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Research Article

Crop Water Productivity of Plantain (Musa Sp) in a Humid Tropical Environment

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Abstract

Crop water productivity defines the relationship between crop produced and the amount of water involved in producing the crop. It is a useful indicator for quantifying the impact of irrigation scheduling decisions with regard to water management. This paper presents CWP quantified from field experimental data. The field experiments were conducted for three years in a tropical region of south Western Nigeria to determine the crop water productivity (CWP) and consumptive use of plantain *(musa sp*) cv. Agbagba. There were four treatments and four replicates based on the level of water application. CWP were computed in terms of crop water use, water applied, and economic returns. Results showed that crop water consumed varied significantly ($P<0.05$) among treatments. Estimated water consumed ranged from 900 mm to 1700 mm from planting to harvest depending on the irrigation water regime. Crop Water Productivity (CWP) in terms of water consumed varied from 0.91 – 1.37 kgm^{-3} for 2006/2007 and 0.91 – 1.41 kgm^{-3} in the 2007/2008 seasons respectively while CWP in terms of water applied varied from 2.82 – 3.98 kgm^{-3} and 2.89 – 4.04 kgm^{-3} in the first and second seasons respectively. The amount of irrigation water applied at the different growth stages of the crop and the growth stage response to moisture stress influenced the status of CWP. The findings indicated that plantain crops were very sensitive to lack of soil water during the total growing season.

Keywords: Plantain biomass, bunch yield, evapotranspiration, crop water productivity, musa, consumptive use.

1. Introduction

Plantains and bananas constitute the fourth most important crop of the world after rice, wheat, and maize and they form the world's second most important traded fruit after citrus, and along with rubber (*Castilla elastica*), cocoa (*Theobroma cacao* L.), sugar (*Saccharum officinarum* L.) and coffee (*Coffee Arabica* L.) one of the five major tropical products entering into world trade [1].

The world plantain area totaled 4.8 million hectares producing 30.6 million tonnes of fruits. The regions with the largest production are Africa and Latin America with respectively 74.2% and 22.5% of world production in comparison with 3.3% in Asia [2]. Plantains flourish in tropical regions and are the most important carbohydrate source in local economies [3]. In West and Central Africa about 70 million people are estimated to depend on *Musa* fruits for a large proportion of their daily carbohydrate intake [4].

In Nigeria plantains and bananas are both important staples and sources of income for subsistence farmers. There has been increasing trend towards large-scale production of the crop [5] in the traditional humid rainforest production zone, and some emergent production zones are located in the sub-humid areas of southeastern Nigeria [6-7]. However most of the increases in plantain production have been due to cropland expansion, rather than increases in yield per hectare. Presently, plantain cultivation has become a feature of great socioeconomic importance in developing countries from the point of view of food security and job creation [8].

Although some research has been conducted on this important crop [9-13], little documented evidence exist to indicate the manner in which the plantain plant uses water or respond to irrigation with respect to yields. Bassoi *et al.*, [13] stated that water is probably the most limiting non-biological factor in plantain production. It is known generally as a plant with a rapid growth rate, high consumption of water, shallow and spreading root distribution, roots with weak penetration strength into the soil [14], low resistance to drought and rapid physiological response to soil water deficit [15].

Data on water use of plantain grown in the tropical humid conditions are essential for optimum irrigation management strategies and water conservation. Crops in general, have reduced crop growth and yields due to soil moisture deficits and hence reduced leaf photosynthesis and a combination of stomatal and non-stomatal limitations [16-21]. The effects of this drought depend on the phenelogical stages when it occurs [22-23]. In the case of plantain, Robinson and Bower, [24] and Eckstein *et al.*, [25]; Eckstein and Robinson, [26] noted that photosynthetic activity decreases with reduction of transpirational and stomatal aperture. Proper irrigation management of plantain should therefore lead to improved productivity and continuous fruits harvest especially in tropical regions where rainfall amounts and distribution are erratic.

