Growth, yield and water use of sweet pepper (*Capsicum Annuum*) in a greenhouse under drip irrigation

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Abstract: Optimum water need of sweet pepper and the critical irrigation level to be applied in order to achieve a reasonable economic yield was determined. Greenhouse (controlled) was conducted with sweet pepper subjected to three (3) varying water applications; 100% full irrigation treatment (FIT), 70% FIT and 50% FIT. Crop water use (evapotranspiration) was determined using the water balance method. For the agronomic parameters measurement, weekly measurements of plant height, stem diameter, number of leaves and canopy temperature were measured. The sweet pepper were determined in batches during harvest. Result showed that the growth parameters significantly ($p < 0.05$) increased with increase in water application. The highest value of 707.78 g was recorded at irrigation treatment that received 70% of FIT while the least value was recorded in treatment that received the least amount with a value of 665.2 at 50% FIT. Overall, similar yield ($p > 0.05$) was observed in the yield quantification. This showed that about 50% of irrigation can be saved to irrigate additional plant. Highest values of irrigation for the irrigation and crop water efficiencies were obtained at the deficit irrigation.

Keywords: greenhouse; sweet pepper; water productivity; crop evapotranspiration; irrigation

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1 Introduction

Sweet pepper (*Capsicum Annuum*) belongs to the family Solanaceae, which is an important group of vegetables grown extensively and also widely cultivated in almost every country of the world. Peppers (*Capsicum Annuum L.*) are widely grown as a spices and vegetables. Peppers are classified as the second most important vegetables in the world in *solanaceae* group after tomato (Hasanuzzaman and Golam, 2011; Adeoye et al., 2014). The average of pepper productivity in the world is 17.76 ton ha^{-1} in 2013 (FAO, 2013), while productivity potency that can be achieved is about 18-24.2 ton ha^{-1} (Rubatzky and Yamaguchi, 1997). It thrives best in warm climate, where frost is not a problem during the growing seasons. In general, it requires temperatures ranging from 25 ℃-35 ℃. The sweet pepper of commerce also known as Bell pepper is one of the most varied and widely used foods in the world; it originated in Mexico and Central America regions and Christopher Columbus encountered it in 1493. It is one of the most important vegetable grown in other parts of sub-humid and semi-arid tropics (Abd-

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Alrahman and Aboud, 2021). Despite its wide acceptability and use worldwide, its production has been majorly limited to field cultivation, and in order to increase its production to meet the demand of the increasing population, its production under a controlled environment like green house could be an option.

Greenhouse is a controllable dynamic system, managed for intensive production of high quality, fresh market produce. Greenhouse production allows for crop production under very diverse conditions. However, there are a number of variables that greenhouse growers have to manage in order to obtain maximum sustainable production from their crops. Greenhouse enables farmer to make best use of the sunlight and even the smallest unheated structure which allow extended growing seasons and production of quality techniques crops with high productivity with full exploitation of genetic potential (Awuku and Egyir, 2018). Among the various protected structures, polyhouse production had been proven as more profitable protected technique for *Capsicum* cultivation (Aruna and Sudagar, 2010). Polyhouse/greenhouse production of *Capsicum* emphasizes appropriate planting densities to boost-up the total production per unit area by utilizing the space available and nutrient applied. The *Capsicum Annuum* is commonly known as sweet pepper, bell pepper or green pepper. They are differed from common hot peppers in size and shape of the fruits, capsaicin content and usage. Despite its economic importance, growers are not in a position to produce good quality *Capsicum* with high productivity due to various biotic (pest and diseases), abiotic (rainfall, temperature, relative humidity and light intensity) and crop factors (flower and fruit drop). Due to erratic behavior of weather, the crops grown in open field are often exposed to moisture stress, fluctuating levels of temperature, humidity, wind flow, *etc*. which adversely affect the crop productivity. Besides this, limited availability of land for cultivation also hampers the production potential. Hence, to obtain a good quality produce and production during off-season, there is a need to cultivate *Capsicum* under protected conditions or controlled environment.

Sweet pepper (*Capsicum*) can be successfully grown under open field conditions and in protected structures, i.e., net house, polyhouse, walk-in-tunnels, plastic low tunnels, etc. (Singh et al., 2004), but its cultivation under open condition is not successful which might be due to poor adoptability under fluctuating atmosphere and produced poor quality food under erratic biotic and abiotic factors (Awuku and Egyir, 2018). The cultivation of *Capsicum* under different protected structures like polyhouse, net house, walk-in-tunnels, plastic low tunnels are the most suitable solutions to the challenging environmental factors as it prevents spreading of insect, pest, and viral diseases. Demand for off season high value crop is also increasing year after year and hence, green house cultivation could therefore be promoted to meet the requirement of cities to a large extent at responsible prices. As there is a tremendous demand in the international market, promotion of greenhouse cultivation helps in reducing the trade of deficits (Adeoye et al., 2014), while the amount of water needed for its cultivation must be optimized.

Accurate estimation of irrigation water requirement is important for the cultivation of sweet pepper. It is critical to schedule irrigation by determining how much water to apply and when to apply water in order to judiciously use and save water, which are generally scarce during dry season in Nigeria and in some other part of the world (Ichwan et al., 2022). Therefore, it is necessary to determine growth, yield, water use and water productivity of sweet pepper under greenhouse from several treatments of irrigation (Ishfaq et al., 2020). Some researchers (Ichwan et al., 2022; Akindele et al., 2021) have evaluated the effect of deficit irrigation on the yield and water use of sweet pepper in a field experiment. But studies that investigated the differential effect of irrigation on the yield and water productivity of sweet pepper are scarce. Drip irrigation was used in the study due to its ability to improve nutrient and water use efficiency (Faloye et al., 2019). Therefore, the objectives of this study are to; (i) determine the effect of varying water applications on growth, water use and yield of sweet pepper (*Capsicum annum*) under greenhouse and ambient conditions; and (ii) evaluate the irrigation and crop water use efficiency of sweet pepper (*capsicum annum*) under greenhouse.

2 Materials and methods

2.1 Experimental sites

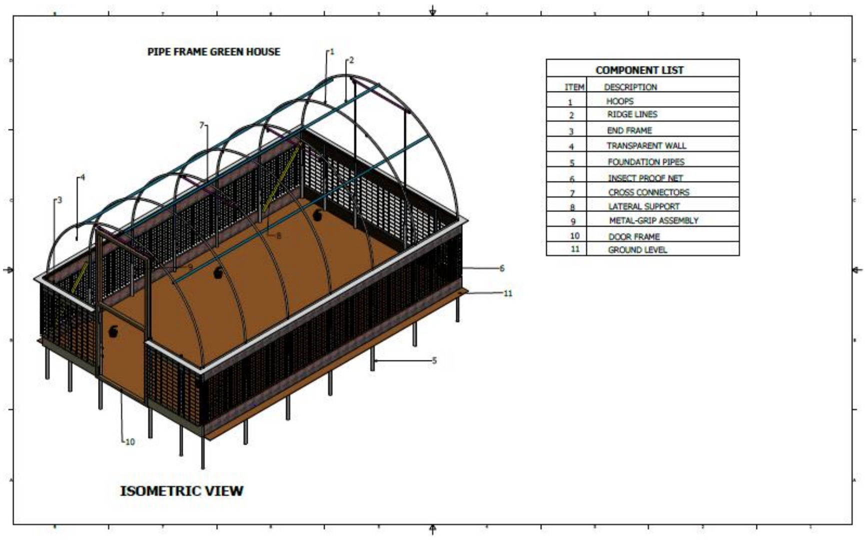
The experiment was conducted in a greenhouse and open field in Teaching and Research Farm of the Department of Agricultural and Environmental Engineering, Federal University of Technology, Research farm Akure, Ondo State between September, 2021 and December, 2021. The location lies on the latitude of 7° 14'N and longitude of 5° 08'E in the humid region of Nigeria and lies in the rain forest zone with a mean annual rainfall between 1300 - 1600 mm and an average temperature of 27°C. The relative humidity ranges between 85% and 100% during the rainy season and less than 60% during the dry season period (Omotade et al., 2019).

2.2 Description of the designed and constructed green house

Green house was designed and constructed to achieve the set objectives of the work. It was made of 15 m long, 6 m wide and 2.4 m high with an east-west orientation, the frame of the green house was made up of the galvanized hollow pipe of 20 mm diameter and 2 mm thickness. In order to control excessive interior temperature and improve the ventilation of the greenhouse in the night and during the day, the base of the greenhouse was covered with net up to the height of about 1.2 m from the ground level, while every other part of the green house was covered with transparent polyethylene bag. The Figures 1 and 2 show the isometric and orthographic view for the conceptual drawing of the greenhouse respectively. The finished structure of the greenhouse and it inner structure is provided in Figures 3 and 4 below.

2.3 Experimental procedure

A 20 × 20 m portion of the experimental farm site of the Department of Agricultural and Environmental Engineering was cleared and stumps were removed. Seed beds (5 m × 5 m) were made in two portions of the cleared land. Sweet pepper seeds were broadcasted uniformly on the prepared seed beds. The seed beds were covered with palm fronds to ensure the necessary temperature condition is attained as well as conserving the moisture within the soil (Murthy et al., 2009). The emerging crop was allowed for a period of two weeks in the nursery before transplanting the viable ones into the cello phone materials which was transferred into the greenhouse for the monitoring of the growth and yield parameters.



