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GROWTH AND YIELD OF TOMATO AS INFLUENCED BY WATER STRESS AT DIFFERENT PHENOLOGICAL STAGES

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ABSTRACT

The study investigates the effect of water stress at different phenological stages on tomato growth and yield. Tomato is a vital vegetable crop in Nigeria, and water scarcity poses challenges to its productivity. The study was carried out in a screen house, water was applied daily with 100% potential evapotranspiration rate except during the ten days water stress applied at every phenological stage. The parameters assessed include number of leaves, plant height (cm), stem diameter (mm), and root and shoot dry weights (g), in addition, the water use efficiency. The results were subjected to Analysis of Variance and the means were compared using Least Significant Difference at 5% level of significance. The results show that there was no significant difference ($p \geq 0.05$) in the water use efficiency of the tomato plants subjected to water stress at the phenological stages. Notably, the study highlights that the vegetative stage is particularly sensitive to water stress, leading to reduced shoot dry weight and compromised overall biomass. Similarly, water stress during the flowering stage diminishes root dry weight. However, the fruiting stage exhibits relatively better yields under water stress than other stages. The findings emphasize the importance of effective irrigation management, particularly during the vegetative phase, to promote optimal plant development. Moreover, the research underscores the significance of providing adequate water during reproductive phases to enhance fruit production and overall plant performance.

KEYWORDS: Tomato, phenology, water use, dry weight, water stress

INTRODUCTION

Tomato (Lycopersicon esculentum Mill.), the second most important vegetable crop next to potato in terms of production (Olaniyi et al., 2010). It is cultivated in every part of Nigeria as long as water is available (Tsado, 2015). It grows rapidly and requires a relatively cool, dry climate for high yield and better quality (Nicola et al., 2005). Water scarcity affects agricultural productivity, as it accounts for over 70% by weight of non-woody plant parts and most actively growing plants may contain over 90% of water (Ordog, 2011). Water scarcity throughout the crop's development damages the crop, reducing productivity and potentially resulting in crop loss (Xiukang and Yingying, 2016).

Tomato plants are sensitive to water stress, with 15% and 22% reductions in yield with 15% and 30% of irrigation reductions, respectively (Obreza et al., 1996; Celebi, 2014). Water loss to the atmosphere is an unavoidable consequence of carrying out photosynthesis and plants require from the soil a water volume that overcomes its metabolic necessities (Chavarria and dos Santos, 2012).

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Global food production relies on water not only in precipitation but also in available water resources for irrigation (Ayanlade and Radeny, 2018). Rainfall is variable, and dry spells occur during and between seasons, with climate change causing contingent dry spells.

Water is an indispensable resource for every form of life, and its importance pervades every aspect of socio-economic development and sustenance of congenial ecosystems. There is competition for water use in every sector, especially in this era of industrialization. However, it is essential to devise water management strategies that will engender the efficient utilization of water, especially at the critical stages of growth and development of tomato for producing good yield. Furthermore, WMO (2010) noted that temperature increases with resultant increased evapotranspiration and possibly related decreases in rainfall at critical times during the growing season, may lead to rise in water demand globally. Since water is a scarce commodity, it calls for efficient use and the development of strategy to utilize limited volume of water for high yields. An inventive approach to optimize agricultural water is conventional deficit irrigation (DI), which is a water-saving strategy under which suboptimal amount of water is supplied to crops either during a particular phenological stage or throughout the whole growing season (Pereira et al., 2002). The DI process irrigates the root zone with less water than that required for evapotranspiration and makes use of suitable irrigation schedules (Oweis and Hachum, 2001). Crop adaptation to water stress due to DI during the growing season changes with the phenological stage (Istanbulluoglu, 2009).

When water is a limiting factor for agricultural production, irrigation with water deficit index provides greater economic return than total irrigation (Zegbe-Domingues et al., 2003). When properly applied, the technique shows great potential to increase water use efficiency, especially in areas of low water availability (Meric et al., 2011). The deficit irrigation could be used for tomato without reduction in yield (Favati et al., 2009).

Improper irrigation management not only contributes to variation in crop yield but may also lead to waste of scarce water resources (Monte et al., 2013). It is necessary to have knowledge of water requirements at every phenological stage and minimize the loss in irrigation water. This could be achieved through applying enough water to wet the rooting area and allow for effective root systems.

Fresh tomato is on high demand all year round as it forms the base for most delicacies in Nigeria coupled with its diverse nutritional benefits, therefore a study on the efficient water use for optimum growth even in the midst of dry spells is of high necessities. Hence, the objective of the study was to assess the effect of water stress at the phenological stages of tomato on its growth and yield

MATERIALS AND METHODS

Study area

The experiment was carried out at the screen-house of the Agronomy Department, University of Ibadan located at latitude 7º27´7.2´´N and longitude 3º53´45.6´´E with an altitude of 258 m above mean sea level.