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Water is a limiting resource and hence the need for its judicious use. In many tropical regions of the world, water (not land) is the most limiting factor to plantain production. Research work on water use productivity (CWP) or water use efficiency (WUE) is a major input to good irrigation water management for sustainable agriculture in irrigated areas [27]. However, studies upon the estimates of crop water productivity for plantains are still incipient. Satisfying crop water requirements, although maximizes production from the land unit; does not necessarily maximize the return per unit volume of water. Improving water productivity can contribute to water savings, which can be used to irrigate additional lands with higher total production and/or improve the sustainability of the existing water resources. However, the supplementary irrigation level at which crop water productivity can be maximized under the rainfed conditions of the humid tropical environment need to be evaluated before improved management strategies can be devised. Thus, the objective of this study was to evaluate the evapotranspiration, yield and crop water productivity of plantain cv. Agbagba, grown under tropical climate conditions.

2. Materials and Methods

2.1 Experimental site and design

Suckers of plantain, cultivar Agbagba (*musa paradisiaca* sp. AAB) were planted in a field experiments between July 2006 - November 2007 and August 2007 – November 2008 at the Experimental Farm of the Department of Agricultural Engineering, Federal University of Technology, Akure, South West Nigeria which lies at latitude 7^{o} 16’ North and longitude 5^{o} 13’ East at an altitude of 351 m above mean sea level. Akure is located in a tropical humid climate with rains spanning up to half of the year. The mean annual rainfall between 1995 and 2007 is about 1300 mm while the minimum and maximum temperatures are about 20°C and 30°C. Mean monthly weather conditions at the experimental location during 1995-2007 are shown in Table 1. Sample of the soil was analyzed at the beginning of the experiments as shown in Table 2. According to FAO classification the soil belongs to category of fine, loamy, mixed hyperthermic Typic Haplauf. The upper layer (0-0.15 m) down the other layers examined (0.15-0.30; 0.30-0.45; 0.45-0.60 m) were sandy clay loam in texture. The average bulk density is about 1.5 gcm^{-3}.

Each experiment was laid out in 16 plots of 20 m x 40 m in a 4 x 4 Randomized Complete Block Design having treatments based on four different levels of water application (see Table 3). A plot was 2 m X 6 m with planting density of 2500 plants ha^{-1} similar to prevailing cultural practice within the locality and in literature [28]. Weeds were controlled chemically and manually and fertilizer was applied based on soil chemical analysis.

The consumptive use of water by the crop was estimated using the water balance equation

$$ET = I + P \pm \Delta S \pm R \pm D \tag{1}$$

where ET = actual evapotranspiration in mm; I = amount of irrigation water (mm); P = effective rainfall (mm); ΔS = change in soil water storage (mm); R = surface runoff, (mm) and D = amount of drainage water (mm).

Table 1. Weather conditions at the experimental location (1995-2007)

Months	Precipitation (mm)	Reference evapotranspiration (mm)	Air temperature (°C)	Relative humidity (%)	Wind speed: 2 m high (ms^{-1})
January	19.3	3.1	26.8	58.5	3.5
February	44.7	3.6	29.9	62.3	4.4
March	37.9	3.4	30.7	61.4	4.8
April	173.2	3.7	30.3	73.6	5.4
May	134.2	3.8	28.5	80.0	4.1
June	199.7	2.8	27.0	80.9	3.2
July	155.3	2.2	25.6	86.8	3.4
August	62.6	4.7	25.2	86.0	3.8
September	240.6	1.9	26.1	85.1	2.3
October	172.7	2.6	27.2	82.6	6.6
November	28.1	3.2	28.8	73.9	2.1
December	14.7	3.6	27.1	71.2	3.3
Total	1282.9	-	-	-	-
Mean		3.0	27.7	75.2	3.9

Location of the Experimental Station: latitude 7^{o} 16’ N; longitude 5^{o} 13’ E, altitude of 351 m

Table 2. Measured soil physical and hydrological properties at the experimental site

Characteristic	Value
Sand (%)	64.0
Clay (%)	24.5
Silt (%)	11.5
Organic matter (%)	1.61
Bulk density (gcm^{-3})	1.50
Field capacity (%)	20.60
Wilting Point (%)	3.43
pH	5.73

Table 3. Summary of Irrigation Treatments

Treatment	Code	Definition
High (full)	T1	0% deficit irrigation
Moderate	T2	50% deficit irrigation
Low	T3	75% deficit irrigation
Control	T0	Control experiment