COMPONENT LIST	
ITEM	DESCRIPTION
1	HOOPS
2	RIDGE LINES
3	END FRAME
4	TRANSPARENT WALL
5	FOUNDATION PIPES
6	INSECT PROOF NET
7	CROSS CONNECTORS
8	LATERAL SUPPORT
9	METAL-GRIP ASSEMBLY
10	DOOR FRAME
11	GROUND LEVEL

Figure 1 Isometric view for the conceptual design of the green house

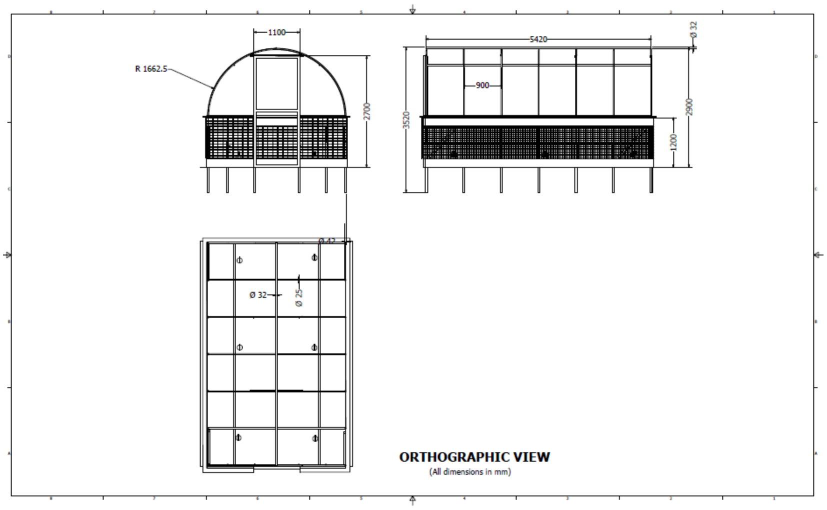


Figure 2 2 Orthographic view for the conceptual design of the green house

Figure 3 Construction of the green house

Figure 4 Inner view of the green houseThe pepper seeds

were spread uniformly over the well prepared beds of nursery and soon after sowing the beds were covered with palm fonts and irrigated with ground water (GW) regularly. The fonts were removed after sowing, when seeds started emerging. Two weeks old seedlings, three in each pot were transplanted in pots containing obtained soils from field in the green house. Thereafter thinning was done retaining only two healthy plants in each pot. The plants were irrigated in the greenhouse using the drip irrigation system which is part of the environ dome greenhouse setup. The inter and intra spacing of the sweet pepper in the greenhouse was 25 cm by 25 cm. The bulk density of soil was determined by collection of soil samples using concentric cylinders of height 10 cm and diameter 5.0 cm. Soil samples were collected from the sack that were already packed with soil after allowing the soil in the sack to settle completely (grain settlement). The cylinders were driven into the soil such that the cylinders are completely filled with soil at both ends of the open cylinder. The samples were covered at one end of the cylinder so as to disallow fall off of soil. The weight of the cylinder with soil was noted and the height and area of the cylinders were measured. The bulk density of the soil was estimated by the ration of the mass of soil to the volume of soil as shown in Equation 1 below (Blake and Hartage, 1986)

$$Bulk\ density\ (\mathrm{g\ cm^{-3}}) = \frac{Mass}{Volume} \quad (1)$$

For the purpose of field capacity estimation, soil in sample sacks were allowed to drain off excess water completely after irrigation. The loose wet soil were then sampled using concentric cylinder for the determination of moisture content of soil at field capacity using the relationship below (Equation 2)

$$FC\ (\mathrm{g\ g^{-1}}) = \frac{Ww{-}Wd}{Ww} \quad (2)$$

Where FC is field capacity (g g^{-1}), Ww is weight of wet soil (g), and Wd is weight of dry soil (g)

The moist soil was transferred to the oven to dry at about 105ºC for 24 hours. The weight of oven dried soil samples were measured while the moisture content at field capacity was estimated from the relationship in Equation 2.

The measured soil moisture content was in percentage and the values were multiplied with the bulk density and soil depth using the relationship in Equation 3.

$$FC\ (mm) = FC\ (\%) \times Bulk\ density\ (g\ cm^{-3}) \times Depth\ of\ soil\ (mm) \quad (3)$$

Weekly measurement of agronomic data were carried out by sampling five (5) sweet pepper plant for the measurements of stem girth, number of leaves, plant height and canopy temperature using infrared thermometer. Harvest of sweet pepper were done in batches and the cumulative of the weight of harvested fruits were calculated under different water applications and their replicates in the greenhouse (control environment).

2.4 Experimental design

The experiment was carried out using a randomized complete block design in the green house. The treatment consisted of water application at three level; 100% FIT (full irrigation treatment), 70% FIT and 50% FIT. At 100% FIT, 70% FIT and 50% FIT, the 100%, 70% and 50% of water required to bring the soil water to field capacity was applied. Also, the sweet pepper was planted under the ambient condition outside of the greenhouse. The irrigation water supply was carried out using drip irrigation control.

2.5 Crop evapotranspiration estimation

For the accurate estimation of the pepper crop evapotranspiration, soil moisture content was monitored on weekly basis using soil profile probe. The irrigation water application to each of the treatment was recorded and changes in soil moisture was monitored for the estimation of crop evapotranspiration. The crop evapotranspiration was determined using the water balance equation (Hillel, 1998). The water balance equation is as follows (Equations 4- 6)

Input = Output

$$P + I = R \pm D \pm \Delta S + ET \quad (4)$$

$$ET = P + I - R \pm D \pm \Delta S \quad (5)$$

ET is the crop evapotranspiration (mm), P is the precipitation (mm), I is the irrigation (mm), R is the runoff (mm), D is the drainage (mm), ΔS is the change in soil moisture stage (mm).

However, precipitation, runoff and drainage within the greenhouse are zero in value. This is because the ET measurement was carried out within the green house, as such there is no record of rainfall, while drainage and runoff were zero since the actual amount of water needed was applied using the drip irrigation system. Therefore,

$$ET = I \pm \Delta S \quad (6)$$

2.6 Irrigation and crop water use efficiency of sweet pepper

Effects of differential application of water on the yield under drip irrigation were evaluated using irrigation and crop water use efficiency. The irrigation water uses efficiency (*IWUE*) and cop water use efficiency (*CWUE*) (g mm^{-1}) were determined using (Equations 7 and 8) (Howell et al., 2006; Faloye et al., 2019).

$$IWUE = \frac{Fruit\ \ yield\,(g)}{TWS\,(mm)} \quad (7)$$

Where *IWUE* has been previously defined and and *TWS* is the total amount of water that was used as input from drip irrigation. Also, the crop water use efficiency (*CWUE*) was determined as the ratio of crop yield to the crop evapotranspiration (ET_c). The Crop water use efficiency (*CWUE*) was computed as the ratio of pepper fruit yield to total ET_c as illustrated in Equation 8:

$$CWUE = \frac{Sweet\ pepper\ \ yield\,(g)}{ET_c\ (mm)} \quad (8)$$

2.7 Data analysis

The data recorded from the experiment were subjected to one-way analysis of variance (ANOVA) using the Minitab 18 software package and the statistical mean comparison were obtained using post hoc test (Duncan multiple range test). F test statistics was applied to assess the significance of the difference at 5% level of probability (p = 0.05) for the growth, yield, water and radiation use efficiencies.

3 Results and discussion

3.1 Soil physical and chemical properties of soil used in the greenhouse obtained from an experimental site

The result of the soil properties used for the greenhouse experiment before the commencement of the experiment is illustrated in Table 1 below. The soil is classified as silty clay loam texture (USDA method) in the top soil which forms mainly the agricultural layer required for the cultivation of most shallow rooted crops like sweet pepper. The soil contains predominantly fine soil. This type of soil always prevent frequent application of water, as a result of this, the crop to be cultivated on this soil wouldn't require regular irrigation (Faloye et al., 2019). The average organic carbon content of 1.39% was observed within the top soil before planting. The top soil average carbon content was higher than the range of 0.6%-1.2% reported by Fasinmirin et al. (2009) as desirable for tropical crop production. The organic matter content recorded before planting was 2.38%. The higher values of the mean organic matter and organic carbon content could be attributed to leaf litter from shed leaves, flowers and root residues decay in-situ. This observation on the higher values of organic carbon and matters are in agreement with the report of Quinn and Keough (2002). The soil had a low level of soil organic carbon, (less than 2.0%). This low value is typical of soils in the humid tropics regions (Jien and Wang, 2013). Also, the values of available phosphorus, cation exchange capacity (CEC) were very low. The mean value of the pH of the soil before planting was strongly acidic.

Table 1 Initial physico-chemical characterization of soil used for the greenhouse experiment before planting

Soil properties	Value
Silt (%)	64.25
Clay (%)	23.1
Sand (%)	13.2
pH	4.29
Organic carbon (%)	1.39
Organic matter (%)	2.38
Total Nitrogen (cmol kg^{-1})	0.35
Phosphorus (P) (cmol kg^{-1})	7.57
Potassium (cmol kg^{-1})	1.03
Sodium (cmol kg^{-1})	0.75
Calcium (cmol kg^{-1})	3.43
Magnessium (cmol kg^{-1})	1.2
Cation exchangeable capacity (CEC)	18.13

3.2 Meteorological data of the study area

3.2.1 Rainfall

Figure 5 showed the daily total rainfall during the period of the experiment (September – December, 2021). Heavy rainfall was observed during the early period of the experiment. The rainfall trend for the experiment period howed a gradual rise from the early period of the experiment, with highest values recorded in the months of September and October, respectively. The rainfall started receding in the month of November, and very scanty. The total amount of rainfall recorded during the experiment was 468.94 mm.