Pre-planting soil sampling and soil analysis

Random soil samples were taken from the University of Ibadan Teaching and Research Farm, Parry Road, ranging in depth from 0 to 15 cm. For the purpose of determining the amount of organic carbon and other elements, the samples were air-dried, bulked up to create a composite sample, and then passed through 0.5 mm and 2 mm sieves, respectively. The distribution of particle sizes was measured and documented.

Nursery and transplanting

Tomato seedlings were cultivated in the University of Ibadan's screen house for four weeks. The seedlings were transplanted into polythene pots (10 kg soil capacity. NPK fertilizer treatment was applied at a rate of 25 kg/ha split at 0 and 6 weeks after transplanting. (FMARD, 2012). The seedlings were watered every day for a week.

Experimental design and layout

Topsoil collected from the field of the Teaching and Research Farm, University of Ibadan was dried, sieved and sterilized to rid the soil of other organisms and weed seeds that may interfere with the growth of the crop. The soil was sterilized by oven-drying at 80ºC for thirty minutes.

The seedlings were watered daily with 100% potential evapotranspiration (100% $ET_{p)}$ water application rate except during the 10 days water stress for every phenological stage. The treatments were applied thus:

Treatment 1: 10 days water stress (started 8 days after transplanting) at vegetative stage

Treatment 2: 10 days water stress (started 33 days after transplanting) at flowering stage

Treatment 3: 10 days water stress (started 44 days after transplanting) at fruit setting stage

Treatment 4: no stress (control)

The experiment was laid out in Randomized Complete Block Design (RCBD) and each treatment was replicated eight times.

Treatments application

A measuring cylinder was used to apply the treatments every other day (two days' interval). The volume of water application (cm^3)

From, $\text{Depth} = \frac{\text{Volume}}{\text{Area}}$

Volume = Depth x Area, where depth (mm) is the sum of the daily mean ET_p for 2 days

Area (cm^2) = πr^2, where r is the radius (cm) of the rim of the polythene pot used.

While applying the water, the effort was made to avoid water loss around the pot-soil interface and trays were placed underneath the polythene pots to capture possible drainage loss.

Determination of soil physical and chemical properties

Particle size distribution was carried out using the Bouyoucos hydrometer method (Bouyoucos, 1962). The textural class of the soil was determined by using the USDA textural triangle.

The soil pH was determined with the pH meter using a glass electrode in a 1:1 soil to water ratio (Udo and Ogunwale, 1986). The organic carbon of the soil was determined using the Walkley Black wet oxidation method (Udo and Ogunwale, 1986).

The available phosphorus was determined with the spectrophotometer using Mehlich III as an extractant (Mehlich, 1984).

Data collection

Growth parameters

The following growth parameters were collected:

1. Number of leaves: Leaves were counted for each treatment weekly
2. Plant height: This was measured weekly; it was measured with the aid of a graduated metre rule. It was measured from the soil line to the apical growth.
3. Stem diameter: It was measured weekly with the aid of a Vernier caliper.
4. Dry (root and shoot) weight: All the plants' parts i.e. root, aerial biomass (leaves and main stem), and fruit(s) were placed in labelled and separate paper bags and dried in the oven at 70ºC until a constant weight was achieved. All the dried materials were weighed on an electric balance. This was done fortnightly.
5. The root to shoot ratio was estimated by dividing the dry root weight (considered as root biomass) by the shoot dry weight (dry weight of stem, leaves and fruit).

Yield and yield components

Yield and yield components parameters collected include:

1.
2. Days to first flower appearance: The number of days it takes the first flower to appear per treatment
3. Days to 50% flowering: The number of days it takes fifty per cent of the tomato plants to flower
4. Days to first fruit appearance: the number of days it takes for the first fruit to appear
5. Days to 50% fruit appearance: The number of days it takes fifty per cent of the tomato population to start to fruit
6. Days to maturity: The number of days it takes the tomato plants to mature from the day of transplanting
7. Fruit (fresh) weight: Fresh fruits were harvested on regular basis 4-5 days after every flowering cycle. These freshly harvested fruits per treatment were assembled and weighed per pot using the electronic balance (0.001 g sensitivity)
8. The number of fruits per plant: The number of fresh fruits per plant was determined by counting and recording the total number of fruits obtained from each treatment.

Water use efficiency (WUE) (g/mm)

Water use efficiency (WUE) is the amount of water used to produce a marketable yield. It was calculated as the yield (fruit per plant) per unit amount of applied water to the crop.

$$WUE = \frac{\text{Yield (g/plant)}}{\text{ETa (mm)}}$$

Data analysis

The results were subjected to the Analysis of Variance (ANOVA) using GenStat statistical software and means were compared using Least Significant Difference (LSD) at 5% level of probability ($P \leq 0.05$).

Results

Table 1 shows the physical and chemical analysis of the soil; it indicates that the soil is slightly acidic. It possessed low total nitrogen and moderate phosphorus and potassium (FMARD, 2012) and it had a loamy sand texture (USDA, 2010).