Water was applied using low gravity drip irrigation system and emitters were spaced along polyethylene lines with stopcock controls at each end of the line to control the timing and quantity of water applied. Irrigation amount was recorded at every water application. The change of soil water storage, ΔS was estimated from moisture content readings up to a depth of 50 cm which was assumed to be the root zone. Runoff was estimated using runoff meters. For periods without rainfall, runoff was obviously nil. The drainage below root zone was estimated using Darcy’s equation. A Watermark Soil Moisture Sensor and the Multipurpose Temperature Probe used with the Vantage Pro2 wireless soil moisture/Temperature station was installed on the experimental field to monitor the soil moisture and soil temperature. Soil moisture contents were also determined by gravimetric method. This was measured in each treatment plot to depths of 50 cm at 10 cm interval starting from the soil surface. Rainfall data were collected using standard rain gauges installed at various points of the experimental farm. The rain gauges were regularly raised above crop canopy to avoid errors due to rainfall interception. Reference evapotranspiration (ET_{ref}) was calculated using monthly temperature, humidity, solar radiation and wind speed according to the FAO Penman Monteith Method [29].

Growth analysis was carried out monthly by harvesting plant material from randomly selected plots of each treatment. Samples were taken in all replicates. Plants were harvested and separated into dry leaves, wet leaves, pseudostem, corm, and fruits. The fresh and dry mass of each sample were determined. Dry matter of plants organs were determined by drying samples in an oven at 65°C for 48hrs. Bunch yield and dry matter yield were determined at maturity. Crop water productivity was calculated as:

i. Crop water productivity in terms of seasonal crop consumptive use:

$$\mathrm{CWP}_{(\text{water use})} = \frac{crop\ \text{yield (kg)}}{SWU\,(m^3)} \tag{2}$$

ii. Crop water productivity in terms of seasonal water applied to the field:

$$\mathrm{CWP}_{(\text{water applied})} = \frac{crop\ \text{yield (kg)}}{SWA.(m^3)} \tag{3}$$

iii. Crop water productivity expressed in economic term:

$$\mathrm{CWP}_{(\text{economic})} = \frac{p\ \times \text{crop yield}}{SWA.(m^3)} \tag{4}$$

where p = price of plantain bunch (price /kg crop yield).

The price of plantain bunch yield in the study area during the 2006 – 2008 irrigation seasons was equivalent to \$1.33/kg based on market survey. Analysis of data was carried out using statistical softwares such as the Statistical Package for Social Sciences (SPSS), Statgraph, MS Excel and Sigma plot 10.0.

3. Results and discussions

3.1 Crop Evapotranspiration (Crop Water Use)

Variations of mean crop evapotranspiration estimates for all treatments are shown as Figure 1. Evapotranspiration against days after planting fitted best to parabolic functions for all treatments with the coefficient of correlation (R^2) ranging from 0.65 to 0.91 [30]. The crop water use was lowest at the emergence and vegetative stages of the plants. It reached the peak at the flowering stages and finally dropped at the maturity/harvest stage. Evapotranspiration is generally higher during the dry season than during the wet season and this was so because of the high solar radiation which resulted to rapid loss of moisture both from soil and the crop surfaces in order to respond to evaporative demand. The maximum value of ET (10.7 mmday^{-1}) was observed among T1 treatment at the 279DAP. Results from the T2 treatment (Figure 2 (b)) showed that 8.1 mmday^{-1} was the highest ET value. Observations among the low treatment (T3) revealed that 6.79 mmday^{-1} was the highest ET while 6.35 mmday^{-1} was the highest ET among the control treatment, T0.