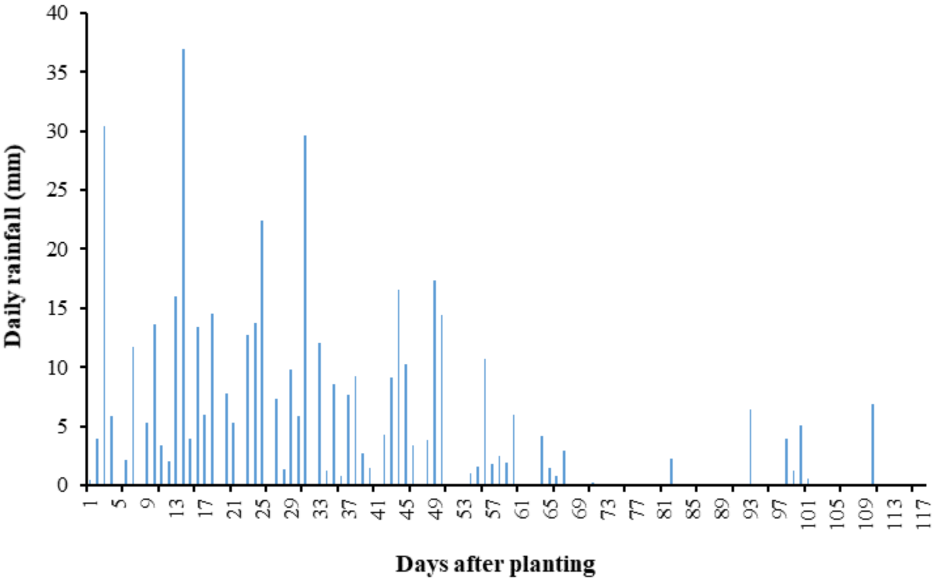


Figure 5 Daily rainfall during the experiment

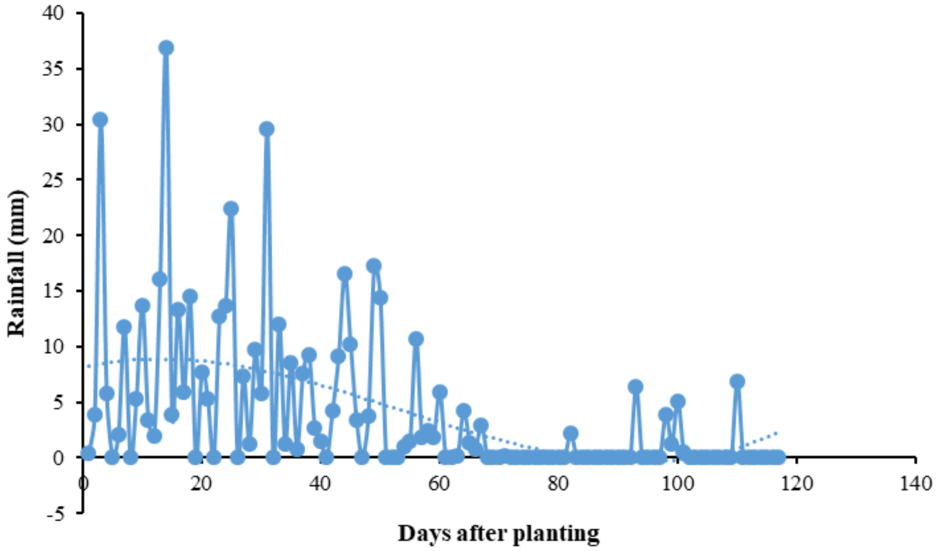


Figure 6 Rainfall trend during the experiment

The daily total rainfall during the period of the experiment (Figure 6) revealed that there was variations in the amount of the daily rainfall. Day 3 after planting of sweet pepper had the greatest amount of rainfall, with a total of 30 mm of rainfall.

3.2.2 Relative humidity (RH) and air temperature

The daily distribution and trend of relative humidity during the growing season of the experiment is illustrated in Figure 7. There was a gradual decline in the mean monthly RH from the month of September to December reaching its minimum value in December. The lowest and highest daily relative humidity observed during the period of experiment were 69.12% and 94.06%, during the months of October and December, respectively. The daily temperature trends for the period of experiment experimental period are presented in Figures 4.4 The highest and lowest daily mean air temperature during the experiment were 26.29 ℃ and 22.53 ℃, respectively. The actual daily mean air temperature observed during the experiment rose gradually from the month of September till November before it started declining up again in the month of December. The recorded mean air temperature trend (Figure 8) showed that air temperature was low at the beginning of the experiment due to higher values of rainfall recorded during this period. The mean air temperature decreased again during the period rainfall increased.

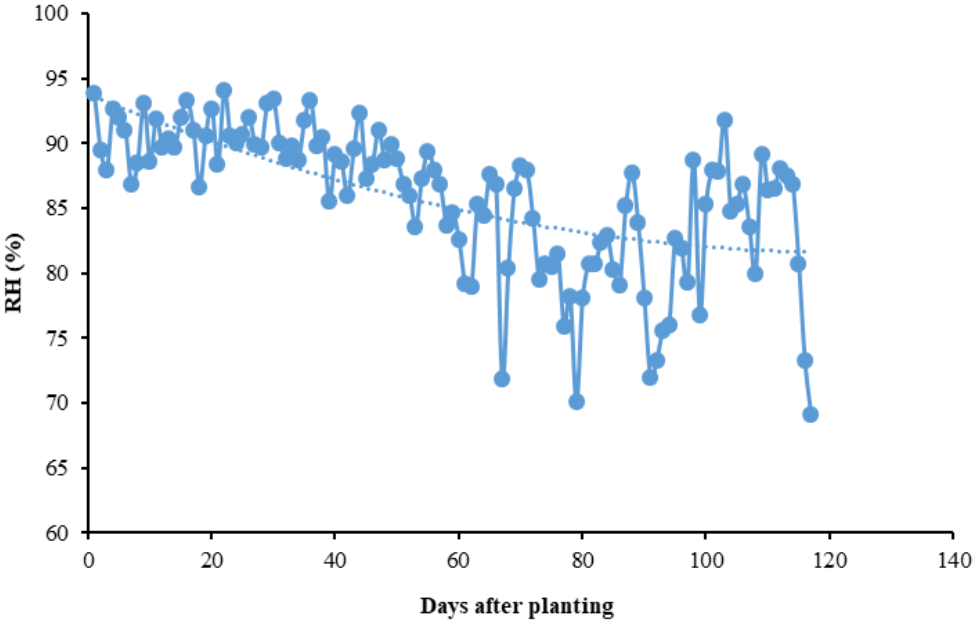


Figure 7 Mean relative humidity trend during the experiment

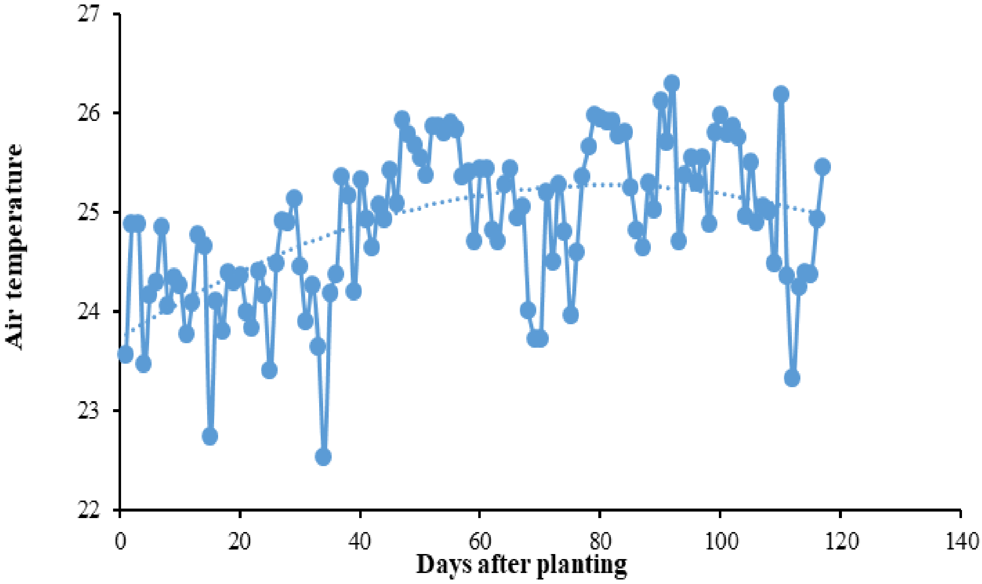


Figure 8 Mean air temperature trend during the experiment

3.3 Change in soil water storage as observed in greenhouse cultivated with sweet pepper

The change soil moisture content for the varying water regime treatments (50%, 70% and 100% FIT) from 0 – 117 days after planting (DAP) up to a depth of 0.3 m (effective root depth) are shown in Figure 9 The dynamic change in stored moisture content show the relationship between the variations of soil moisture content stored under the drip irrigation as a function of Julian day in each irrigation treatment. There was a general rise in change in soil moisture content with respect to Julian days. The highest change in soil water storage was observed at 100% FIT while the lowest values were mostly recorded at the 60% FIT.

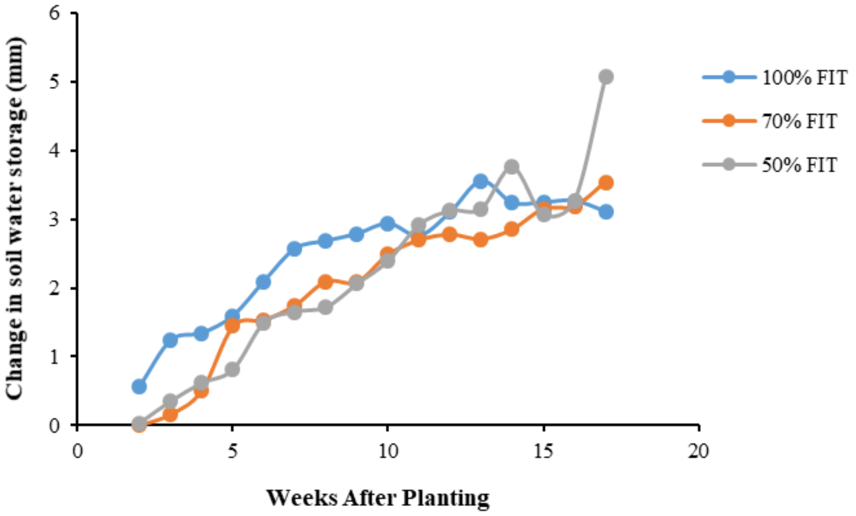


Figure 9 Change in soil water content as affected by varying application of water in greenhouse