Table 1: Particle size distribution and chemical properties of experimental soil

Soil Properties	Values
pH (H_2O)	6.4
Organic matter (g/kg)	9.8
Total N (g/kg)	0.16
Available P (mg/kg)	7
K (cmol/kg)	0.5
Mg (cmol/kg)	0.74
Ca (cmol/kg)	3.5
Zn (mg/kg)	1.4
Fe (mg/kg)	5.5
Mn (mg/kg)	25.6
Sand (g/kg)	870
Silt (g/kg)	80
Clay (g/kg)	50
Textural class (USDA)	Loamy sand

Growth response of tomato to water stress at different phenological stages

Plant height

Water stress at different phenological stages had no significant (p≥0.05) effect on the heights of tomato plants on first, second and fourth week after transplanting (Figure 1). On the third week after transplanting (3WAT), the height of tomato plant under water stress at vegetative stage was significantly lower (60.20 cm) as compared to other levels of water stress. The height of tomato plant at 5WAT was significant (p≤0.05) among the treatments with tomato plants subjected to water stress at flowering stage producing the least mean value (96.60 cm) while the tomato plants under water stress at the fruiting stage had the highest mean value of height (118.7 cm) which was not significantly different (p≥0.05) from tomato plants under water stress. On the 6WAT, tomato plants without water stress recorded the highest mean height (131.50 cm) which was not significantly different (p≥0.05) from water stress at the fruiting stage while water stress at flowering stage recorded the least mean height (109.90 cm) which was not significantly different (p≥0.05) from tomato plants subjected to water stress at vegetative stage.

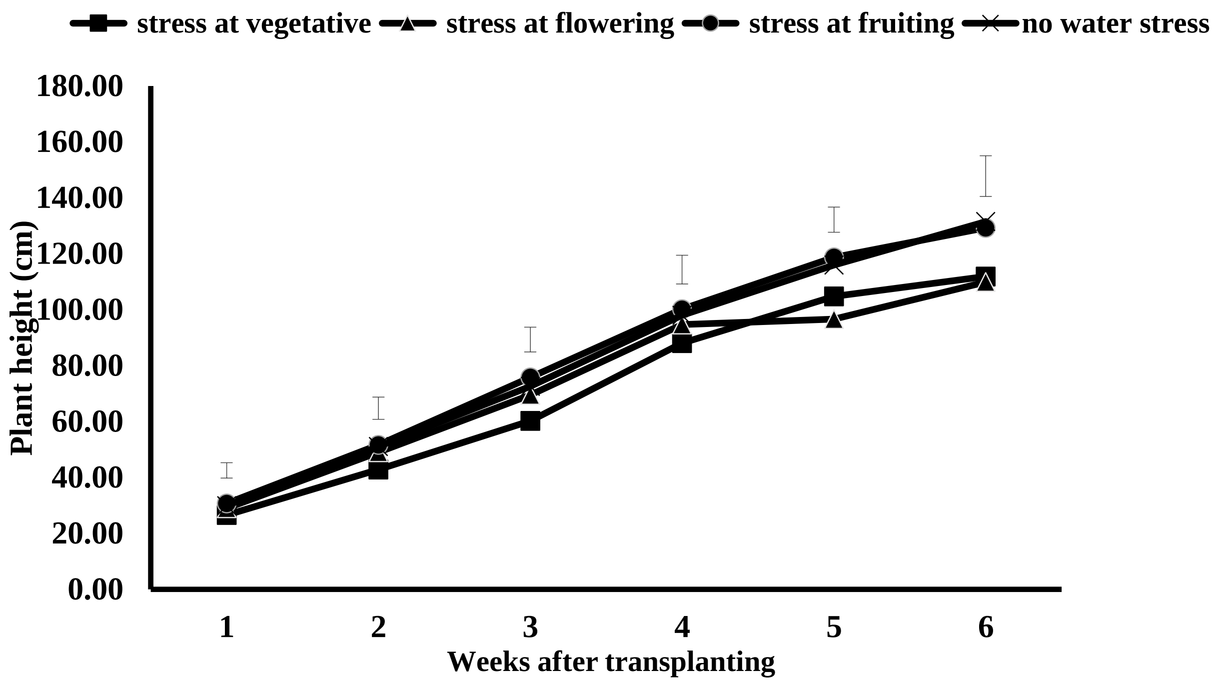

Figure 1: Plant height of tomato as influenced by water stress at different phenological stages (Error bars denote LSD)

Number of leaves

There were no significant differences (p≥0.05) among all the treatments at 1WAT (Figure 2). On the 2WAT, there were significant differences (p≥0.05) among the treatments in the number of leaves of tomato plant. However, water stress during the fruiting stage produced the highest mean number of leaves (96.20) while water stress at vegetative stage produced the lowest mean value (67.70). From the 3WAT to the end of the vegetative stage, tomato plants subjected to water stress at vegetative stage significantly (p≥0.05) produced the lowest mean number of leaves compared to other treatments and there was no significant difference in the number of leaves produced between the tomato plants under no water stress and the ones subjected to water stress at fruiting stage.