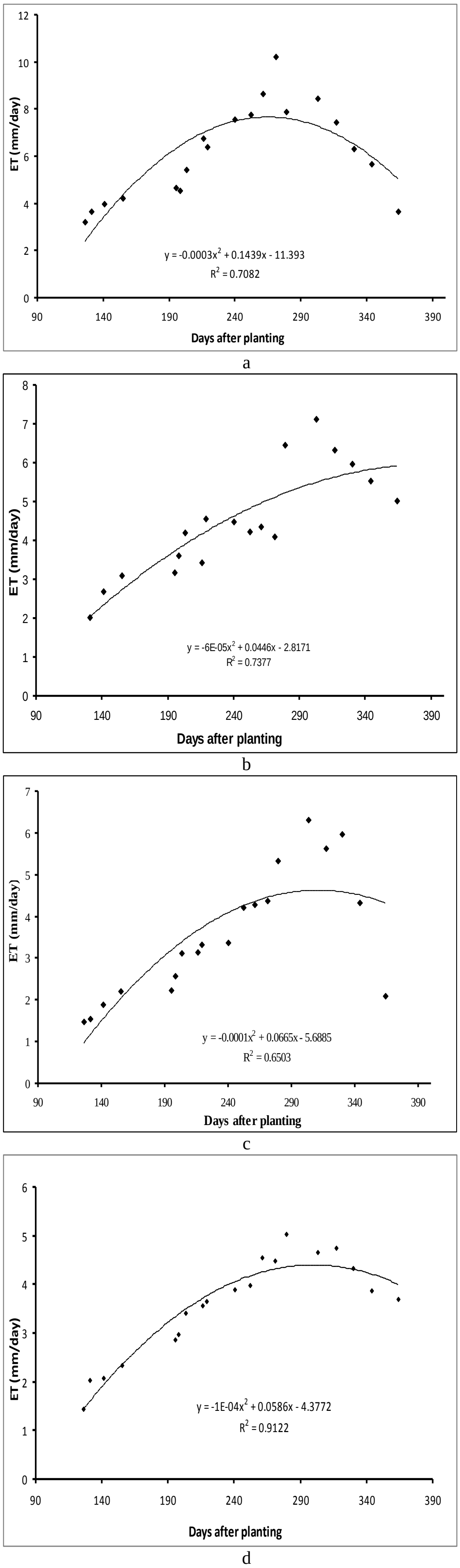

Fig. 1. Crop Evapotranspiration of *musa* on function of days after planting in treatments (a) T1 (b) T2 (c) T3 and (d) T0 during 2006/2007 experiment.

There were variations in the crop evapotranspiration rates among treatments and this could be ascribed to the differential water application to treatments in which case the treatment that received high irrigation have sufficient water to meet evapotranspiration needs. This result compares well with the findings of Bassoi et al., [13] who reported a maximum of 7.3 mmday^{-1} at the flowering stage during the first growing season, in a field experiment carried out to investigate the water consumption, crop coefficient and physiological behaviour of the banana crop in Brazil. Similar results have also been reported by [31]. The result also demonstrated that stress was evident in the rainfed treatment, T0 as established by the lower availability of water in the profile particularly in the dry periods of the year when compared to other treatments. Investigations by other researchers have shown that drought stress resulted in reduced plant growth [32]. It was also noticed that some plants in the control treatment permanently wilted before reaching maturity stage. This may not be unconnected with water stress at the sensitive stages of the crop (252-301DAP) which falls between the vegetative and flowering stages of the crops. Calvache [23] noted that flowering stage was the most sensitive to water stress in crops, particularly, for shallow rooted crops. Atteya [22] noted that water stress in plants induces a decrease in photosynthesis and growth. The rate of assimilation in the leaves is reduced as drought stress coinciding with flowering delays fruit bulking and results in an increase in the flowering initiation – fruit bulking interval and consequently a reduction in yield. This finding was also consistent with that of Antolin and Sanchez-Diaz [33], who reported reduced stem length of previously stressed compared with unstressed alfalfa. He concluded that drought inhibited cell elongation, reduced photosynthesis, interfered with nutrient uptake, and altered plant hormone levels.

The relationship observed between the measured consumptive use and biomass yield for each treatment are presented in Figure 2. Estimated water consumed ranged from 900 mm to 1700 mm from planting to harvest in the order of T0, T3, T2 and T1 treatments respectively. For example, in the fully irrigated treatment (T1), crop consumptive use at 413DAP (at harvest) was 1691.5 mm while crop consumptive use was 910.7 mm at same period for treatment T0. Correspondingly, highest biomass yield was 23.2 tha^{-1} at harvest for T1 treatment while lowest value of biomass yield was 8.3 tha^{-1} in T0 treatment. Statistical analysis confirmed that supplemental irrigation had significant effect ($p<0.05$) on biomass and bunch yield (Tables 4 and 5).