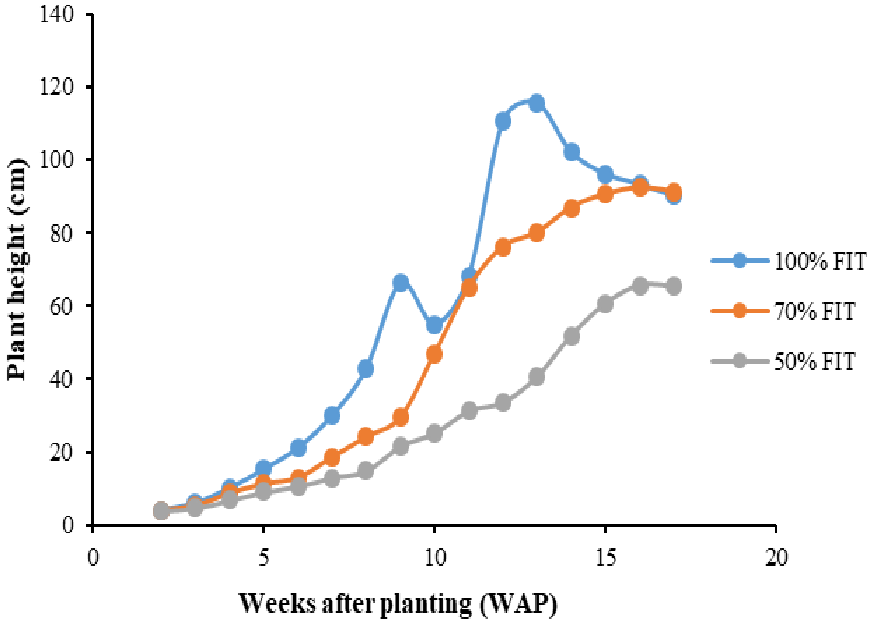


Figure 10 Dynamic change in plant height as a function of weeks after planting under different water applications

3.4 Agronomic responses of sweet pepper under varying irrigation regimes

3.4.1 Responses with respect to plant height

The mean plant height measurement taken from all the irrigation treatment and their respective replicates, up to 117 DAP are shown in Figure 10. The Figure showed the relationship between sweet pepper height with time after sowing (days) in all the irrigation treatments. It was observed that there was rapid increase in the height of the crop during the vegetative and development stages of the crop growth and until it got to the flowering stage, when the rate of growth was relatively slow. From the period of flower initiation, there was no remarkable differences in the height of the crop at this period. This is in agreement with the report of Allen et al. (1998) who stated that at mid-season, crops generally reach its peak, and experience decline thereafter. The highest value of plant height was recorded at 100% FIT, while the lowest value was recorded at 50% FIT. The average plant height were 28.64, 46.50 and 58.0 cm at irrigation treatments of 50%, 70% and 100% FIT, respectively. Result from the Analysis of variance (ANOVA) showed that the plant height was significantly ($p < 0.05$) (Figure 11) impacted by the differential irrigation amounts the sweet pepper were subjected to.

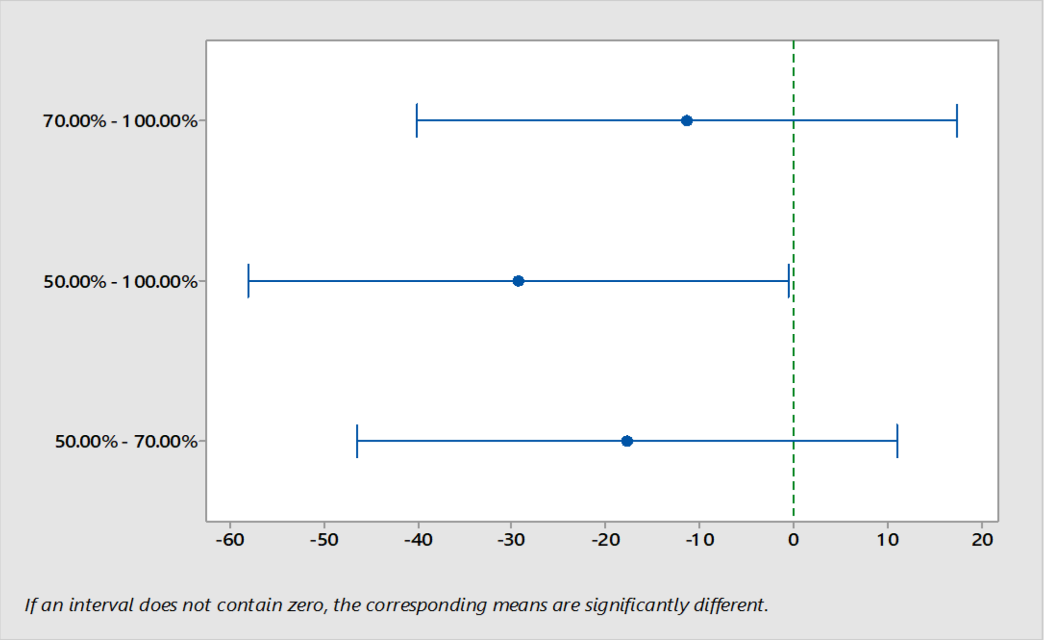


Figure 11 Graphical illustration of analysis of variance for plant height (cm)

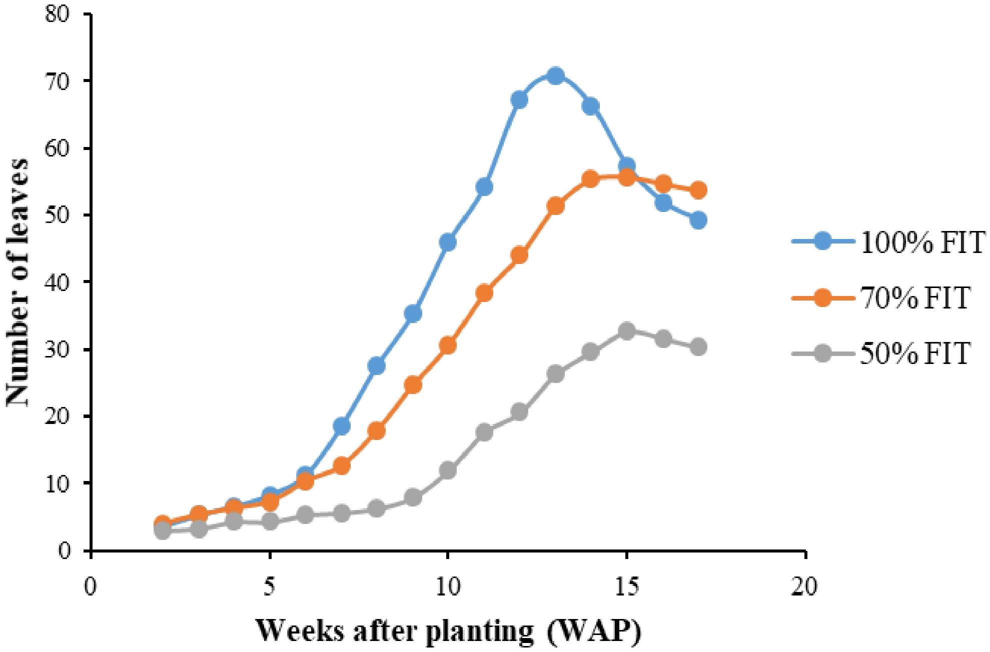


Figure 12 Dynamic change in number of leaves as a function of weeks after planting under different water applications

3.4.2 Responses with respect to number of leaves

The graphical illustration of the relationship between mean number of leaves and weeks after planting are shown in Figure 12 for all the irrigation treatments up to 117 DAP. Figure 12 show the changes in the number of leaves with time (WAP). From the graph of mean number of leaves against time after sowing in weeks, it is clearly seen that, the control treatment, which received adequate water supply to meet evaporative demand has the highest number of leaves than the deficit irrigation treatment plots (50% and 70% FIT). It was observed that there was rapid increase in number of leaves during the crop vegetative stage. Beyond this period of growth (mid-season and late season), there was no remarkable differences in the number of leaves observed in all the irrigation treatments under drip irrigation system in the greenhouse. The number of leaves were 15.08, 29.52 and 36.27 cm at 50%, 70% and 100% FIT, respectively. Results showed that there was significant difference ($p < 0.05$) in the effect of the irrigation treatments on the growth

(Figure 13).