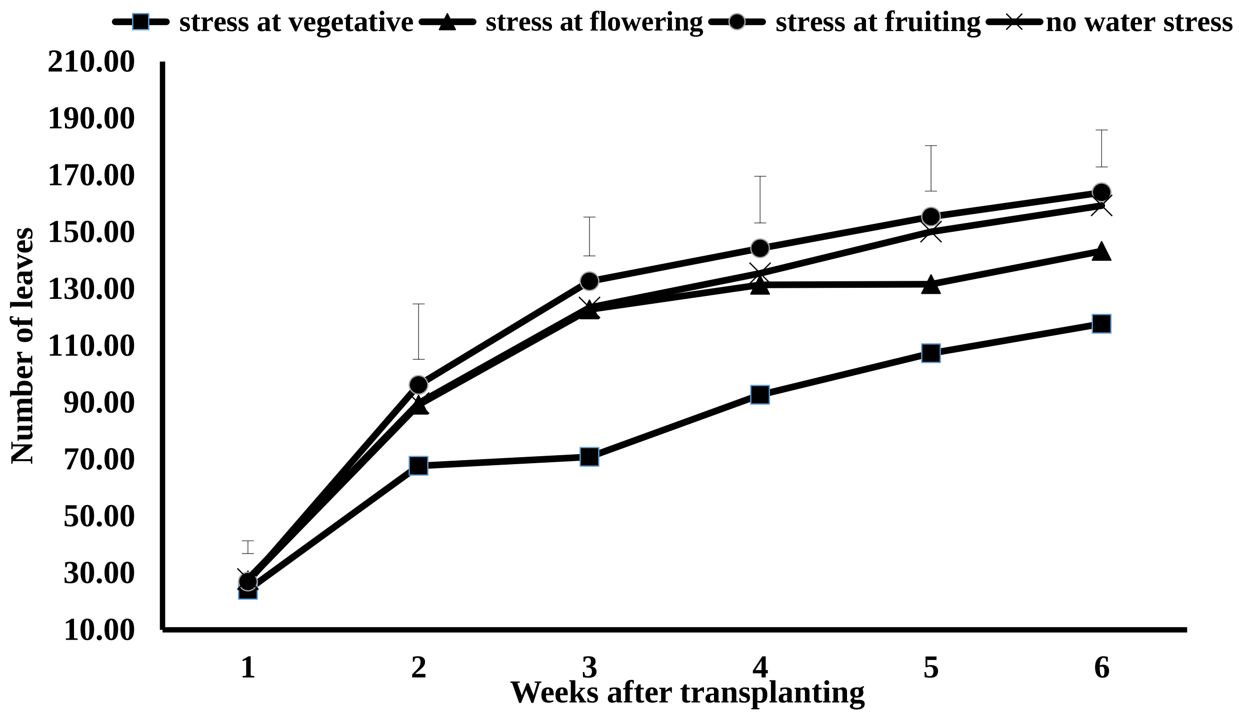

Figure 2: Number of leaves of tomato as influenced by water stress at different phenological stages (Error bars denote LSD)

Stem girth

There were no significant differences among the treatment means throughout the vegetative stage (Figure 3). At the end of the vegetative stage, tomato plants with no water stress had the highest mean value (6.70 mm) while tomato plants stressed at vegetative stage had the lowest mean value (6.36 mm).

