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Growth, Yield and Water use Pattern of Chilli Pepper under Different Irrigation Scheduling and Management

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ABSTRACT

The damaging effect of climate change on global food security has assumed a frightening dimension leading to food shortages due to water scarcity especially in developing nations. The need for efficient irrigation scheduling for improving productivity especially pepper therefore, became imperative. In light of this the growth, yield and water-use pattern of chilli pepper under limited water conditions was determined in Akure, Nigeria. Experimental set-up was a randomized complete block design of four treatments and three replicates. Plot A was irrigated at full evapotranspiration (100% ET) for three days, Plot B at 75% ET for four days; Plot C at 50% ET for five days while Plot D was irrigated at 25% ET for seven days. Agronomic, soil parameters and crop's consumptive water use were measured and results subjected to statistical analysis. Findings showed varying responses of chilli pepper to different water treatments. Average plant height values and stem diameters in plots A, B, C and D were 138.8, 132, 177.5 and 159 and 1.7, 2.0, 2.3 and 2.1 cm, respectively. Total yield values in all the treatments were 1.28, 1.45, 2.64 and 1.75 ton ha^{-1} in A, B, C and D, respectively. Consumptive water use of crop was maximum in all the plots at 13 Weeks After Planting (WAP), 2.85 mm in A, 3.25 mm in B, 3.58 mm in C and 3.63 mm in D. Increasing water application beyond C does not result into increased growth and yield but losses. Statistical analysis among the agronomic parameters showed significant difference ($p<0.05$) in all the treatments. The tremendous effect of water use pattern on the yield and agronomic parameters of the crop was evident from the study.

Key words: Agronomic parameters, consumptive use, climate change, evapotranspiration, food security

INTRODUCTION

Chilli pepper (*Capsicum* spp.) is one of the most important vegetables in the world. It has a rapidly growing period of 90 to 150 days while some species like the *Capsicum annum* (bell pepper) are true perennials. Chilli originated from the Americas with their cultivars now grown around the world because they are widely used as food and medicine (Mazourek *et al*., 2009). Pepper (*Capsicum* spp. *Capsicum annum* and *Capsicum frutescens*) is a crop plant grown extensively under rain-fed conditions with very high yields when the rainfall is about 600 to 1250 mm (Channabasavann and Setty, 2000). Pepper (*Capsicum* spp.) fruits vary in shape, color, pungency and texture, with *C. annuum* var. *annuum L.* being the most widely cultivated

(Russo and Biles, 2004). The fruits are an important vegetable crop for the fresh market and processed products. Chilli pepper does well in climate with temperatures ranging between 18 to 27°C during the day and between 15 to 18°C during the night (Campiglia *et al*., 2010). It has been found that lower night temperature ensures greater branching and more flowering while on the other hand, warmer night temperatures slows down the process. Increase in population has led to increase in the demand of food (pepper) and fibre which has also resulted in the adoption of irrigation to sustain plant growth (Delfine *et al*., 2000). Irrigation is practiced in all parts of the world where rainfall does not provide enough ground moisture (Bhuiya *et al*., 2003). The essence of irrigation is to make water available for storage within the soil strata for the plants usage and some to be removed by evaporation and runoff due to the irrigation design and management (Jaimez *et al*., 1999). Hence, effective irrigation scheduling is essential to curtail water losses due to runoff and excessive infiltration resulting in percolation. When water supplies and irrigation equipment are adequate, irrigators tend to over-irrigate, believing that applying more water will increase crop yields. Instead, over-irrigation can reduce yields because the excess soil moisture often results in plant disease, nutrient leaching and reduced pesticide effectiveness hence, the quantity of water pumped can often be reduced without reducing yield (Rajic *et al*., 1997). However for optimum irrigation scheduling, sound knowledge of the soil-water status, crops water requirements, crop stress status, potential yield reduction if the crops remain in stressed condition are required to maximize profit and optimizes water and energy use (Zegbe-Dominguez *et al*., 2003; Kang *et al*., 2002). Since varying water application would result in considerable differences in growth and yield (Chandra *et al*., 2011; Awodun, 2007; Rajic *et al*., 1997) and considering the importance of pepper to mankind therefore, estimating crop water use for optimum growth and efficient water utilization becomes inevitable. Burgeoning human population should be matched with corresponding food production and existing method of using rain-fed agriculture for production is obviously no longer reliable as a result irrigation has been proved to be an alternative out of impending food shortage in coming decades (Olalla and Valero, 1994). It is in line of the above that an attempt was made to determine the consumptive water use pattern of chilli pepper with specific regard to growth and yield under varying irrigation scheduling and different water management scenarios in Akure, Nigeria.

