Effect of Water Stress on the Yield of Selected Vegetable Crops in the Southern Guinea Savannah Ecological Zone of Nigeria

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Abstract

Water stress effect on the yield of tomato (Lycopersicum Esculentum) and onion (AlliumCepa) crops was carried. This study is aimed at understanding the required amount of water needed by onion and tomato plants daily and to predetermine the yield expected from scheduled irrigation under limited water supply. Randomised complete block design experimental layout was employed and replicated five times. The irrigation interval observed was controlled on the first block of regular four days; the second, third and fourth blocks were irrigated six, seven, and nine days respectively. The result of onion showed the highest yield of 31.5 kg/plot (12 t/ha) from the four days regular irrigation interval, followed by six days irrigation interval with a yield of 30.9 kg/plot (11.77 t/ha). The lowest yield of 18.3 kg/plot (6.97 t/ha) was obtained for the nine days irrigation interval. Similarly, the highest yield of 43.1 kg/plot (16 t/ha) in regular four days irrigation interval and the lowest yield of 13.4 kg/plot (5.1 t/plot) for nine days interval was recorded for tomato. The result of this study shows that irrigating at an interval of four to five days has the highest significant yield of 16 t/ha and under critical conditions, the farmer can irrigate seven days as up to 65% - 70% yield was obtained. Irrigation should not be scheduled nine (9) days because about 42% of the yield is lost. It is therefore concluded that the yield water use relationship shows that both onion and tomato crops increases with an increase in the rate of seasonal evapotranspiration provided water application rate does not exceed the required amount at the required amount.

1. Introduction

Irrigation is a process by which water is applied artificially or applied to the soil for crop use to increase crop production [1] [2] [3]. Irrigation water is applied to supplement the water available from rainfall, soil moisture and the capillary rise of groundwater [4]. In many areas of the world, the amount of precipitation is not adequate to meet the moisture requirements of crops. Hence, successful crop production often requires sufficient provision for irrigation. According to Sharma and Sharma [5], the role of irrigation systems is classified as direct and indirect benefits. The immediate benefits include; increase in crop production output through high yield to attain self-sufficiency in food, cultivation of cash crops, land value appreciates differently, domestic water supply to town and villages and hydro-power generation. The indirect benefits include an increase in the gross domestic product of the country, increase in revenue from the sales of farm produce, tax on food grains, increase in employment, retards migration to cities for livelihood, farm labourers get higher wages, the creation of more jobs/incomes and rise to the whole array of agro-based industries. Irrigation aims to supply water to cropped fields to maintain crop evapotranspiration (ETc) when precipitation is insufficient [6]. Water is becoming increasingly scarce worldwide. Thus aridity and drought are natural causes of scarcity. More recently, human-made desertification and water shortages have aggravated inherent deficiency while at the same time, population is increasing and therein an increase in competition for water among water user sectors and regions [7]. The rapid population growth worldwide and the high demand for water are of great concern. There are growing competitions among municipal, industrial and agricultural use for the limited amount of available good quality water [8]. According to Michael [9], it is essential to accurately estimate irrigation water requirements for water project planning and management. In arid and semi-arid regions precipitation is low and therefore water is scarce. There is, therefore, the need to conserve available water resources.

Improved management and planning of the water resources are needed to ensure proper use and distribution of the water among competing users. To achieve maximum use of water, there is a need for planning as regards water usage which will include the employment of techniques and practices that deliver a more accurate supply of water to crops.

Deficit (or regulated) irrigation is a way of optimising water use efficiency

(WUE) for higher yields per unit of irrigation water asked. Reduction of return as a result of low irrigation, especially under the situation of scarcity of water, may be compensated by increased production from the additional irrigated area with the water saved from deficit irrigation [10] [11].

Water required by plants from the day of sowing to the day of harvest including the various form of water losses under specific climate regime is called crop water requirement. During this process, adequate soil moisture is maintained through rainfall and irrigation so that it does not limit plant growth and crop yield. This study aims to determine the minimum water requirement for the maximum yield for tomato and onion using a deficit irrigation system.

2. Material and Method

2.1. Study Location

The research was carried out at Kaduna Polytechnic Demonstration farm, Nariya which is located on latitude 10°16'N and longitude 7°21'E at an altitude of 600 - 800 m above the sea level, during the dry season between the period of November 2016 and April 2017. Figure 1 presents the map of the study area from the map of Kaduna State, Nigeria.