3.2 Crop Water Productivity

The computed crop water productivity in terms of water consumed ($CWP_{(water\ use)}$) and water applied ($CWP_{(water\ applied)}$) for the total plantain biomass are presented in Table 6 for 2006/2007 and 2007/2008 experiments. $CWP_{(water\ use)}$ for the various treatments varied from 0.91 – 1.37 kgm^{-3} for 2006/2007 and 0.91 – 1.41 kgm^{-3} in the 2007/2008 seasons respectively while $CWP_{(water\ applied)}$ varied from 2.82 – 3.98 kgm^{-3} and 2.89 – 4.04 kgm^{-3} in the first and second seasons respectively. The T1 treatment which received a 581.7 mm depth of water in the first season cropping recorded the highest $CWP_{(water\ use)}$ of 1.37 kgm^{-3}. The trend was the same in the second season. With the water application of 605.3 mm, T1 recorded the highest $CWP_{(water\ use)}$ of 1.41 kgm^{-3}. T2 treatment which received 467.2 mm depth of water in the first season recorded a $CWP_{(water\ use)}$ of 1.21 kgm^{-3} while in the second season with a water application of 517.2 mm, $CWP_{(water\ use)}$ was 1.24 kgm^{-3}. The least $CWP_{(water\ use)}$ in the case of total biomass yield were recorded in treatment T0 (which received no water application) recorded a $CWP_{(water\ use)}$ values of 0.91 and 0.90 for 2006/2007 and 2007/2008 respectively.

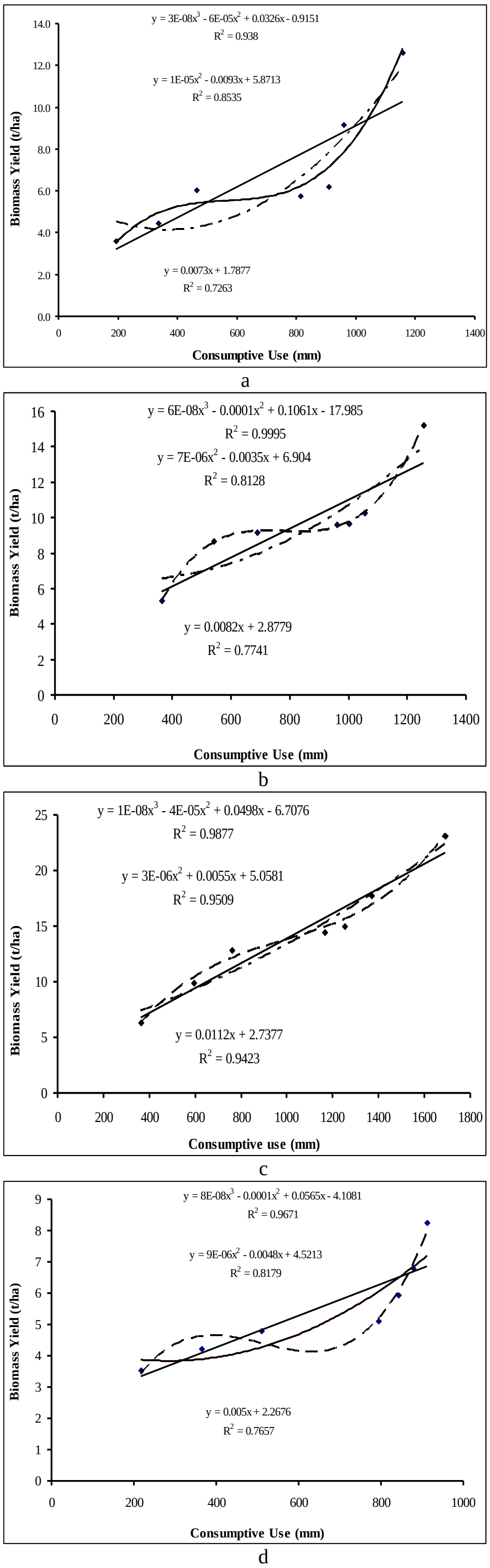

Fig. 2. Biomass Yield vs Seasonal Consumptive use for (a) T3 (b) T2 (c) T1 and (d) T0

Table 4. Total biomass yield, consumptive use, seasonal water applied and rainfall

Treatment	Biomass yield (tha^{-1})	Water Applied (mm)	Rainfall (mm)	*CU (mm)
2006/2007 experiment				
T1	23.22 (±2.2)**a	581.7	850	1691.5
T2	15.24(±0.7)b	467.2	850	1254.3
T3	12.63(±0.4)c	447.5	850	1157.1
T0	8.25(±2.1)d	-	850	910.7
2007/2008 Experiment				
T1	24.44 (±1.8)a	605.3	927	1734.4
T2	16.45 (±0.7)b	517.2	927	1328.6
T3	14.16 (±1.1)c	489.6	927	1197.3
T0	8.80 (±0.6)d	-	927	975.8