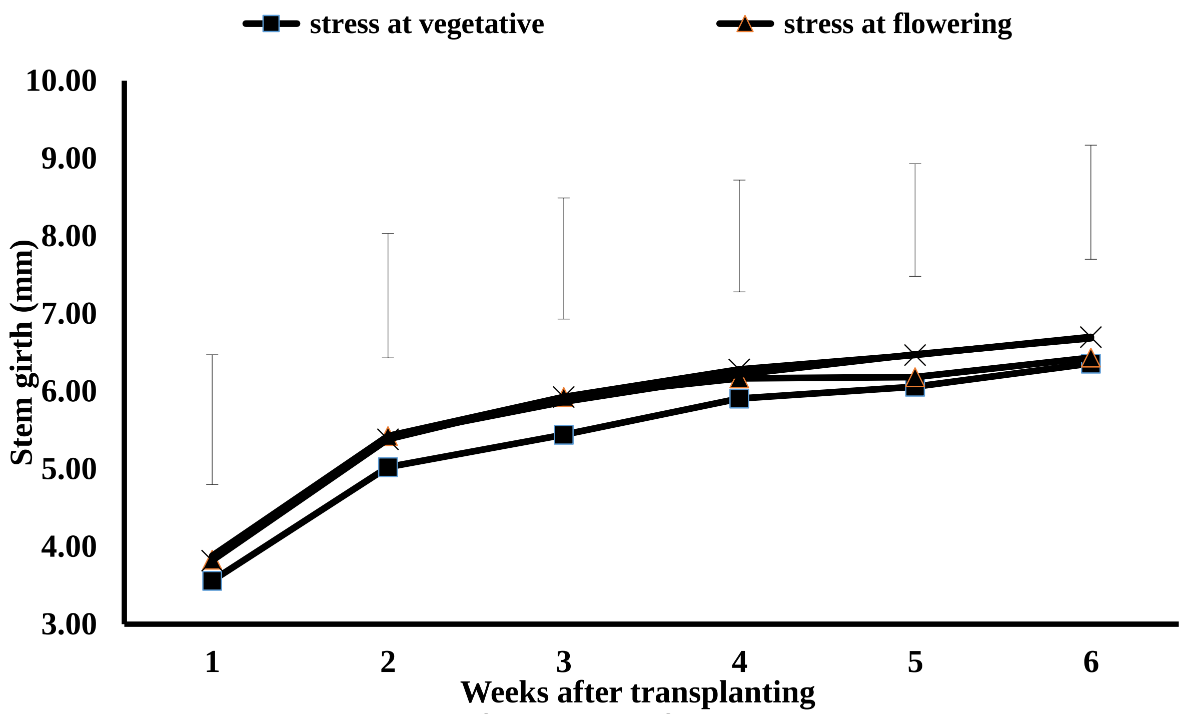

Figure 3: Response of stem girth of tomato to water stress at different phenological stages (Error bars denote LSD)

Shoot dry weight

At 2WAT and 4WAT, there were no significant ($p \geq 0.05$) differences in the shoot dry weight of tomato plants subjected to water stress at different phenological stages (Figure 4).

At 6 WAT, tomato plants under no water stress significantly ($p \geq 0.05$) produced the highest mean shoot dry weight while the tomato plants subjected to water stress at vegetative stage produced the lowest mean shoot dry weight.

At 8 WAT, there was no significant ($p \geq 0.05$) difference in the mean shoot dry weight of tomato plants with no water stress and those subjected to water stress at fruiting stage. Also, there was no significant ($p \geq 0.05$) difference in the mean shoot dry weight of tomato plants subjected to water stress at vegetative and flowering stages. Tomato plants without water stress produced the highest mean shoot dry weight while the water stressed tomato plants at flowering stage produced the lowest mean value.

At 10 WAT, tomato plants with no water stress significantly ($p \geq 0.05$) produced the highest mean shoot dry weight among all treatments while there were no significant differences among the water stressed tomato plants at different phenological stages. There was a slight decrease in the mean shoot dry weight of tomato plants subjected to water stress at fruiting stage.

Root dry weight

At 2 WAT and 4WAT, there were no significant ($p \geq 0.05$) differences in the root dry weight of tomato plants subjected to water stress at different phenological stages (Figure 5).

At 6 WAT, tomato plants with no water stress significantly ($p \geq 0.05$) produced the highest mean root dry weight while tomato plants subjected to water stress at vegetative stage produced the lowest mean root dry weight. At 8 WAT, tomato plants under water stress at flowering stage were significantly produced the least mean root dry weight while tomato plants under no water stress significantly had the highest mean value.

There were no significant differences among the treatment means at 10 WAT.

Root to shoot ratio

Tomato plants subjected to water stress at flowering had the highest mean root to shoot ratio at 2 WAT which was not significantly ($p \geq 0.05$) different from tomato plants under water stress at vegetative stage (Figure 6).

At 4 WAT, there were no significant ($p \geq 0.05$) differences in the root to shoot ratio of tomato plants subjected to water stress at different phenological stages. The root to shoot ratio of tomato plants under water stress at flowering and vegetative stages plunged while the root to shoot ratio of tomato plants with no water stress and those under water stress at fruiting stage increased slightly.

At 6 WAT, tomato plants subjected to water stress at vegetative stage had the lowest mean root to shoot ratio which was significantly ($p \geq 0.05$) different from the mean values of tomato plants with no water stress but not significantly different from tomato plants under water stress at flowering and fruiting stages.

At 8 WAT, there were no significant ($p \geq 0.05$) differences in the root to shoot ratio of tomato plants subjected to water stress at different phenological stages. The tomato plants subjected to water stress at vegetative stage had the highest mean root to shoot ratio which was significantly different from tomato plants under water stress at flowering stage.

There were no significant ($p \geq 0.05$) differences among the treatment means at 10 WAT. Both the tomato plants under water stress at vegetative and those with no water stress had slight decreases in the mean root to shoot ratio while that of the tomato plants under water stress at flowering and fruiting stages increased.