2.2. Climatic Condition of the Site

The region according to the NiMet report of 2018, experiences a severe deficit in rainfall from November to April and sometimes a surplus of rain from July to September with an average range of 1500 mm. The average incoming solar radiation range from 15.6 mj/m^2/day in August to 21.0 mj/m^2/day in March. The range in solar radiation implies that light, humid temperature with a significantly limiting potential crop production between November and mid-February with
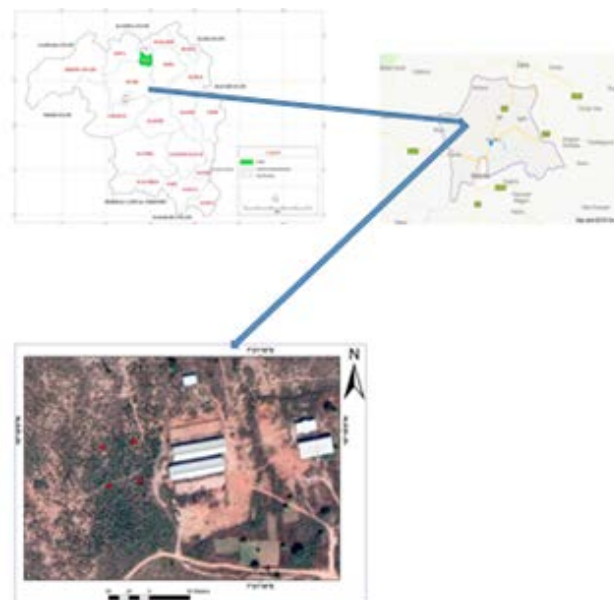
Figure 1. Google map of the study area.

temperature ranging from 19˚C to 25˚C, while for the remaining month of the year, the daily temperature ranges from 25˚C to 32˚C.

2.3. Soil Texture Classification

Eight sets of soil samples were collected within the rooting depths of the plots (that is from 0 - 30 cm), and the containers were labelled for ease of identification. The samples were dried at room temperature of 27˚C for 24 hours. The samples were crushed to fine particles and sieved using a sieve size of 2 mm. 50 g of the sieved soil was weighed and placed in a conical flask, and 100 ml of Calgon solution was added to the soil in the flask, mixed and allowed to settle for 30 minutes. A blank solution prepared was poured in a 100 ml Calgon solution into a 1000 ml measuring cylinder, then distil water of 900 ml to reach 1000 ml mark of the measuring cylinder was added to it after which the soil and Calgon were mixed for 30 minutes. The hydrometer was inserted, and the stop clock set after 40 seconds the first reading, as well as the thermometer reading for the temperature, was taken. The second reading was taken after leaving the sample for 2 hours. The texture of the soil samples was determined using a soil texture triangle which was based on relative proportion and specifically on % sand, silt and clay in a given soil sample. The percentage of sand, silt and clay in the samples was determined from Equations (1)-(4) below;

$$\%\left(si+c\right)=\frac{CHR1}{Ws}\times100 \tag{1}$$

$$\%c=\frac{CHR2}{Ws}\times100 \tag{2}$$

$$\%si=\%\left(si+c\right)-\%c \tag{3}$$

$$\%s=100-\%\left(si+c\right) \tag{4}$$

where si is the silt content, c is the clay content, s is the sand content, $CHR1$ is the first corrected hydrometer reading and $HR2$ is the second corrected hydrometer reading, while Ws is the weight of the sample.

The soil organic matter was determined using Walkley-Black Wet Oxidation meter. The percentage of organic matter in the sample was determined from Equation (5) (a and b) below;

$$\%\text{Organic Carbon}=\frac{N\left(V1-V2\right)\times0.3F}{W} \tag{5a}$$

$$\%\text{organic matter in soil}=\%\text{ Organic carbon}\times1.724 \tag{5b}$$

where N is the normality of ferrous sulphate solution; $V1$ is the ml ferrous ammonium sulphate required for the blank; $V2$ is the ferrous ammonium sulphate required for the sample; W is the mass of the sample in gram and F is the correction factor of 1.33

2.4. Experimental Design

Randomised Complete Block Design (RCBD) was used for this experiment. The

experimental material is assumed to be homogenous, therefore, and there is no restriction in the randomisation. Check basin Surface irrigation method was employed. Each basin was irrigated through a break in the embankment and water allowed through a furrow running along the slope adjacent to the basin until it is ponded to a level of about 15.0 mm which is the appropriate water requirement for tomato.