*CU = consumptive use. **Numbers in parenthesis show the standard deviations. Mean Values in the same column followed by different letters indicate significant differences according to Duncan's comparison of means at 5% level

Table 5. Plantain bunch yield (dry), consumptive use, seasonal water applied and rainfall

Treatment	Bunch yield (tha^{-1})	Water Applied (mm)	Rainfall (mm)	*CU (mm)
2006/2007 experiment				
T1	10.18 (±0.2)**a	581.7	850	1691.5
T2	6.96 (±0.8)b	467.2	850	1254.3
T3	5.47 (±0.6)c	447.5	850	1157.1
T0	3.85 (±0.4)d	-	850	910.7
2007/2008 Experiment				
T1	12.89 (±2.3)a	605.3	927	1734.4
T2	7.52 (±0.7)b	517.2	927	1328.6
T3	6.41 (±0.8)c	489.6	927	1197.3
T0	4.37 (±0.9)d	-	927	975.8

*CU = consumptive use. **Numbers in parenthesis show the standard deviations. Mean Values in the same column followed by different letters indicate significant differences according to Duncan's comparison of means at 5% level

Table 6. Crop water productivity for total biomass yield

Treatment	($CWP_{(water\ use)}$) kgm^{-3}	($CWP_{(water\ applied)}$) kgm^{-3}	$CWP_{(economic)}$ $\$m^{-3}$
2006/2007			
T1	1.37	3.98	5.29
T2	1.21	3.26	4.33
T3	1.09	2.82	3.75
T0	0.91	-	-
2007/2008			
T1	1.41	4.04	5.37
T2	1.24	3.18	4.23
T3	1.18	2.89	3.84
T0	0.90	-	-

Table 7 shows the $CWP_{(water\ use)}$, $CWP_{(water\ applied)}$ and $CWP_{(economic)}$ in the case of plantain bunch yield for 2006/2007 and 2007/2008 seasons respectively. $CWP_{(water\ use)}$ for the various treatments varied from 0.42 – 0.60 kgm^{-3} and 0.45 – 0.74 kgm^{-3} for the first and second seasons respectively. T1 which received 581.7 mm depth of water in the season had the highest $CWP_{(water\ use)}$ of 0.60 kgm^{-3}. The trend was the same in 2007/2008 season. With water application depth of 605.3 mm, the $CWP_{(water\ use)}$ value was 0.74 kg^{-3}. T2 treatment received 467.2 mm depth of water had $CWP_{(water\ use)}$ value of 0.55kgm^{-3} in first season cropping. The value was 0.57 kgm^{-3} for a water application depth of 517.2 mm for 2007/2008. T0 had the least values of $CWP_{(water\ use)}$ amongst the various treatments with values of 0.42 and 0.45 kgm^{-3} respectively. T0 depended on climate throughout the growing season except water received for establishment. These results implied that T1 produced 60 and 74 $kgha^{-1}$ of bunch yields for the first and second seasons when compared to 55, 47 and 42 $kgha^{-1}$ produced by T2, T3 and T0 respectively for the first season and 57, 54 and 45 $kgha^{-1}$ produced for T2, T3 and T0 respectively for the second season.

Table 7. Crop water productivity for bunch yield

Treatment	($CWP_{(water\ use)}$) kgm^{-3}	($CWP_{(water\ applied)}$) kgm^{-3}	$CWP_{(economic)}$ $\$m^{-3}$
2006/2007			
T1	0.60	1.76	2.33
T2	0.55	1.49	1.98
T3	0.47	1.22	1.63
T0	0.42	-	-
2007/2008			
T1	0.74	2.13	2.83
T2	0.57	1.45	1.93
T3	0.54	1.31	1.74
T0	0.45	-	-

A comparison of $CWP_{(water\ use)}$ for all treatments showed that bunch production per unit of water used for T1 was about 8, 22 and 30% higher than treatments T2, T3 and T0 respectively in the first season. In the second season, plantain bunch produced per unit of water used in T1 was about 23, 27 and 39% respectively. The implication of this was that treatment T1 had a better water utilization efficiency than treatments T2, T3 and T0 in both seasons. Better water utilization efficiency in T1 may be associated with adequate water applied during the growth stages.