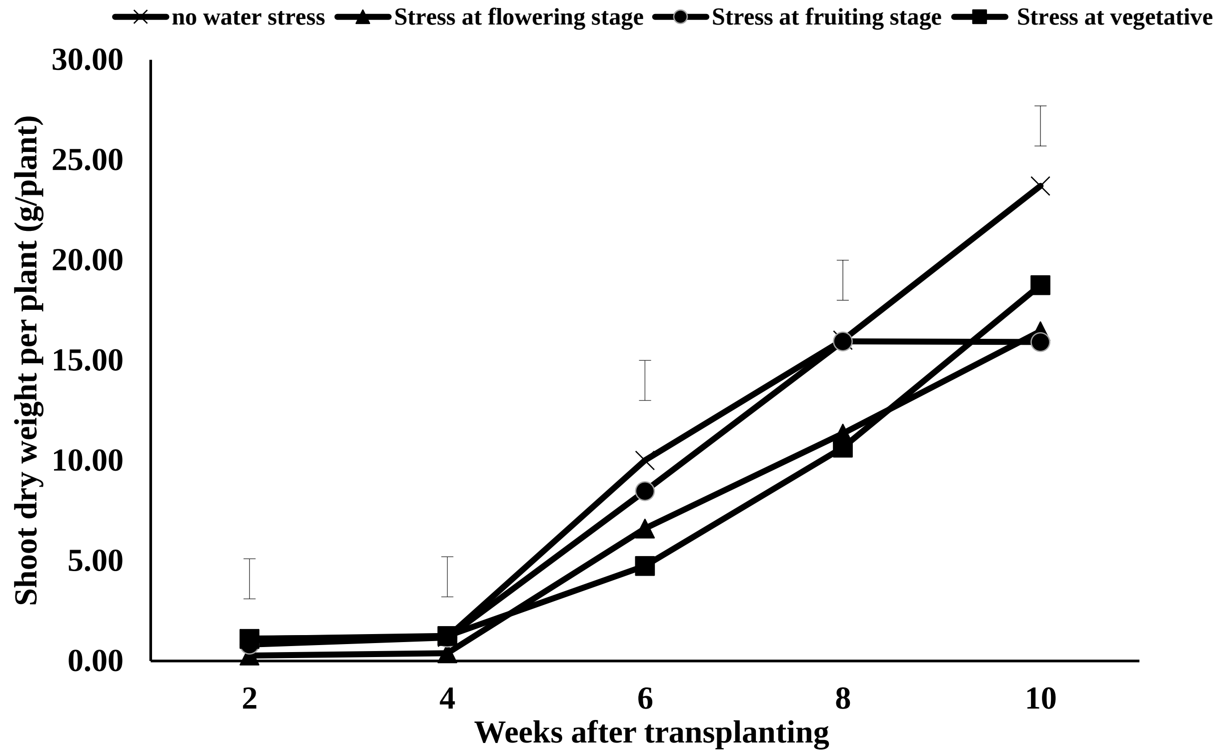

Figure 4: Shoot dry weight of tomato as influenced by water stress at different phenological stages (Error bars denote LSD)

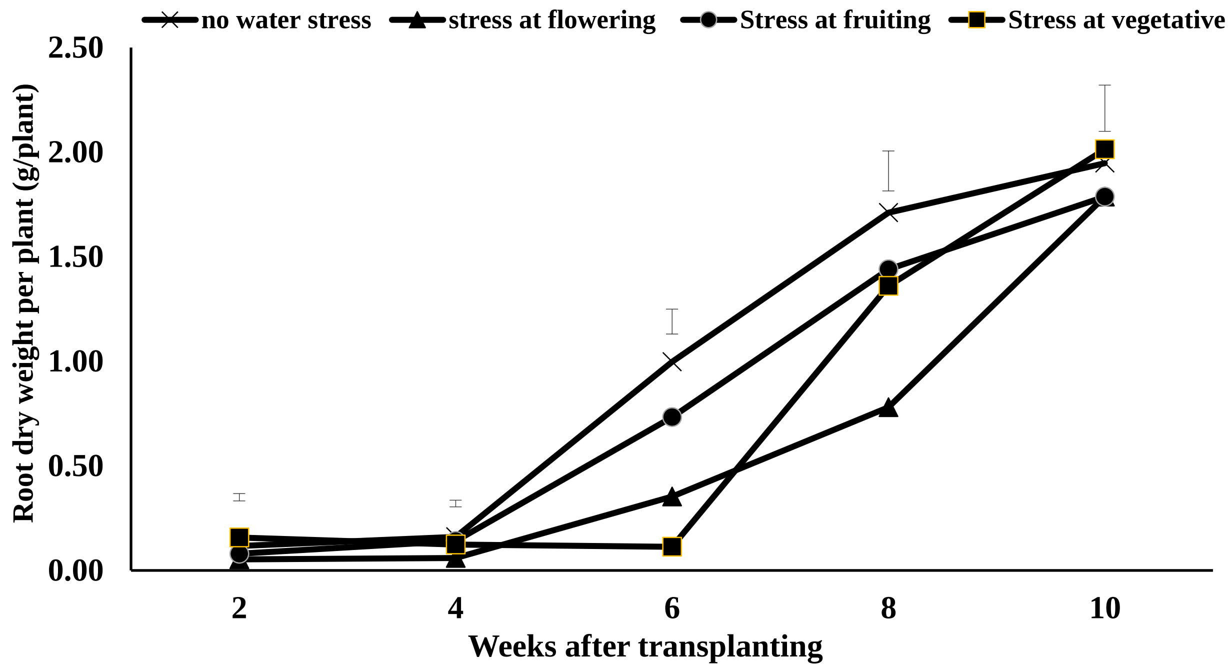

Figure 5: Root dry weight as influenced by water stress at different phenological stages (Error bars denote LSD)