The experimental plots were laid out using a chain surveying method. The instruments used were measuring tape, ranging poles and pegs for labelling. The layout was 2 m × 2 m for each plot, and 20 plots of the experimental unit were used, the total area of 11 m × 12 m which is 132 m^2 or 0.0132 ha for tomato, while the layout for onion was 3 m × 2.5 m for each plot and 18 plots of the perimental unit was used with the total area of 10.5 m^2 or 0.0163 ha. This laying out of the plots is in accordance with the works of Maisiri *et al.*, [12]; Medeiros *et al.*, [13]; Anzalone *et al.*, [14]; Ashrafuzzaman *et al.*, [15] and Alliaume *et al.*, [16].

The data collected were subjected to statistical analysis and the means were tested using the least significant difference at 5% level of significance. All the statistical analyses were conducted using statistical package SPSS 16.

3. Results and Discussion

Crop yield and water stress are vital most especially in areas where irrigation is practised. This study will enable the farmer to know the appropriate irrigation water application and scheduling. In this study, the relationship between water stress and crop yield of tomato and onion were established based on the experimental results.

The physical and chemical properties for the experimental plots were determined between depths of 0 - 15, 15 - 30, 30 - 45 and 45 - 60 cm. The topmost layer of the soil gives silt loamy at a depth of 15 cm while from the depth of 15 to 45 cm give clay loamy. At 60 cm depth, the soil texture was clay nature, these classes were determined with the soil texture triangle. This soil texture is the characteristic nature of the soils within the study area and is in accordance with the works of Tuller and Or [17]; Li and Shao [18] and Lu *et al.*, [19]. The chemical properties of the soils show that pH was slightly alkaline in water and in calcium chloride solution it was strongly alkaline. This is similar to the findings of Mckinley *et al.*, [20]; Sunil *et al.*, [21] and Minasny *et al.*, [22]. The content of sodium (Na^+), potassium ion (K^+), magnesium ion (Mg^{2+}), calcium ion (Ca^{2+}) and CEC was observed to be within the permissible limits of planting onion and tomato plants. The result justified that the soil at the experimental site is suitable for the growth of tomato and onion in northern Nigeria. Table 1 and Table 2 present the physical and chemical properties of the sampled soils obtained from the experimental sites.

Irrigation Scheduling

The irrigation water requirement for the study location was determined as 8.46

Table 1. Physical properties of soil in the experimental plot.

Depth (cm)	Moisture Content (%)	Bulk Density (g/cm^3)	Textural Class
0 - 15	20.7	1.29	Silt Loam
15 - 30	21.9	1.29	Clay Loam
30 - 45	22.5	1.46	Clay loam
45 - 60	25.2	1.31	Clay

Table 2. Chemical properties of soil in the experimental plot.

| Parameters	Units
pH in water	5.2
pH in 0.01 m/CaCl$_2$	4.8
% organic carbon	0.92
Available phosphorus (mg/kg)	26.8
% Total nitrogen (NT)	0.0
Na$^+$ (mg/kg)	0.89
K$^+$ (mg/kg)	0.38
Mg^{2+} (mg/kg)	1.40
Ca^{2+}(mg/kg)	4.83
CEC (mg/kg)	8.20

cm while the daily water requirement was 0.07128 hamm/day, net water requirement was calculated as 0.00825 m^3/sec and irrigation interval for the site was calculated as 4 days. These parameters gave the actual irrigation interval and crop water need for the plants under consideration.

The growth of onion plant on the experimental site shows an increase in the growth rate in treatment 1 while treatments 2 and 3 had a slight difference between them. This is similar to the works of Pejic *et al.*, [23] and Metwaylhy [24] which indicates that irrigation on treatment 1 is better than the other two regarding growth rate. Thus, treatment 1 stands a better chance to produce better onion bulbs and leaves the analysis of variance for seasonal ET as obtained in the F calculated value as 11.28 for all the treatment and 12.60 for the blocking effect. The values were observed to be higher than the calculated value at 5% (2.57) and 1% (4.03) level of significant difference in crop yield. This difference shows that the higher the seasonal evaporation, the higher the crop water requirement for the plants. Similar conditions were observed for the growth rate of tomato. This observed condition is similar to the works of Ismail and Ozawa [25] and Enciso *et al.* [26] (Figure 2).