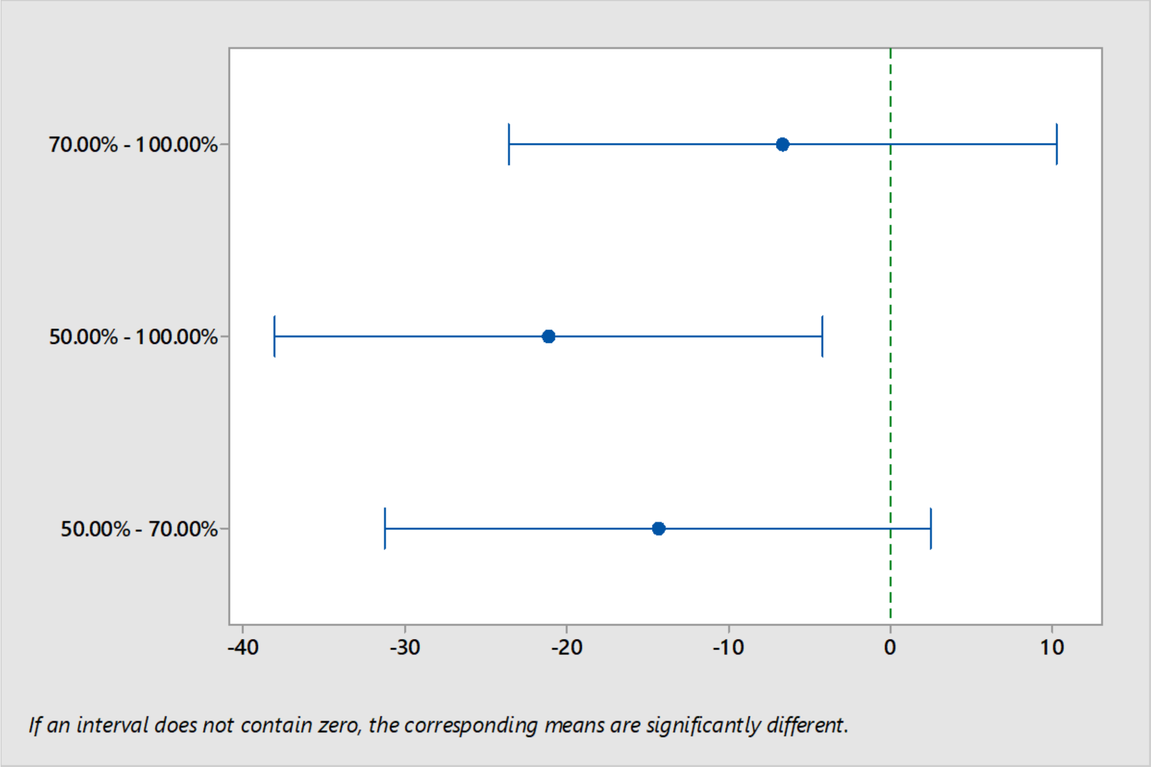


Figure 13 Graphical illustration of analysis of variance for number of leaves

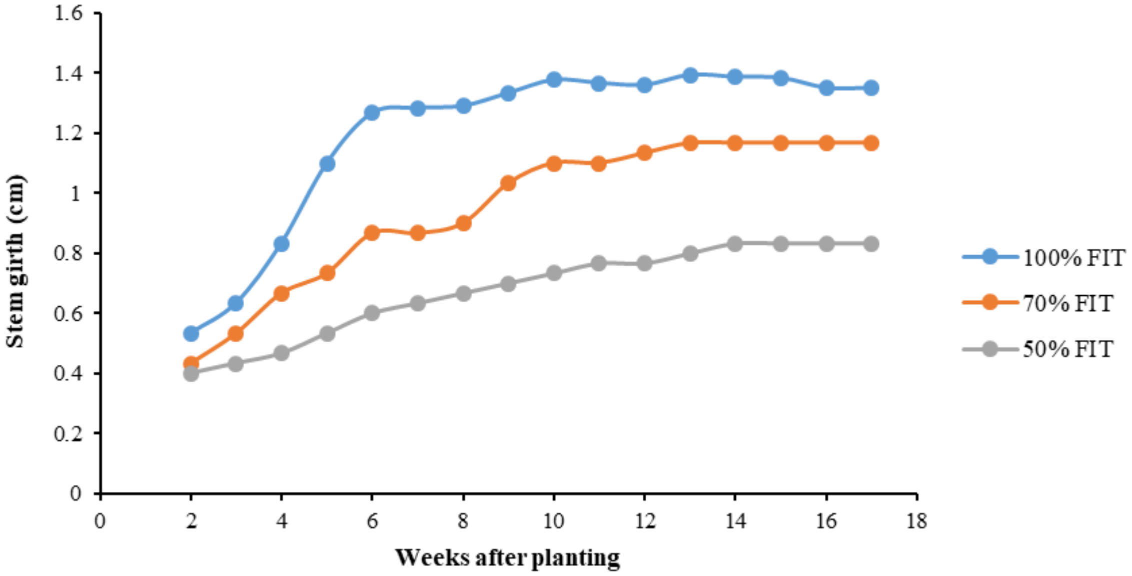


Figure 14 Dynamic change in stem girth as a function of weeks after planting under different water applications

3.4.3 Responses with respect to stem girth

The mean stem girth from all the irrigation treatment up to 117 DAP is shown in Figure 14. The figure showed the graph of the relationship between the mean stem girths and weeks after planting. It was observed that at some few weeks after emergence there was no much noticeable difference in the mean stem girth among all the irrigation treatments. There was a rapid increase in the mean stem girth after the emergence stage to fruiting stage of the crop, which was relatively constant till maturity. The average values of the stem girth were 0.68, 0.95 and 1.20 cm at irrigation treatments of 50%, 70% and 100% FIT, respectively. The result from Analysis of Variance (ANOVA) showed that there was significant difference ($p < 0.05$) among the mean values of the stem girth (Figure 15).

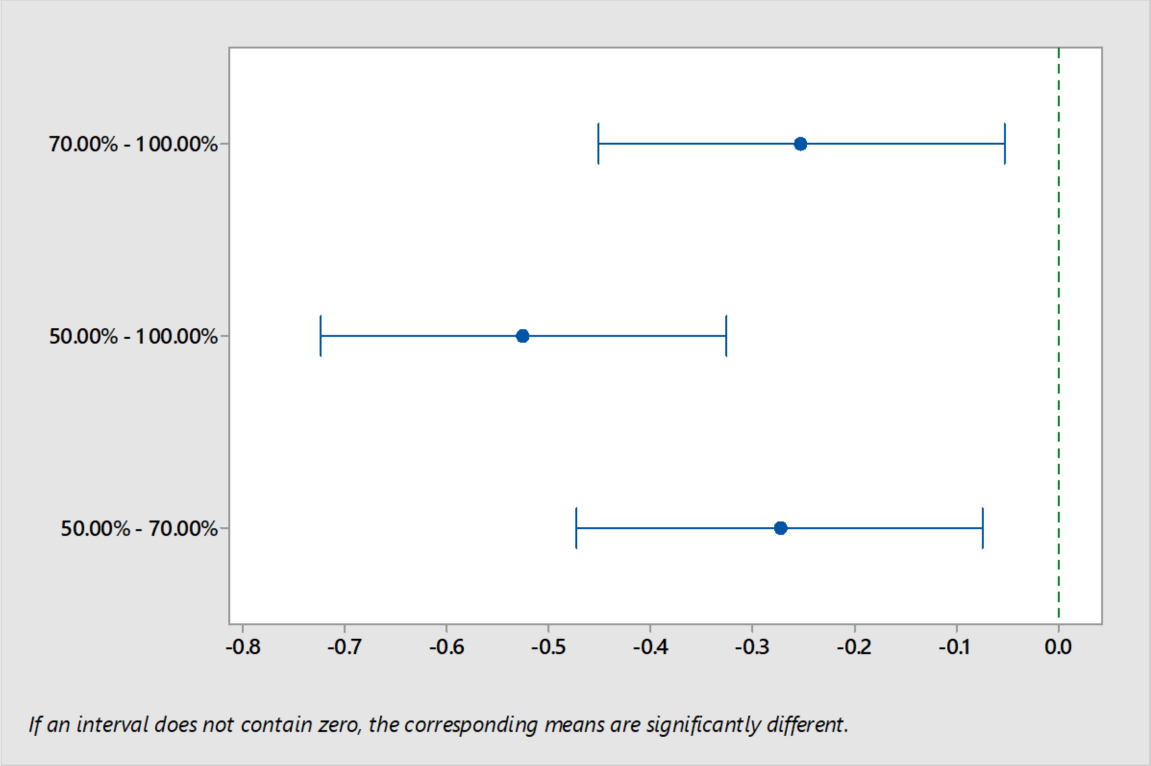


Figure 15 Graphical illustration of analysis of variance for stem girth

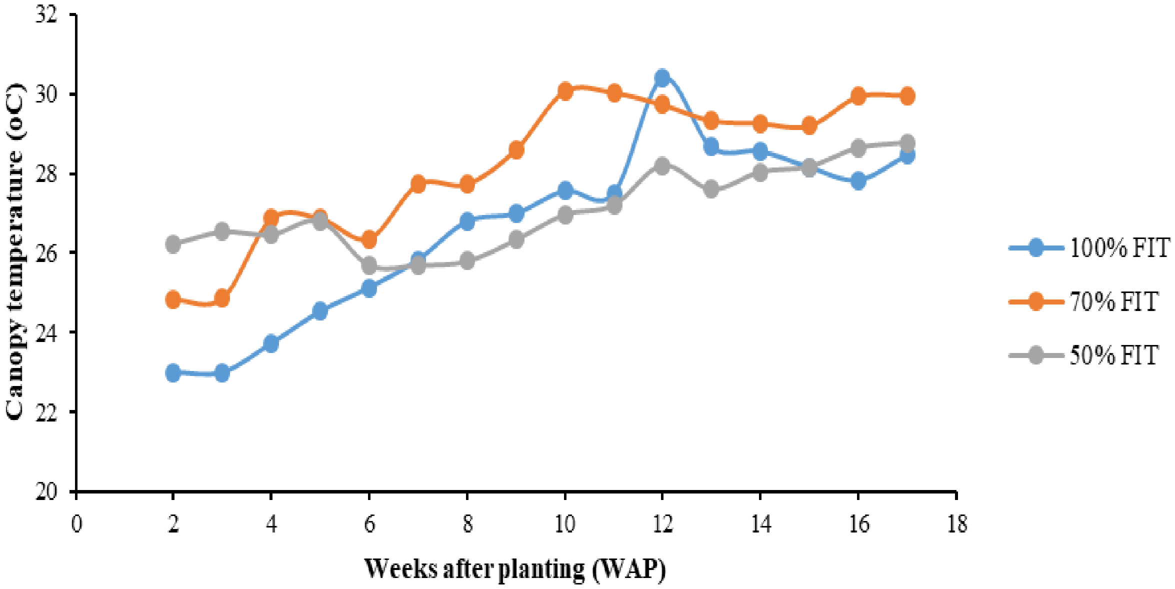


Figure 16 Dynamic change in stem girth as a function of weeks after planting under different water applications

3.4.4 Responses with respect to canopy temperature

The variation of the sweet pepper canopy temperature with respect to weeks after planting is illustrated in Figure 16 below. The highest value of canopy temperature were mostly recorded at the 70% FIT and sometimes at 50% FIT, while the lowest value were mostly recorded at the 100% FIT during the weekly observation. The measurement of the leaf temperature is important since it is one of the indices for quantifying crop water stress in plants. Some researchers (Jones, 2004; Yuan et al., 2006; Wang et al., 2009) have evaluated the canopy temperature for different plants to determine when to irrigate, and this also determine how much (magnitude) the plant has been stressed. This is in agreement with the report of our study with the lowest value of canopy temperature of 26.64°C recorded at 100% FIT, followed by with a value of 27.07°C at 50% FIT and the highest value of 28.21°C recorded at the 70% FIT. The lower the temperature the less stressed the plant, and the higher the leaf canopy (Cremona et al., 2004; Erdem et al., 2010; Yildirim et al., 2012). Overall. The lowest leaf temperature was recorded at the irrigation treatment that received full amount of irrigation water, higher values were mostly recorded at the deficit irrigation. The result of Analysis of Variance (ANOVA) showed that there was a significant difference ($p < 0.05$) in the effect of irrigation on the canopy temperature (Figure 17).