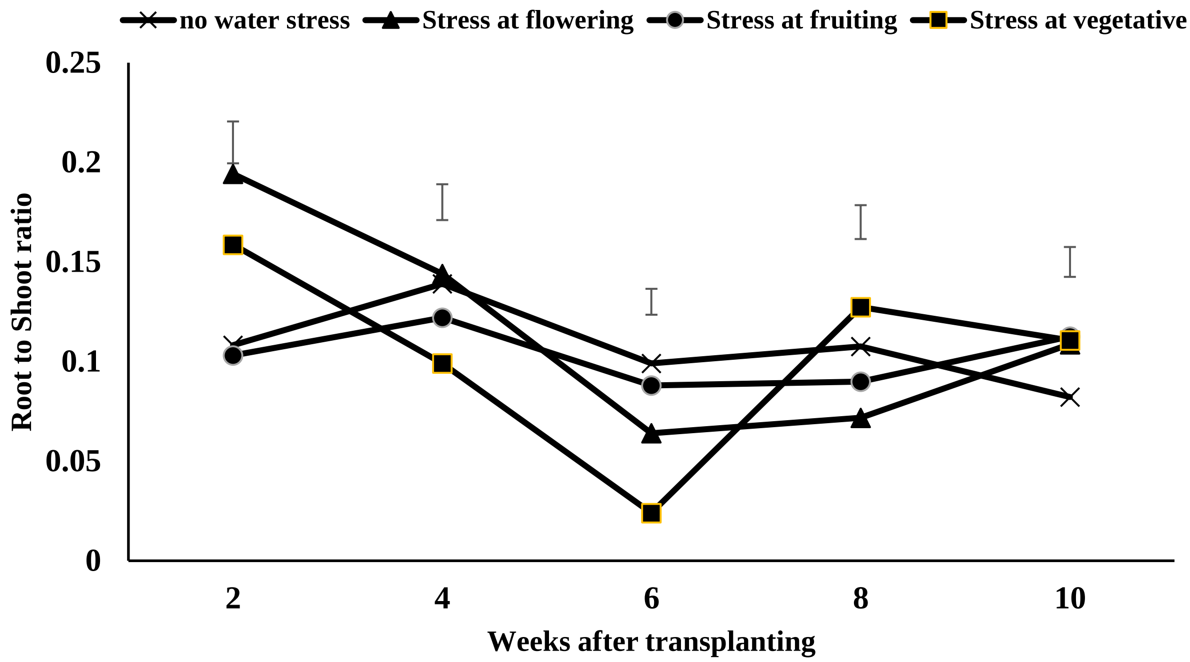

Figure 6: Root to shoot ratio as influenced by water stress at different phenological stages (Error bars denote LSD)

Response of tomato yield and yield components to water stress at different phenological stages

Days to first flower appearance

There was significant (p≥0.05) difference in the days to first flower appearance between tomato plants subjected to water stress at vegetative stage and the other treatment means (Table 2). Tomato plants subjected to water stress at vegetative stage produced first flower at 35.2 days followed by tomato plants with no water stress (30 days) while tomato plants under water stress at flowering stage produced the first flower within the shortest period (28.3 days).

Days to 50% flowering

There were no significant (p≥0.05) differences in the number of days to 50% flowering on tomato plants subjected to water stress at flowering and fruiting stages and those without water stress (Table 2). However, it significantly (p≥0.05) took 50% of tomato plants under water stress at vegetative stage longer mean number of days (49.5 days) to flower compared to other treatments.

Number of flowers

There were no significant (p≥0.05) differences in the number of flowers among the water stress conditions (Table 2). However, tomato plants under water stress at fruiting stage produced the highest mean number of flowers (12.4) while those under water stress at vegetative stage produced the least mean number of flowers (10.4).

Days to first fruit appearance

Tomato plants subjected to water stress at vegetative stage was significantly different from other treatments in terms of the days to first fruit appearance (Table 2). Tomato plants under water stress at fruiting stage produced the first fruit within the shortest period (37.7 days) which was not significantly (p≥0.05) different from the tomato plants with no water stress (40.2 days) and those with water stress at flowering stage (40.5 days) while those subjected to water stress at vegetative stage was later (46 days).

Days to maturity

There were significant (p≥0.05) differences in the days to maturity between the tomato plants with no water stress and those under water stress at vegetative and fruiting stages (Table 2). The mean number of days to maturity of tomato plants under water stress at fruiting stage (68.8 days) was the shortest while those under water stress at vegetative stage (94.8 days) was longest.