MATERIALS AND METHODS

Site description: The study was carried out at the Agricultural Engineering Department research farm of the Federal University of Technology, Akure, Nigeria from January through April, 2010. Akure is located on latitude 07°17N and longitude 05° 14E of the equator. The farmland was prepared using manual methods with dimensions in a Randomized Complete Block Design (RCBD) with 4 treatments (2×2 m) and 3 replicates. Two hundred grams of cow dung was applied to each treatment using standard practices. The soil moisture content and pH were determined before transplanting to the plots. Pepper was raised in nursery and transplanting was conducted five weeks after planting (5 WAP) (Abdullah *et al*., 2001). Irrigation water was applied continually at the rate full evapotranspiration (100% ET) when the soil reaches field capacity in all plots until the 30th day after transplanting (4 WAT), when plants were well established.

Irrigation scheduling: Irrigation was applied to study the growth and yield responses of pepper (*Capsicum* sp.) at different levels of water application which were categorized into four depending on the scheduling made available to the crop. The classification was a function of the crop's actual evapotranspiration (ET) administered at different but periodic intervals in all the treatments. The schedules are as follows: treatment A received water applied at full ET (100% ET) for three days in a week; treatment B received water applied at three-quarter (75% ET) for four days in a week; C received water applied at half ET (50% ET) for five days in a week and D received water applied at one-quarter ET (25% ET) everyday of the week. Several researchers have reported and defined the term 'Evapotranspiration' to refer to the combined processes of evaporation from soil surface and transpiration from leaves. Again, different types of ET existed such as 'potential ET' reference ET, actual ET and crop ET. For this study, actual ET was used and it was estimated from energy-balance equation given as:

$$ET_a = I + P \pm D \pm R + \Delta S \quad (1)$$

Where:

ET_a = Actual evapotranspiration
I = Irrigation
P = Precipitation
D = Drainage
R = Runoff
ΔS = Change in soil water storage

Measurements: Two different categories of parameters viz: soil and agronomic (plant) were measured before and during the experiment. Soil Moisture Content (MC) was measured directly before and during the experiment weekly using a moisture meter with depth probes at various depths which ranged from 10 through 40 cm in all the treatments (Ibitoye, 2006). Field capacity and bulk density were determined using gravimetric analysis method and by conventional computational procedure respectively (Ibitoye, 2006). As for the agronomic parameters, plant heights, number of leaves were measured using measuring rule, stem diameters was determined using vernier caliper while canopy shading were measured canopy analyzer. All this was done weekly till harvesting while grain yield was determined after harvest.

Statistical analysis: The significance of the observed correlation coefficients was tested by using't' test. This was carried out on all parameters considered at 95% level of significant ($p < 0.05$).