The growth stages of onion with ET 243 mm in R_1 treatment 1 had the best growth of 85.4 mm when compared with other treatments as observed in Figure 3. This is closely followed by R_3 treatment 2 with the growth of 80 mm at the ET of 232.3 mm, while the least growth was recorded as 71.2 mm in R_4 treatment
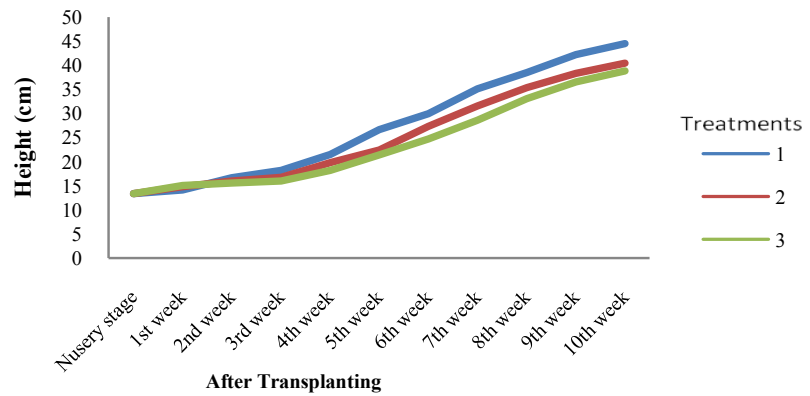
**Figure 2.** Growth of onion plant concerning irrigation.
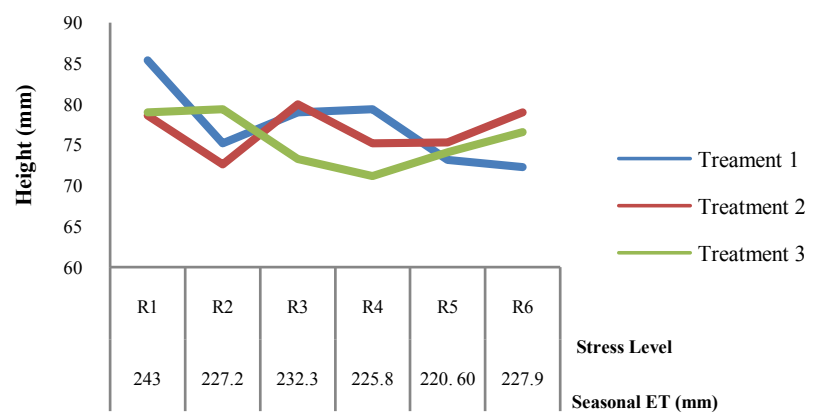
Figure 3. Growth stage and seasonal evapotranspiration (ET) as measured from the experimental plot (mm) for onion.

three which shows that deficit irrigation has a significant effect on the growth of plants.

The highest total yield of onion was recorded at R_3 at 13.4 kg followed by R_1 at 12.7 kg, and the least is R_5 at 11.5 kg as observed in **Figure 4**. The individuals yield base on treatments have the best yield R_3 treatment 1 with 5.6 kg closely followed by R_6 treatment one which is the control with 5.5 kg, and the least yield was recorded at R_5 treatment 3 with the value 2.8 kg. This is similar to the works of Shalini [27].