Crop water productivity expressed in terms of water applied ($CWP_{(water\ applied)}$) varied from 1.22 – 1.76 and 1.31 – 2.13 for seasons one and two respectively. In T1, the highest values of $CWP_{(water\ applied)}$ were recorded for both seasons. With seasonal water depths of 581.7 and 605.3 mm, the $CWP_{(water\ applied)}$ were 1.76 and 2.13 kgm^{-3} for seasons one and two respectively. The lowest $CWP_{(water\ applied)}$ were recorded in the T3 which received seasonal water depths of 447.5 and 489.6 mm in seasons one and two respectively.

$CWP_{(water\ applied)}$ is an indicator of how much the total water applied in the field was efficiently harnessed for production benefit. This means that in T1, 176 and 213 $kgha^{-1}$ of plantain bunch was produced from every 100 m^3 applied to grow the crop in the first and second seasons respectively. T2 produced 149 and 145 $kgha^{-1}$ bunch for every 100 m^3 of water applied in first and second seasons, while T3 produced 122 and 131 $kgha^{-1}$ for every 100 m^3 of water applied also in the first and second seasons respectively. The economic crop water productivity varied from 1.63 $\$/m^3$ and 1.74 $\$/m^3$ in the treatment which received the lowest seasonal water applied to grow the crop to highest values of 2.33 $\$/m^3$ and 2.83 $\$/m^3$ in T1 for seasons 2006/2007 and 2007/2008 respectively. The economic crop water productivity has similar trend with $CWP_{(water\ applied)}$.

The ranges of crop water productivity from the treatment were closer to the range of 1.2 and 3.7 kgm^{-3} reported in literature for banana crop around the world. Hedge and Srivas [10] estimated water use efficiency (WUE) of banana cv. Robusta ranging from 2.8 – 3.7 kgm^{-3} according to the soil water availability. Bassoi *et al*., [13] reported 1.17 kgm^{-3} for banana cv. Pacovan. The CWP reported here far exceeded the crop water productivity reported for maize which varied from 0.3 – 2.7 kgm^{-3} [30, 34, 35]. It must however be noted that crop water productivity values are influenced by crop variety and water management practices. Van Dam and Malik, [36] and Hartfield *et al*., [37] observed that water use efficiency is influenced by crop morphology, soil conditions, agricultural practices and atmospheric variables.

4. Conclusion

Crop water consumed varied significantly ($P<0.05$) among treatments. Estimated water consumed ranged from 900 mm to 1700 mm from planting to harvest depending on the irrigation water regime. This confirms that plantain respond favourably to water. Supplemental irrigation had significant effect ($p<0.05$) on biomass yield. The biomass yield in the highly irrigated treatment was about 280% that of control treatment.

Crop Water Productivity (CWP) in terms of water consumed (i.e. Water use efficiency, (WUE) varied from 91 to 137 $kgha^{-1}$ of biomass per 100 m^3 of water consumed according to level of irrigation water regime. Hence plantain has a better utilization of water consumed when irrigated. Similarly CWP in terms of water applied varied from 398 to 282 $kgha^{-1}$ of biomass per 100 m^3 of water consumed according to level of irrigated water regime.

CWP in terms of water consumed (i.e. Water use efficiency, (WUE) varied from 42 to 60 $kgha^{-1}$ of bunch yield per 100 m^3 of water consumed according to the level of irrigation water applied. Similarly CWP in terms of water applied varied from 122 to 176 $kgha^{-1}$ of bunch yield per 100 m^3 of water consumed according to the level of irrigation water applied. The status of crop water productivity (either maximized or reduced), was dictated by the amount of water applied and the crop growth stages. Generally highly irrigated treatment showed higher CWP than other lower irrigation treatments and control which showed that plantain respond favourably to water application. In the rainfed farming systems of the tropical region, where water supply is often limited due to erratic rainfall pattern, agronomic practices should aim to utilize the water available for crop growth in an efficient way. Improved production from a limited water supply can result from increasing the total amount of water used by the crop through supplemental irrigation. Therefore, to achieve higher CWP and profitability from this crop, supplemental irrigation was required to grow the crop in rainfed tropical regions.

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