RESULTS AND DISCUSSION

Soil analysis: Information on the soil's physical properties from the study site was as reported in (Table 1). The bulk density's value of 1.38 g cm^{-3} was recorded in the experimental site. Though

Table 1: Physical properties of soil samples from the study area

Parameters	Values	Parameters	Values
Bulk density (g cm^{-3})	1.38	Phosphorous (mg kg^{-1})	10.20
Average field capacity (%)	22.6	Calcium (mol kg^{-1})	5.50
pH	5.5-5.9	Magnesium (mol kg^{-1})	5.0
Organic matter (%)	3.52	Sand (%)	62
Nitrogen (mg kg^{-1})	0.30	Clay (%)	26
Potassium (mg kg^{-1})	0.22	Silt (%)	12

Source: Ibitoye (2006)

higher density values tended to reduce root growth and also retard intake of some nutrients such as potassium and phosphorus, it still gave some stability to the crops against environmental factors as wind (Timm *et al.*, 2004). The 1.38 g cm^{-3} recorded were found most suitable for maximum root growth and access to water and nutrients uptake by the root. This was similar to the findings of Timm *et al.* (2004). This was however different from the findings of Salako *et al.* (2007) in Abeokuta, a town over 700 km West of Akure, the study area, all in Southwestern Nigeria. Average field capacity had a value of 22.6%, which gave the soil water retention ability for the roots to tap from after losses. Findings close to this was reported by Reichardt *et al.* (2001) under similar circumstance in Brazil and therefore, good for optimum crop development. The soil's pH ranged between 5.5 and 5.9 though acidic, it is the preferred soil range for good growth and optimum yield of pepper. It was reported that the best pH range for chilli pepper production was 5.0 to 6.0 and this was also reported by Salako *et al.* (2007). Organic matter had an average value of 3.52% while the nutrients constituents of nitrogen, phosphorus, potassium, calcium and magnesium were 0.3, 0.22, 10.20 mg kg^{-1}, 5.5 and 5.0 mol kg^{-1}, respectively were in sufficient quantities for optimum production of pepper under standard environmental conditions. The percentage composition of sand, clay and silt of 62, 26 and 12% also confirmed the presence of organic matter, particularly with the value of silt which makes the soil good enough for crop production. The soil classification using the USDA textural triangle is sandy clay loam. These results were similar to findings of Liu *et al.* (2008) and Reichardt *et al.* (2001). The moisture content was highest in treatment A, ranging between 22.5 and 20.9%, depending on weather factors (particularly sunshine hours which increases daily evapotranspiration). This was because irrigation was done at full ET throughout the week; hence more moisture still remained in as soil moisture after losses. In treatment B, soil moisture content ranged between 20 and 17.5%. This was also high considering the rate of irrigation scheduling. Moisture content in treatment C ranged between 14.2 and 16% and in treatment D, it ranged between 13 and 10.2%. The increase in soil moisture would only increase available water in the soil and would continue to ensure nearly field capacity situation for of the soil from which crop roots could take from. This however, does not imply increase water use in the treatments.

Agronomic parameters: The result of measured average plant heights in all the treatments with the corresponding Weeks After Planting (WAP) is as shown in Fig. 1. From the Fig. 1, there was a steady but gradual increase of plant heights in all the treatments. It was evident also that treatment C was clearly distinguished, as the plants were highest from the observation standpoint were compared with others. It was about 80 cm in 12 WAP and reached one meter mark (100 cm)