Considering the whole yield based on the seasonal evapotranspiration ET, treatment 1 gave the best yield of 31.5 kg followed by 25.0 kg in treatment 2 and 18.3 kg in treatment 3 with the ET of 464.5 mm, 458.7 mm and 453.6 mm respectively. This determined value shows that drought stress and scarce water resources are the most significant limiting factors affecting agricultural production. Therefore a need to rank the treatment using LSD of 1.65 value for T_1, T_2, and T_3. Treatment T_1 was found to be significant than treatment T_2 and is highly substantial than Treatment T_3. This result has shown that under critical condition, irrigation can be carried out at an interval of 10 days since the difference is 5.5 kg. The obtained yield result is in accordance with the works of Serhat and
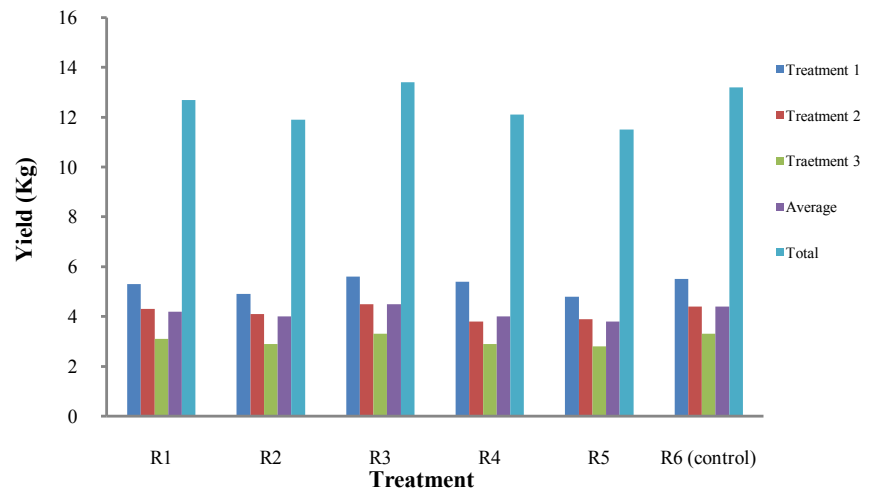
Figure 4. Onion yield (Kg) obtained from the experimental plot.

Cigdem [28]. In their study, they recorded that deficit irrigation effect on onion yielded 51 t/ha, 39 t/ha and 31 t/ha for treatments T_1, T_2 and T_3 respectively with ET of 372 mm, 292 mm and 224 mm respectively (Figure 5).

The growth stages of tomato from the experimental plot have 87.20 mm as the highest ET value for Y_0 of R_1 which is the control. This value is closely followed by Y_3 of R_1 a recorded value of 80.00 mm. Almost all the growth stages fell within the range of the averages of between 81.56 - 66.42 mm except for values from Y_3 for R_3, R_4 and R_5 that are below the range of the averages (Table 3). Table 3 further shows that the tomato plants for Y_0 had the best growth. This growth experienced may be due to the adequate supply of water to the treatment which served as the control plot. The ANOVA statistical analysis shows that F calculated the value of 15.56 for the treatments and 6.93 for the replication were observed to be more than the table values at 5% (3.49 and 3.26) and at 1% (5.96 and 5.41) respectively. The level of significance was different for the crop yield which shows that the higher the seasonal evapotranspiration, the more the crop required water.

It was observed that the best yield was at Y_0 which could be linked to the adequate water supply to the plot which as the control. This yield from Y_0 was closely followed by yields from Y_1, Y_2 and Y_3 respectively. This low yield fell below the total average of yields which is recorded at 5.44 kg/plot as presented in Table 4. Considering the yield in t/ha the results recorded are as follows Y_0 (4.32 × 10^{-6}), Y_1 (2.66 × 10^{-6}), Y_2 (1.35 × 10^{-6}) and Y_3 (3.72 × 10^{-7}). From the results of the yield, it was observed that the control Y_0 had the best yield in t/ha so far while treatment Y_3 has the lowest yield in t/ha as recorded in Table 4. This is similar to the works of Boamah *et al.* [29].

ANOVA result shows that the f calculated value of 458.21 for the treatment was higher than the table value at 5% (3.49) and 1% (5.96) level of significant differences in crop yield as it is non-substantial. The F calculated value of 1.58 for the replication was less than table value at 5% (3.26), and 1% (5.41) level of

Table 3. Growth stages and seasonal evapotranspiration as measured from the experimental plot (mm).

Treatment	R_1 (mm)	R_2 (mm)	R_3 (mm)	R_4 (mm)	R_5 (mm)	Total (mm)	Average mm/plot
Y_0	87.2	85.4	79.6	79	76.6	407.8	81.56
Y_1	79.4	79.4	74.1	73.2	72.3	378.4	75.68
Y_2	75.2	73.3	73.3	72.3	71.2	365.3	73.06
Y_3	80	72.6	62.2	60	57.3	332.1	66.42
Total	321.8	310.7	289.2	284.5	277.4	1483.6	283.72

Table 4. Yield obtained from the experimental plot.