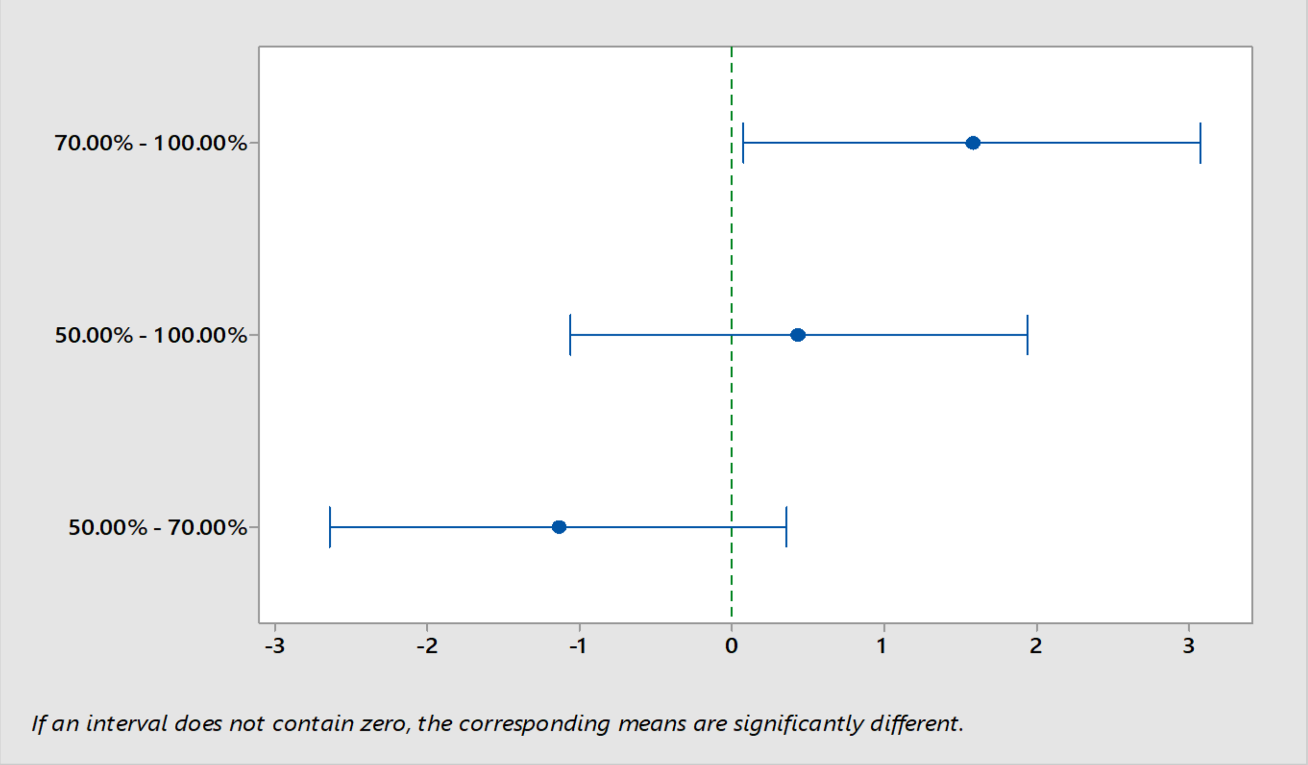


Figure 17 Graphical illustration of analysis of variance for the sweet pepper canopy temperature

Table 2 Irrigation amount, change in water storage and seasonal evapotranspiration of sweet pepper

Treatment	Irrigation amount (mm)	Change in water storage	Seasonal ET (mm)
50% FIT	142.0	16.50	54.5
70% FIT	99.4	16.03	83.37
100% FIT	71.0	40.14	101.86

4.5 Response of irrigation of the crop evapotranspiration

The crop evapotranspiration is the crop water use by plant and combine both the process of evaporation and transpiration (Faloye et al., 2019). Table 2 below showed the crop seasonal evapotranspiration estimated by soil water balance method for various irrigation treatments. It showed the total depth of irrigation water applied during the growing season under the greenhouse using drip irrigation. The total irrigation water applied to the irrigation treatments were 71.0, 99.4 and 142.0 mm of water, supplied/applied in treatments 100%, 70% and 50% FIT, respectively (Table 2).

From Table 2, the crop seasonal evapotranspiration for sweet pepper was highest in the control treatment (100% FIT) with a value of 101.86 mm and were 83.37 and 54.5 mm for the 70% and 50% FIT, respectively. Therefore, the crop seasonal evapotranspiration of sweet pepper estimated under the greenhouse ranged from 54.5 – 101.86 mm. This range of values are much lower than those seasonal ET range of 365 to 528 mm and 207 to 398 mm reported by Sezen et al. (2006) and Smittle et al. (1994), respectively. The lower values of ET measured from the study in the greenhouse could be attributed to alteration of the natural environment, that is, control environment where the sweet pepper was planted, characterized by reduced air temperature and solar radiation, thus resulting in reduced evaporative demand.

4.5.1 Weekly evapotranspiration of sweet pepper as influenced by the different water applications

Figures 18 to 20 showed the variations of mean evapotranspiration estimates under drip irrigation systems in the greenhouse as a function of weeks after planting. Water use of crop was highest (9.95 mm week^{-1}) at irrigation treatment that received 100% FIT at exactly 10 weeks after planting. However, the highest evapotranspiration (8.39 mm week^{-1}) was observed on plot irrigated at 70% FIT on week 11 after planting with highest value of 5.64 mm week^{-1} recorded at 50% FIT on week 10. The coefficient of determination between the crop evapotranspiration and the growth stages of the sweet pepper from emergence to maturity was the highest in the irrigation treatment that received the highest amount of water (0.92). There were variations in the crop water use and this was due largely to the different irrigation treatments adopted for all irrigation treatments. The irrigation treatment that received frequent irrigation have enough water to meet evapotranspiration needs. This observation is in agreement with the report of Fasinmirin et al. (2009) who also discovered that irrigation treatment plot receiving enough water always meet evapotranspiration needs of crops. The graphs showed that the least water use was recorded at the initial stage and keep rising till the mid-season is attained and later experience a downturn after the period of peak demand has been attained. Similar trend of observations are reported for different researchers (Allen et al., 1998; Fasinmirin et al., 2009). The coefficient of correlation showed that the models in Figures 18 to 20 are strong for predicting crop evapotranspiration, with coefficient of determination (R^2) ranging between 0.80 – 0.92. The change in the shape of the graph of evapotranspiration against weeks after planting showed the effect of the irrigation treatments the sweet pepper were subjected to. The underline factor affecting the shape and nature of the graph is the soil water extraction pattern (Faloye et al., 2019), which is differentiated by how the plant root is modified due to varied water application. Plant receiving adequate water supply tend to develop deeper and broader roots capable of extracting more water from the soil.