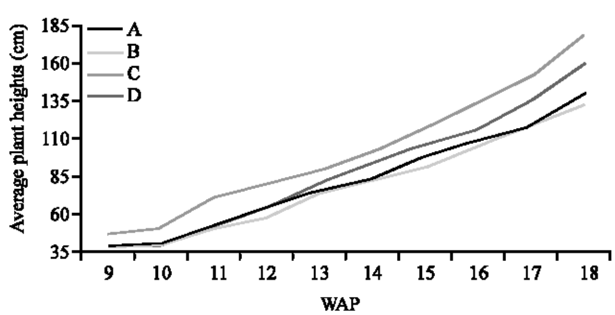

Fig. 1: Average plant height vs Weeks After Planting (WAP) in all the treatments

in 14 WAP. At 18 WAP, plant height in treatment C stood at 178 cm, about 18.5 cm higher than the closest, which was in treatment D. This was an indication that there is a clear relationship between the plant heights with respect to water use. The maximum average plant heights in treatments A, B and D were 139, 132 and 160 cm, respectively which showed that although more quantities of irrigation was scheduled (particularly in A and B), it did not translated to corresponding increase in height. It is most probable that the quantities applied may have been too much for the crop use hence percolation losses. Fu *et al.* (2010) reported that though water is one major factor required for increasing pepper production, voids in soil structure were also needed to allow expansion of soil aggregates and roots during changes in soil temperature. In case of treatments A and B, higher percentage of the voids may have been filled with water, keeping the soil at saturation always and preventing this important aspect of water uptake hence reducing performance of plant under such conditions. This is similar to the findings of (Bahmani *et al*. 2009). Constant saturation and over-saturation reduces crop growth and development especially for a crop like pepper that does not require too much water. It also promotes emission of Green House Gas (GHG), especially carbon dioxide, methane gas and nitrous oxide, one of the factors in climate change that increases global warming. The emission of GHG has been reported to be responsible for over 80% of enhanced global warming (Pathak *et al*., 2005).

There was also a significant but gradual increase in average stem diameters in all the four treatments during the experiment while the pronounced increase was found in treatment C (Table 2). There is a direct relationship between plant height and stem diameter when compared with the quantity of water used. In treatment C, average stem diameter ranged from 1.1 to 2.3 cm while in A, it ranged from 0.7 to 1.7 cm, the treatment that received full ET daily. Campiglia *et al*. (2010) reported that apart from water, soil nutrients especially nitrogen and phosphorus have significant influence on the growth and development of pepper. This was reflected in the development of stem diameters in all the treatments on average consideration. This showed that increasing water application does not directly result in increased crop development and was supported by Chandra *et al*. (2011) in a similar study conducted.

Canopy Shading (CS) is the degree of inclination of the leaves otherwise referred to as leave orientation or Mean Tilt Angle (MTA). Denser formation of foliage was due to, among other factors, age of the crop. Formation of foliage, apart from being a direct effect of water application was also due to photosynthesis due to direct incidences of sunlight. Since all the treatment received water at various quantities, the values of CS continued to rise but the pronounced increased were recorded in treatment C (Table 3). The values ranged from 41.8 to 93.3 from 9 through 18 WAP. Others had high values but not high enough when compared with values in treatment C. Treatment A had CS values ranging from 33 through 82, B ranged from 38 through 90 while

Table 2: Average stems diameters of plants in all the treatment vs. Weeks After Planting (WAP)

	WAP									
Plots	9	10	11	12	13	14	15	16	17	18
A	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.6	1.7
B	1.0	1.1	1.2	1.2	1.3	1.4	1.5	1.7	1.8	2.0
C	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.8	2.0	2.3
D	0.8	0.8	0.9	1.0	1.1	1.2	1.3	1.5	1.9	2.1

WAP: Weeks after planting

Table 3: Average canopy shading of plants in all the treatment vs. WAP

	WAP									
Plots	9	10	11	12	13	14	15	16	17	18
A	33.0	35.0	36.8	39.0	46.5	56.5	65.8	70.5	77.5	81.8
B	38.0	39.3	41.5	42.5	50.3	60.0	68.5	76.3	85.0	89.5
C	41.8	43.3	46.3	47.3	54.5	63.0	73.3	82.8	86.3	93.3
D	40.8	42.3	43.8	45.8	52.0	60.3	71.0	81.0	87.5	92.3

WAP: Weeks after planting

Table 4: Average number of leaves of plants in all the treatment compared with Weeks After Planting (WAP)

	WAP									
Plots	9	10	11	12	13	14	15	16	17	18
A	11	13	16	18	20	22	24	27	29	33
B	9	12	14	16	18	20	22	24	27	31
C	17	22	24	27	29	32	36	41	45	49
D	16	21	24	26	28	31	35	38	42	46

