (gs) of tomato. Stomatal conductance increased with water level indicating a linear relationship between water levels and gs. Deficit regimes of 39 and 53 reduced stomatal conductance below the value obtained with the control (100 % FC) by 69 and 64 % respectively (Figure 5).

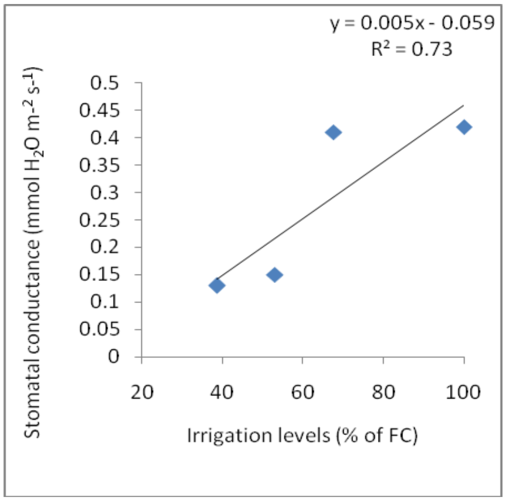


Figure 5: Effect of sustained deficit irrigation on the leaf stomatal conductance of tomato

3.6. Leaf water potential

Water potential is a critical factor for growth and normal functioning of cells. As such the state of the prevailing water potential is an important determinant of plants response to water deficit stress. The result of this study showed that treatment with sustained deficit irrigation significantly (P≤0.05) affected the leaf water potential of tomato. Deficit regimes of 39, 53 and 68 % FC reduced leaf water potential below the value obtained with the control by 56, 50 and 35 % respectively (Figure 6**).**

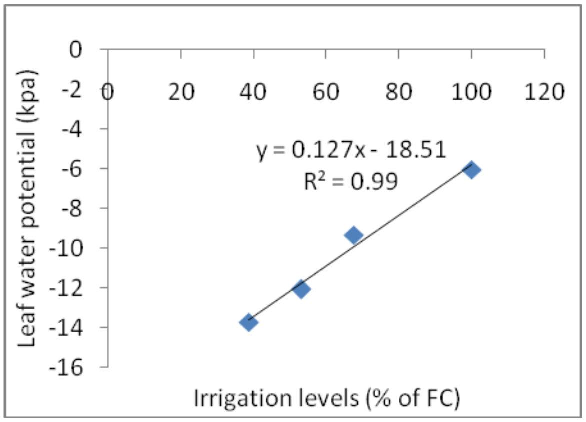


Figure 6: Effect of sustained deficit irrigation on the leaf water potential of tomato

The relationship between leaf water potential and irrigation was significantly linear (R2=0.99) demonstrating that the higher the water deficit the lower the leaf water potential.

3.7. Water use efficiency (WUE)

Water use efficiency gives an indication of the efficiency with which plants use the water supplied to produce and accumulate assimilates. The result of analysis revealed that water use efficiency reduced in tandem with reduction in the level of irrigation (Figure 7). The relationship was significantly linear and positive (R2=0.91). Tomato plants subjected to full irrigation (control) treatment had the highest WUE (12 kg m-3). This value was 38, 22 and 10 % higher than the WUE values obtained from plants irrigated at deficit levels of 39, 53 and 68 % FC.

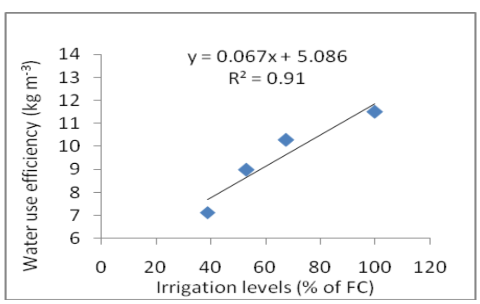


Figure 7: Effect of sustained deficit irrigation on the water use efficiency of tomato

3.8. Nutrient content

Water is a limiting factor in plant-nutrient relations and as such useful insight for the management of deficit programs could be obtained from a study of its effect on nutrient accumulation. N, P, K, Ca and Mg content of tomato plants were significantly ($P \leq 0.05$) affected by the application of sustained deficit irrigation treatments (Table 1). Tomato plants subjected to the full irrigation (control) accumulated 31.19 % more N than the deficit treatments and 22 and 24 % more P than the 53 and 39 % FC deficit treatments respectively. There was no significant difference between full irrigation and 68 % FC treatments in their effect on P content of tomato shoot. Deficit treatments also reduced K content of shoot by 28, 46 and 48 % and Ca by 23, 90 and 91 % for 68, 53 and 39 % FC deficits respectively compared to the control. Deficit treatments however had no effect on Zn and Mn content of tomato shoot.

Table 1: Effect of sustained deficit irrigation on the nutrient content of tomato shoot

Irrigation levels (%)	Macro nutrient content (%)					Micro nutrient content (ppm)	
	N	P	K	Ca	Mg	Zn	Mn
100	3.27a	0.32a	2.49a	1.47a	0.57a	140a	227a
68	2.32b	0.30a	1.79b	1.35b	0.62a	120a	257a
53	2.25b	0.25b	1.35b	1.25c	0.22b	120a	193a
39	2.18b	0.21b	1.30b	1.23c	0.2b	100a	263a
$HSD_{0.05}$	0.29	0.05	0.59	0.84	0.07	100	126

Means followed by the same letter are not significantly different ($P \leq 0.05$)

Table 2: Correlation Coefficient between parameters

The correlation coefficient revealed a significant correlation among different parameters studied. YWUE was positively and strongly correlated with Pn (R2=0.96), gs (R2=0.90) and fruit weight (R2=0.91).