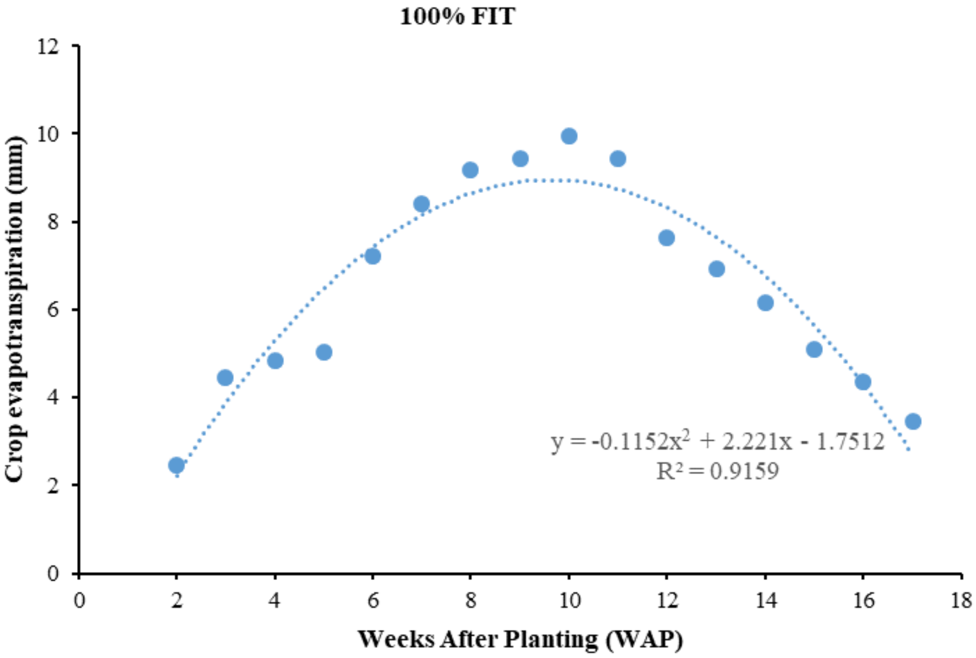


Figure 18 Weekly evapotranspiration of sweet pepper at 100% FIT

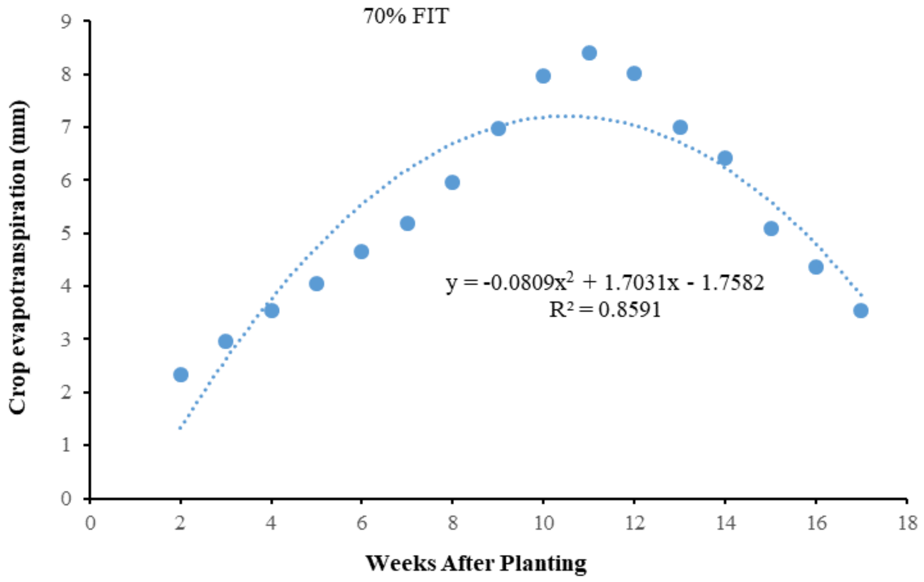


Figure 19 Weekly evapotranspiration of sweet pepper at 70% FIT

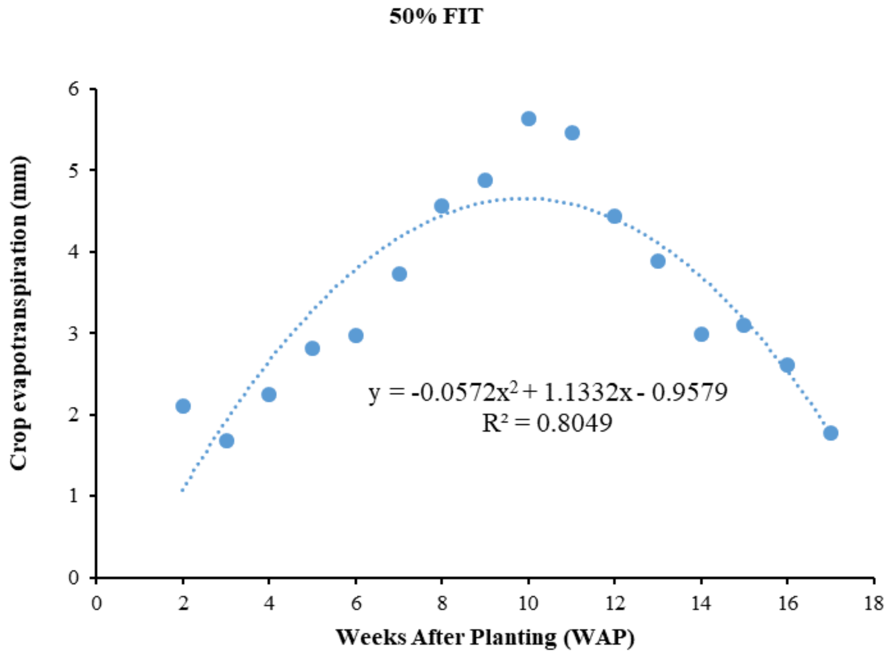
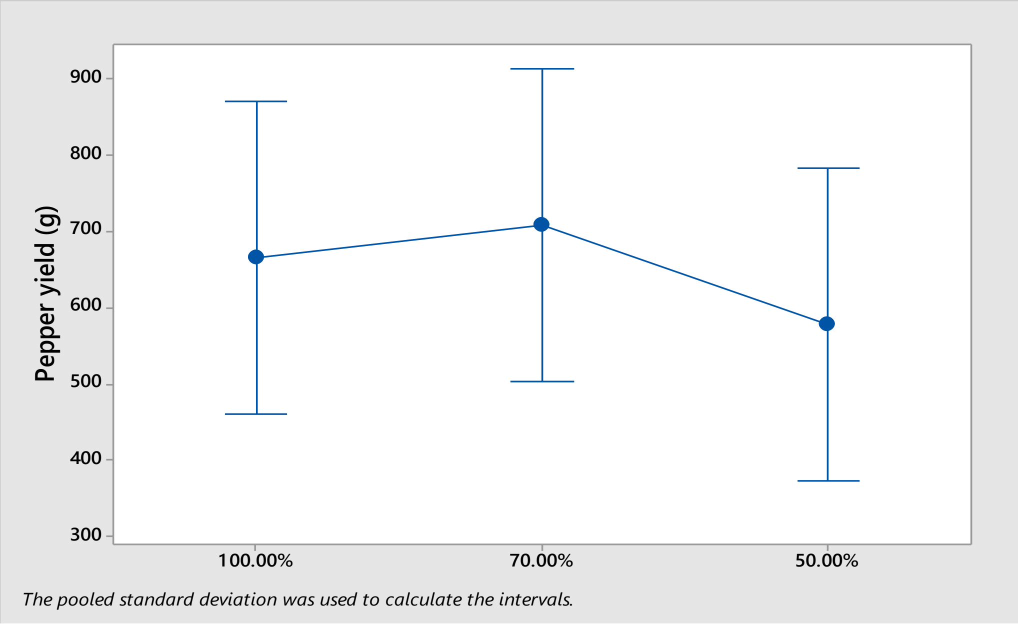


Figure 20 Weekly evapotranspiration of sweet pepper at 50% FIT

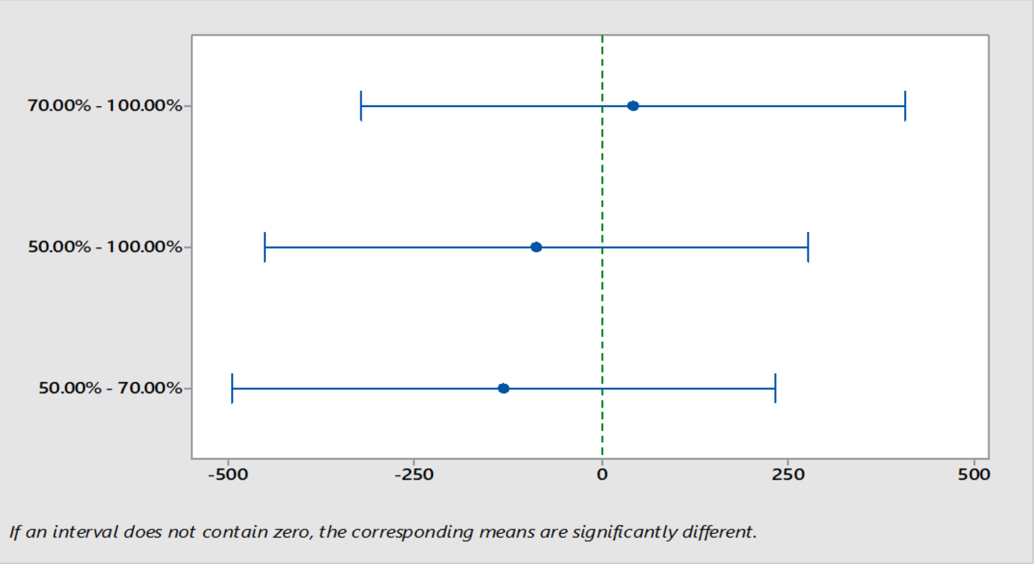
4.6 Effect of irrigation on the sweet pepper yield

The results of the sweet pepper fruit yield are given in Figure 21. The average value of the sweet pepper yield was highest at the irrigation treatment (70% FIT) that received the second highest amount of water, while lowest value was recorded at irrigation treatment (50% FIT), where the least amount of water was received. The sweet pepper yield harvested from treatment 100%, 70% and 50% FIT in the greenhouse ranged from 576.77 to 707.80 g. The yield decreased as the irrigation water amount applied reduced, but the optimum amount of water was recorded at 70% FIT. This means that about 30% of irrigation water could be saved to irrigate another plant or the same plant. The result reported in this study is compatible with those of (Demirtas and Ayas, 2009; Gençoğlan et al., 2006). However, the Analysis of variance (ANOVA) showed that there was no significant difference ($p > 0.05$) among the fruit yield obtained in the treatments. This may be due to the amount of water applied during each irrigation event at each irrigation treatment. On the contrary, some researchers (Gençoğlan et al., 2006; Sezen et al., 2006; Demirtas and Ayas, 2009; Gul et al., 2011) reported the significant effect of irrigation of sweet pepper yield. The differences the result from our study may depend on several factors, which include the variety of pepper, climate of the region, soil properties and effective use of water may also influence the sweet pepper yield and its quality. In this, sweet pepper was planted in a greenhouse which may also contributed to similarity in the yield, with similar yield ($p > 0.05$) (Figure 22) obtained at irrigation treatments of 50% and 100% FIT. This result implies that about 50% of the irrigation water could be saved for further use. This improvement in the water use can be attributed to the control environment where the sweet pepper was planted. Another possible explanation may be explained by differences in the response of the sweet pepper to the irrigation water amount may be attributed to the variety and agronomic practices such as wedding time and application of soil amendment during the planting. Varieties of crops, including sweet pepper respond differently to differential application of water to plant, which may have explained differences in the yield of our result and the studies of those mentioned above.



The pooled standard deviation was used to calculate the intervals.

Figure 21 Influence of different applications of sweet pepper on the pepper fruit yield



If an interval does not contain zero, the corresponding means are significantly different.

Figure 22 Graphical illustration of analysis of variance for the sweet pepper yield

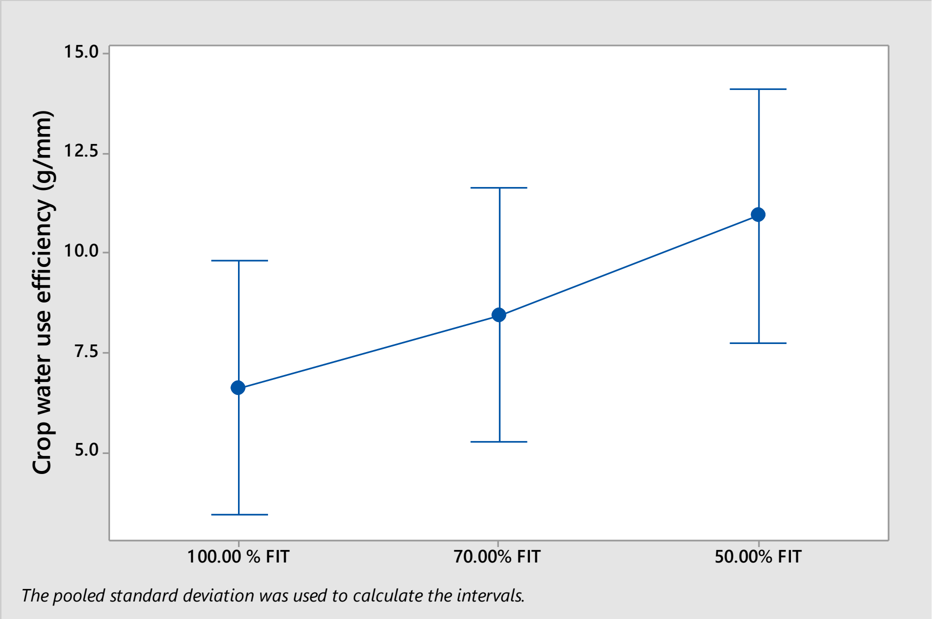


Figure 23 Crop water use efficiency of sweet pepper under different water applications