WAP: Weeks after planting

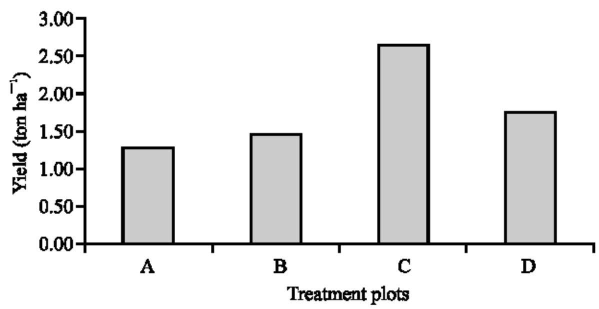

Fig. 2: Comparative analysis of average yields in all the treatment plots

treatment D recorded vales ranging from 41 and 92. Campiglia *et al*. (2010) reported the effect of nutrients and fertilizer application of formation of canopy and got results similar. Akinbile *et al*. (2007) and Akinbile (2010) also reported similar observations.

The average number of leaves has direct relationship with water and nutrient applications and use. Since too much water applied would retard crop development in root and shoot zones, leaves number would not be an exception. Treatment A had average number of leaves ranging from 11 to 33, treatment B had its range from 9 to 31, C had 17 to 49 while D had 16 to 46 (Table 4). Under well-watered conditions, photosynthesis with chlorophyll brings out the lush green and radiant colouration of leaves and its width is also a function of nutrients and water availability for uptake from the root zones.

Comparative analysis of average yields in all the treatment plots

Pepper yield: Harvesting of pepper commenced in 15 WAP and was done on a weekly basis for five weeks. The grain yield harvest of each treatment plot were collected and weighed separately. The average yield values were determined and compared with each other from other plots. From Fig. 2, it was evident that treatment C had the highest average yield of 2.64 ton ha^{-1} when compared with values from treatments A, B and D which were 1.28, 1.45 and 1.75 tons ha^{-1}

respectively. Similar results were obtained by Ade-Ademilua *et al.* (2009) in his study. There was a direct relationship between quantity of water used by the crop and yield hence this result. This was different from the quantity of water applied and yield as it was clear from the values that increasing water application (as in treatment A) does not guarantee increased water use and increased yield. This was similar to the findings of (Akinbile, 2010) in case of upland rice within the same region. Pepper yield varied significant from one region to the other and several factors such as topography, soil type, water quality, seed variety, cultural practices method, soil tillage and fertilization application (Liu *et al.*, 2008). For the yield on a sandy loam soil such as this, average yield of 2.64 ton ha^{-1} was desirable but a much higher yield could be obtained under similar soil conditions with fertilizer application (Liu *et al.*, 2008).

Water use pattern: The results of crop water use from 7 WAP through 17 WAP were as shown in Fig. 3. The general trend of the result was that the treatment with highest water application had the lowest water use and the treatment with lowest water application had the highest water use. Treatment A that received water (full ET) throughout the week had the average weekly crop water use ranging from 2.43 to 2.85 mm day^{-1}. B (with 0.75 ET) had its water used between 2.9 and 3.25 mm, C (0.5 ET) had between 3.19 and 3.58 mm while D with (0.25 ET) had its values between 3.31 and 3.63 mm. The other observation was that the maximum water use was in 13 WAP and was common all through within the treatments. Treatment A had 2.85 mm day^{-1}, B, 3.25 mm day^{-1}; C had 3.58 mm day^{-1} while D had 3.63 mm day^{-1} in the same week (Fig. 3). This may be due to among many other factors, increased incidences of sunlight and extraterrestrial radiation during the week and increased metabolic activities within the crop. Similar results was reported by Kang *et al.* (2001) in case of rice. In all the agronomic parameters previously discussed, treatment C seemed to have higher values than other treatments but in the case of water use, D, was highest all through. This was a clear indication that efficient irrigation scheduling is vital for optimum growth. Increasing water application beyond the need of crop would only result in losses in form of surface run-off, deep infiltration, percolation and seepage losses and not contribute significant to agronomic and yield increased as it was observed in this study (Akinbile, 2010). The gradual reduction in water use after 17 WAP was an indication that the vegetable had completed its growth and further water application does not result in yield increase, hence the reduction. The stage may be referred to as maturity even though harvest continued until such a time when the