| Treatment	R_1	R_2	R_3	R_4	R_5	Total (Kg)	Average (kg/plot)
Y_0	10.20	10.60	11.30	11.01	10.90	54.01	10.80
Y_1	6.20	6.05	6.35	7.28	7.30	33.18	6.64
Y_2	3.20	2.90	3.50	3.20	4.10	16.90	3.38
Y_3	1.30	1.15	0.40	0.60	1.20	4.65	0.93
Total	20.90	20.70	21.55	22.09	23.50	108.74	21.75
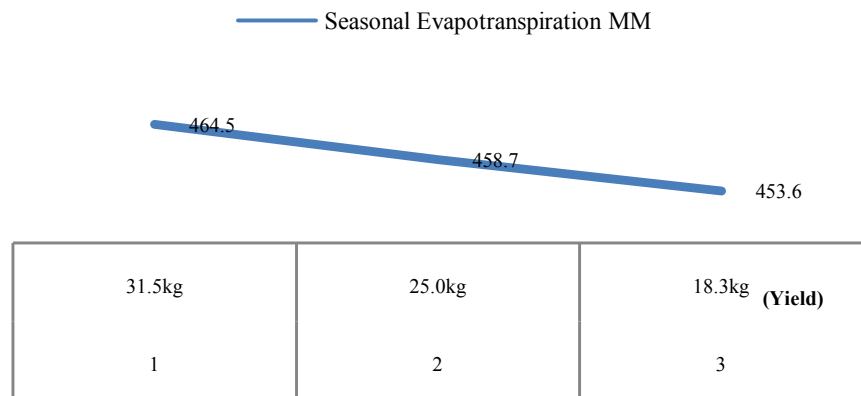
Figure 5. Stress effect on onion yield and seasonal evapotranspiration ET.

significant differences for crop yield. Therefore, there is the need to rank the means treatment using LSD at 5% and 1% of 27.98 and 42.04 respectively. Y_1, Y_2 and Y_3 were found to be highly significant where Y_1, Y_2 and Y_3 are stress for 3 days, 5 days and 7 days more than 7 days regular interval respectively.

The relationship of yield and water use of tomato established in **Figure 6** shows that as the water use increases the yield of tomato also increases. This increase in yield implies that water deficit causes the defect to crops and affects the quality and quantity of the crop to be produced. This is similar to the works of Blum [30] [31] and Hatirli *et al.* [32].

The yield of tomato from the Y_0 site has the highest yield of 54.01 kg on the plot where seven days irrigation interval was applied, as the irrigation interval
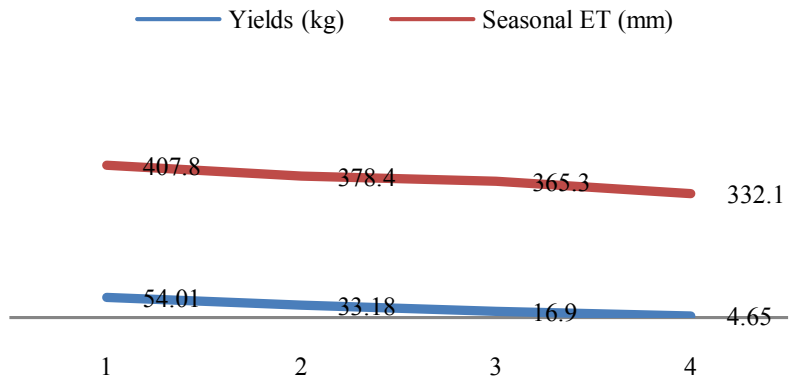
Figure 6. Showing yield – water use relationship.

increases the yield decreases as observed in **Figure 6**. This yield is closely followed by 33.18 kg and 16.9 kg for Y_1 and Y_2 respectively. This is in agreement with the study of Sladana *et al.* [33] where they obtain 44.05 g, 36.08 g and 36.03 g for Y_1, Y_2 and Y_3 at plant water use of 29.56 mm, 21.19 mm and 21.13 respectively.

4. Conclusions

In this study, irrigation treatments significantly affected yield, height, diameter and weight of onion bulbs and tomato fruits. There was a significant difference in the yield from the result obtained, at the three growth stages of both onion and tomato when it was stressed with an additional day from the regular interval of 7 days.

The maximum yield was both obtained from treatment 1 (control) which proved that no stress was observed during the growth stage. For onion T_2 which was stressed for an additional three days (10 days) shows little importance and T_3 which was noted for an additional seven days (14 days) shows more stress while for tomato T_2 and T_3 which were stressed for another three days and 5 days interval shows little importance based on the yield obtained. Finally, the yield water use relationship shows that the yield of onion and tomato crop increases with an increase in the rate of seasonal evapotranspiration.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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