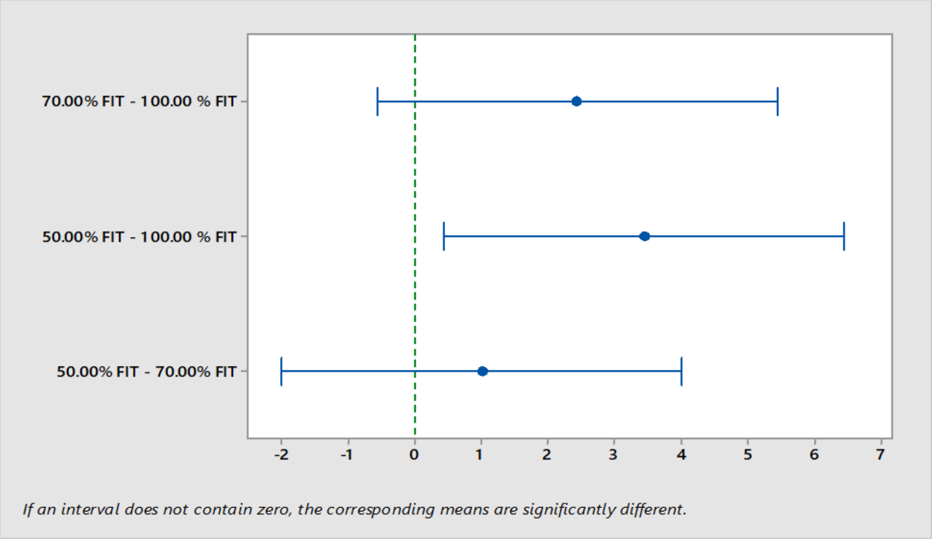


Figure 24 Analysis of variance for the crop water use efficiency of sweet pepper under different water applications

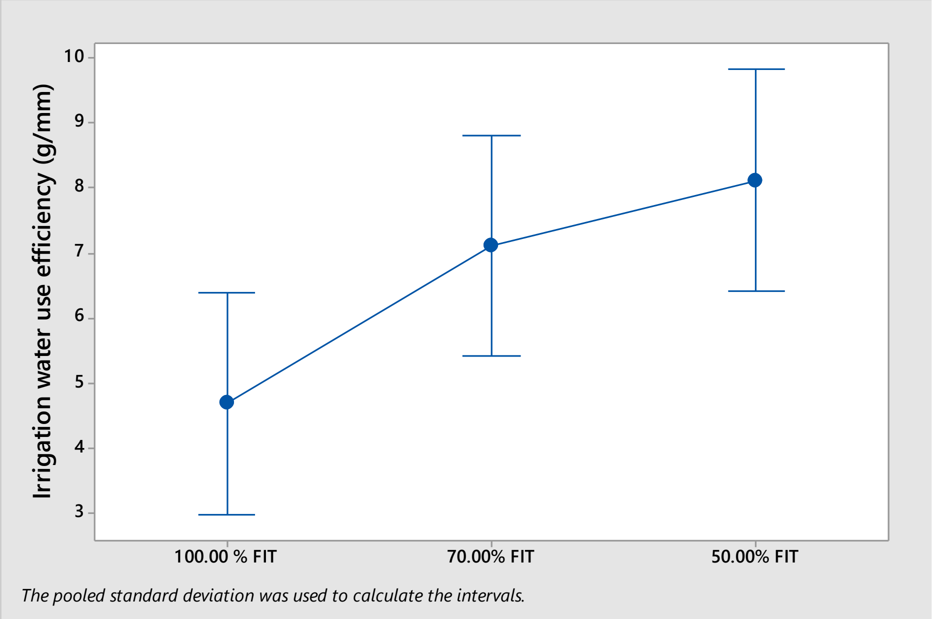


Figure 25 Irrigation water use efficiency of sweet pepper under different water applications

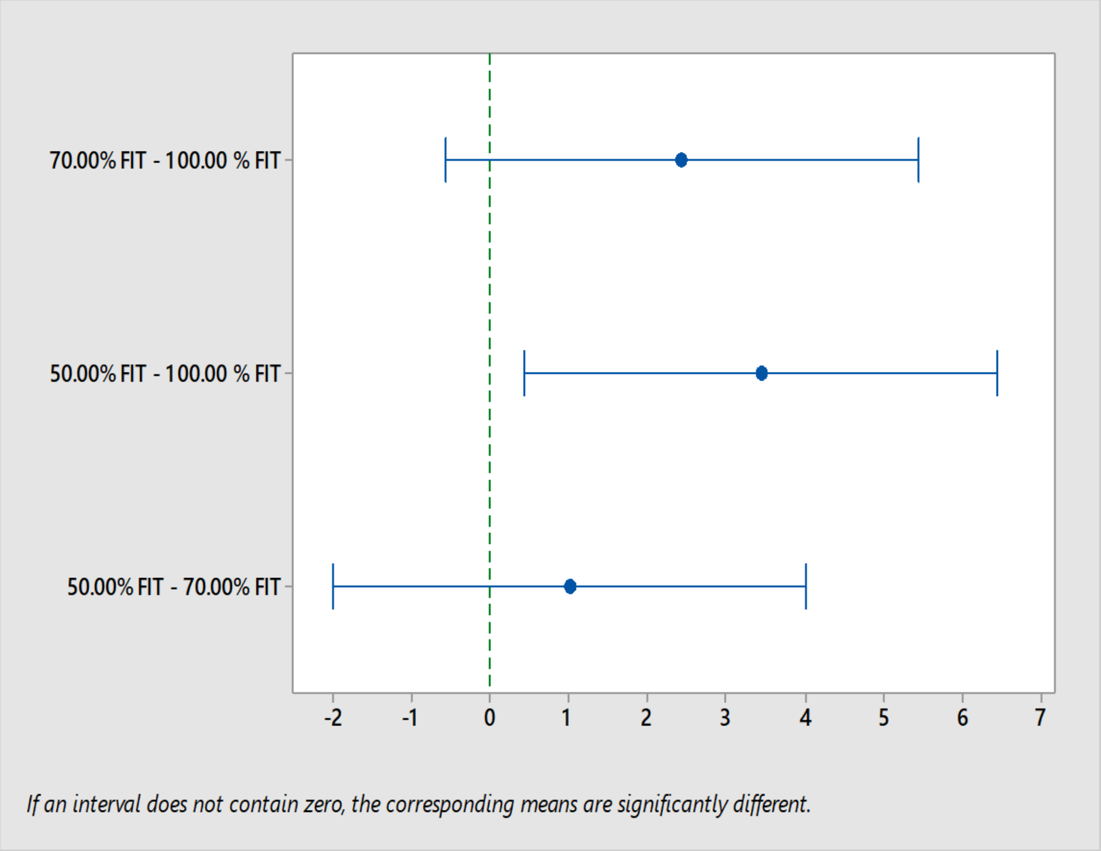


Figure 26 Graphical illustration of analysis of variance for the sweet pepper irrigation water use efficiency

4.7 Irrigation and crop water use efficiency of sweet pepper

In this study, the irrigation and crop water use efficiencies where evaluated to optimize the amount of water applied to cultivate sweet pepper in a greenhouse using drip irrigation system. Results from this study showed that the crop water use efficiency (CWUE) were 6.62, 8.45 and 10.94 g mm^{-1} in irrigation treatments 100%, 70% and 50% FIT, respectively (Figure 23). Result from the study showed that the highest value of crop water use efficiency was observed at the treatment that received the least amount of water. Similar observation were reported by Faloye et al. (2019) who reported the highest and lowest amount of crop water use efficiencies in the irrigation treatments that received the lowest and highest amount of water respectively. The result of the Analysis of Variance (ANOVA) (Figure 24) showed that there was no significant difference ($p > 0.05$) in the effect of irrigation application treatments. This result showed that under the green house, the sweet pepper were grown under conducive environment, thus encouraging the increased yield of sweet pepper. More so, the micro-climate within the greenhouse might have its solar radiation lowered, while the air temperature is reduced as well. This alteration of the weather condition within the greenhouse might have contributed to the improvement in the use of water by the plants (Mashhor et al., 2020). In addition, the use of drip irrigation, which is well known for improving water and nutrient efficiencies of crops (Fasinmirin et al., 2009; Faloye et al., 2019) due to its ability to reduce water loss during operation and apply water directly to the roots of plants for efficient and effective uptake.

The irrigation water use efficiency (IWUE) of 4.685, 7.121 and 8.124 g mm^{-1} were recorded at irrigation treatments 100%, 70% and 50% FIT, respectively (Figure 25). Similar to the CWUE, the lowest and highest value of IWUE were recorded at the irrigation treatment that received the highest and lowest amount of water. Also, considering the influence of the irrigation treatments on the IWUE, significant effect ($p < 0.05$) (Figure 26). When the results concerning the irrigation water use efficiency

(IWUE) were compared to the findings of different researchers, we found similar agreement with other studies (Chartzoulakis and Drosos, 1999; Gençoğlan et al., 2006).

5 Conclusion

This study presents the investigation of differential effect of water application on the growth and yield of sweet pepper in a greenhouse under drip irrigation. Based on the outcome of this study, the following can be concluded;

There was no significant difference ($p > 0.05$) in the yield of sweet pepper at the application rates of 100%, 70% and 50% FIT under drip irrigation system in the greenhouse. This imply 50% of irrigation water need of sweet pepper could be saved to irrigate additional land.

The growth, yield and crop evapotranspiration of maize mostly increase as the amount of water applied increases.

The highest irrigation and crop water use efficiency was recorded at the irrigation treatment that received the lowest amount of water (deficit irrigation). This further imply that deficit irrigation in a greenhouse is a good strategy to improve the water used by crops.

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