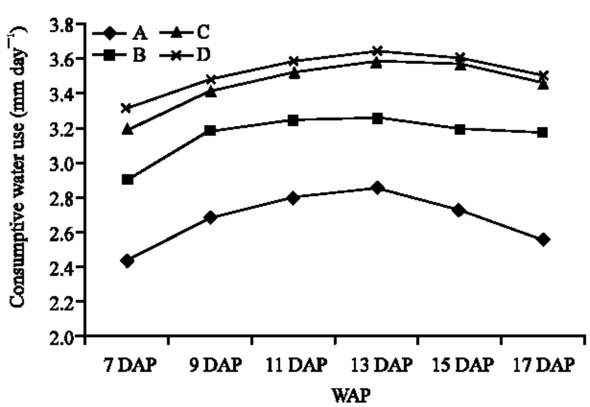

Fig. 3: Crop water use vs. Weeks After Planting (WAP) in all the treatment plots

Table 5: Correlation coefficient of different plant parameters from the study data

Parameters	ASD	APH	ANOL	ACS	TYLD	CWU
ASD	1					
APH	0.8**	1				
ANOL	0.8**	0.97***	1			
ACS	0.96***	0.68	0.74*	1		
TYLD	0.89**	0.93***	0.85**	0.74*	1	
CWU	0.92***	0.74*	0.83**	0.98***	0.72*	1

($p < 0.05$) ***Very highly significant **Very significant *Significant. ASD = Average stem diameter, APH = Average plant height, ACS = Average canopy shading, TYLD = Total yield, CWU = Crop water use

'season' was over and the stand stopped producing the required yield. However it could be could be concluded that pepper at the initial state (growth stage) requires more water for development and at the maturity stage as it grow towards the completion of their life cycle; lesser quantity of water was required. This explains the parabolic nature of the water use curves. Hence it could be concluded that pepper required moderately high quantity of water to thrive for optimum yield.

Test of significance of the observed correlation coefficients: The significance of the observed correlation coefficients have been tested by using't' test is as shown in Table 5. Out of the total 15 correlations found between two parameters, 5 were found to have very highly significant at 5% level (r>0.9), 5 were very significant (r>0.8) and 4 were significant (r>0.7). The correlation between Average Canopy Shading (ACS) and Average Plant Height (APH) was found to be low (r>0.68) at p<0.05. Some of the correlations observed existed between TYLD and ASD (0.89), CWU and TYLD (0.72) and ACS and ANOL (0.74), respectively. Some of the highly significant correlations were discernible between ACS and ASD (r = 0.96), ANOL and APH (r = 0.97) and between CWU and ACS (r = 0.98). In all the parameters tested using t-test correlation analysis, there were significant differences in all the parameters considered at 95% confidence interval also confirming a relationship between the growth, yield and water use pattern of chilli pepper for optimum production.

CONCLUSION AND RECOMMENDATIONS

The importance of pepper production to food security especially in Nigeria is of significant importance for continued sustenance of improved agricultural productivity. From the study, it was observed that variation in water scheduling had significant impact on growth and yield of the vegetable. This was reflected in the crop's agronomic parameters response to water use pattern during the experiment. It was also shown that the water use pattern tremendous effect on the yield and agronomic parameters of the crop. One thing was evident from the study; too much water application would not and did not result in higher yield. This is particularly important considering the issue of optimum water use wherein new strategies such as Alternate Wetting and Drying (AWD) is being advocated for efficient water use and for increased productivity. For efficient irrigation scheduling and excellent water management, treatment C was suggested for optimum production. However, the issue of increasing global temperature (global warming) occasioned by increase in night-time temperature was not considered hence it should be looked into. Recent changes in weather have shown that increased temperature increases rate of abortion of crops in the soil, thereby reducing the crop yield for optimum production.

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