	WUE	Ψ_w	HT4	HT6	HT8	LA	Sdw	rdw	N	P	K
WUE	1										
Ψ_w	-0.57*	1									
HT4	0.49^{ns}	-0.82*	1								
HT6	0.32^{ns}	-0.73*	0.79*	1							
HT8	0.37^{ns}	-0.79*	0.77*	0.94*	1						
LA	0.67*	-0.85*	0.78*	0.80*	0.87*	1					
Sdw	0.57*	-0.89*	0.91*	0.89*	0.93*	0.95*	1				
Rdw	0.40^{ns}	-0.92*	0.78*	0.80*	0.83*	0.74*	0.83*	1			
N	0.59*	-0.76*	0.72*	0.78*	0.70*	0.71*	0.79*	0.74*	1		
P	0.45*	-0.93*	0.83*	0.72*	0.77*	0.83*	0.86*	0.85*	0.57*	1	
K	0.66*	-0.86*	0.69*	0.80*	0.84*	0.90*	0.89*	0.82*	0.86*	0.70*	1

*, ns are significant and not significant ($P \leq 0.05$). WUE: Water use efficiency; Ψw: Leaf water potential; HT4, HT6, HT8: Height at 4, 6 and 8 weeks after transplanting; LA: Total leaf area; sdw: Shoot dry weight; rdw: Root dry weight; N: Nitrogen content; P: Phosphorous content; K: Potassium content

4. Discussion

Deficit irrigation is an important water saving strategy that requires careful management due to the negative influence of its implementation on growth and yield. This effect has been attributed to the instigation of stress related responses [17]. In this study, the imposition of deficit irrigation reduced all the parameters studied. However the earliness and degree of the effect depended on the severity of the deficit. Tomato plants subjected to 39 % deficit treatment gave the earliest and most drastic reduction in height beginning from 4 WAT. Response to the other deficit treatments was more gradual and the reduction became apparent only at 6 WAT. Results also showed that the effect of deficit was more pronounced on the shoot than root growth as demonstrated by the difference in the rate of stress - induced reduction in dry weight. This is possibly the result of a greater ability in the root to maintain a higher degree of tissue hydration under deficit condition [18]. This effect of deficit on growth may be indicative of differential rate of effect of the different levels of deficit on nutrient accumulation and sugar metabolism. The result showed a strong and significant, positive correlation between nutrient content and all growth parameters studied (Table 3). Nitrogen and phosphorous has been reported to influence cytokinin content in plants and it is likely that reduced uptake and accumulation due to effect of severe stress may have affected cytokinin levels and together with reduced sugar metabolism may have resulted in reduced production of expansin protein, limiting cell wall elasticity [19, 20, 21]. Furthermore, the relationship between sugar level and growth was emphasized by [22] who submitted that at low sugar levels plant growth was inhibited by the expression of the sucrose non-fermenting related kinase-1 genes (SnRK1). In this study deficit irrigation significantly reduced the net photosynthetic rate of tomato thus reducing the supply of sugar which likely, instigated the expression of growth limiting genes. The effect of deficit on growth is also likely the result of a reduction of growth - induced water potential fields [23] which may have interrupted the flow of water from the xylem to the meristem thereby inhibiting cell elongation. In this study, the implementation of deficit irrigation reduced the water potential of tomato plants below that of the control plants. Water potential was also strongly to very strongly correlated with all growth parameters. [24, 25] had also reported similar effect of deficit treatment on growth of tomato.

The effect of deficit irrigation on water potential is also likely a factor in the reduced nutrient content of tomato plants subjected to the different deficit treatments. It has been demonstrated that reduced water potential as well as energy availability for nutrient assimilation contribute to reduced nutrient availability and mobility under water stress conditions [26]. However, other workers have shown that the effect of deficit irrigation may result in an increase in nutrient content [27]. In the current study, deficit irrigation treatment reduced the N, P, K, Ca and Mg content of tomato shoot. This is in line with [28] who showed that reducing irrigation water level to 40 % of the field capacity led to a reduction in the N and K content of tomato plants. In addition to reduced water potential other factors that reduce nutrient uptake and distribution under cell water deficit include increased suberization, reduced transpiration and membrane disruptions as a result of stomatal closure [29].

The reduced photosynthetic rate observed in this study is partly the result of stomatal closure which is often among the earliest responses of plants to water stress, usually due to up-regulation of abscisic acid (ABA) production [6]. In this study, stomatal conductance was reduced by the implementation deficit irrigation. This corresponds with the submissions of [30]. Reduced stomatal conductance sets off a series of events that impinge negatively on the photosynthetic rate, including reduced CO2 assimilation, reduced utilization of reducing power by the Calvin cycle, reduced activity of photosynthetic enzymes such as RUBISCO, nitrate reductase, sucrose phosphate synthase enzymes and increased generation of reactive oxygen species [31].

Whereas water stress - induced reduction of stomatal conductance is considered beneficial for the enhancement of water use efficiency [32], severe and prolonged stress often nullifies this and may cause a reduction in WUE instead. This is because in addition to its effect on the rate of photosynthesis which reduces assimilate production, it also complicates phloem translocation. According to [33] reduced water potential reduces the driving force for phloem transport, the flow speed of individual assimilate molecules and increases the demand for more phloem tubes to facilitate assimilate transport. [34] had demonstrated the significance of dry matter accumulation and remobilization in the enhancement of water use efficiency. In the current study, water use efficiency of tomato was reduced by the application of deficit irrigation. [35] had shown that reduction of water supply below 60 % of crop evapotranspiration reduced the water use efficiency of tomato.

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