Number of fruits

Tomato plants without water stress significantly (p≥0.05) produced the highest number of fruits (5.42) compared to those under water stress at vegetative (3.58) and flowering stages (3.33) but not significantly different from those under water stress at fruiting stage (5.25). However, tomato plants under water stress at vegetative and flowering stages produced number of fruits that were 33.9% and 38.6% respectively less than tomato plants with no water stress (Table 2)

Table 2: Yield components of tomato as influenced by water stress at different phenological stages

Treatments	Days to first flower appearance (days)	Number of flowers	Days to 50% flowering (days)	Days to first fruit appearance (days)	Days to maturity (days)	Number of fruits
No stress	30	11	44.3	40.2	81.8	5.4
Stress at flowering stage	28.3	11.3	44.8	40.5	76.3	3.3
Stress at fruiting stage	29.3	12.4	40.8	37.7	68.8	5.3
Stress at vegetative stage	35.2	10.4	49.5	46	94.8	3.6
LSD (p≥0.05)	2.5	ns	4.5	3.8	6.4	1.0

Fruit weight per plant

There were no significant differences in the fruit weight per plant of tomato subjected to water stress at different phenological stages however, tomato plants with no water stress significantly ($p \geq 0.05$) produced the highest mean fruit weight per plant (136.2 g/plant) (Table 3). Tomato plants subjected to water stress at vegetative, flowering and fruiting stages produced fruit weight per plant that were 35.9%, 39.5% and 39.95% respectively less than the tomato plants with no water stress.

Water use efficiency

The result showed that tomato plant with no water stress had the best water use efficiency (0.4 g/mm) while those subjected to water stress at different phenological stages had equal values with 0.2 g/mm apiece (Table 3).

Table 3: Yield of tomato as influenced by water stress at different phenological stages

Treatments	Fruit weight/plant (g/plant)	Amount of water used (mm)	Water Use Efficiency (g/mm)
No water stress	136.2	362	0.4
Stress at flowering stage	61.6	323	0.2
Stress at fruiting stage	78.7	328	0.2
Stress at vegetative stage	61.1	323	0.2
LSD (p≥0.05)	56.2		

DISCUSSION

Water stress affected the rate of growth and yields of tomato. There was decrease in heights of the tomato plants subjected to water stress at the vegetative and flowering stages while non-stressed tomato plants followed a progressive trend. Likewise, the leaves and the stem responded negatively to water stress. Furthermore, the amount of water applied to tomato plants has a direct relationship with the growth. The reduction in plant height is associated with the decline in the cell enlargement and more leaves senescence (Chavarria and Pessoa dos Santos, 2012). Similar results were arrived at by Kinark et al. (2001) where plant height and stem diameter of water stressed plants were smaller than the equivalent component in the well-watered plant. Klepper et al. (1971) indicated that the stem diameter changes reflect changes in stem tissue hydration.

There were decreases in the root and shoot dry weights of tomato plants subjected to water stress. Reduction of shoots, wet and dry weights, under water deficit stress has been reported in Zea mays L. (Ashraf et al., 2007), Beta vulgaris L. (Hussein et al., 2008), Cicer arietinum L. (Gunes et al., 2006; Rahbarian et al., 2011).

Barely 50% of the fruits were produced from the flowers that bloomed under the well-watered tomato plants, this might be due to reduced pollination in the screen house. Furthermore, the plants are protected from wind that can shake the flowers to stimulate the release of pollens (Wudiri and Henderson, 1985). However, the early stressed tomato plants (vegetative and flowering stage) produced 34% and 38% less fruit with respect to the tomato plants with no water stress. This is in line with Birhanu and Tilahun (2010) that reported a decreased number and sizes of tomato fruits from plants subjected to moisture stress. The same observation of water stress on tomato yield parameters was also reported by Zotarelli et al. (2009). Rahman et al. (1999) found that water stress decreased yield, flower number, fruit set percentage and dry matter production in the tomato varieties tested.

The tomato plants without water stress had twice the water use efficiency compared to water stressed plants. This is in consonance with Rahman et al. (1999) who observed that water use efficiency decreased with increasing water stress. This implies that water deficit at various phenological stages may not increase the water use efficiency. It was observed that the number of fruits produced also had impact on the water use efficiency which was attributed to flowers dropping due to water stress. The fruiting efficiency in screen house may also contribute as the well-watered tomato plants produced just 50.7% of the flowers that formed. Tomato plants subjected to water stress at fruiting stage produced the highest mean number of fruits with better water use efficiency compared to the other water stressed tomato plants; an indication that water deficit at fruiting stage is more economical.

CONCLUSIONS

The study found that water stress negatively impacts tomato growth at the phenological stages, affecting plant height, leaf production, flowering and fruiting stages. The vegetative stage has the most significant negative effects, while flowering and fruiting stages have milder effects. Additionally, water stress at the fruiting stage had a relatively better yield compared to the water stress imposed at vegetative and flowering stages.

Water stress at the vegetative stage reduces shoot dry weight, affecting overall plant biomass. The flowering stage also reduces root dry weight, potentially affecting nutrient and water uptake during the reproductive stage.

Proper irrigation management and adequate water supply during the vegetative stage are crucial for optimal growth and development. Monitoring and providing sufficient water during reproductive stages can support fruit production and overall plant performance.

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