Water Use, Growth, and Yield of Drip Irrigated Cassava in a Humid Tropical Environment

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Abstract: Field experiments were conducted at the Agricultural Engineering Experimental Farm of The Federal University of Technology, Akure, during 2006/2007 and 2007/2008 seasons to investigate the response of cassava under drip irrigation. The experiment was laid out in a randomised complete block design (RCBD) with three replications. The treatments were based on four different water regimes; with T_{100} receiving 100% available water (AW), T_{50} and T_{25} receiving 50% and 25% of AW and T_0 with zero irrigation (control treatment). Disease free stems of the cassava cultivar TMS 91934 were planted at a spacing of 1 m by 1 m. The results indicated that T_{100} full treatment produced the highest average total dry matter yield of 49.12 and 37.62 t/ha in 2006/07 and 2007/08 cropping seasons, respectively. However, the average total dry matter production in T_{50}, T_{25}, and T_0 showed significant differences in their values. Low total dry matter yields of 7.12 and 5.92 t/ha, respectively, were associated with T_0 for the two cropping seasons. The total water use of 1491.75 and 1701.13 mm was recorded for T_{100}, while total water use of 729.00 and 651.13 mm were obtained for T_0 in the two cropping seasons. The water use efficiency determined for the two cropping seasons ranged between 7.38 kg/ha and 32.93 kg/ha. The percentages of total water applied from total water use for T_{100} were 51.11% and 61.72%, while 14.83% and 17.85% were recorded for T_{25} for 2006/07 and 2007/08 cropping seasons, respectively.

Keywords: cassava; drip irrigation; irrigation regimes; soil-water regimes; supplemental irrigation; water use, water use efficiency; yields

Cassava is one of the most important staple foods in the human diet in the tropics, and ranked as the sixth most important source of calories in the human diet worldwide (FAO 1996; Alfredo *et al.* 2000). Oguntunde (2005) reported that total production of cassava in Africa had increased from 35 to 80 million tons between 1965 and 1995, with Nigeria leading the rest of Africa. In many parts of Africa, cassava leaves and tender shoots are consumed; because the leaves contain about 7% of protein (fresh weight) and a high level of lysine (Mabrouk *et al.* 1987). Cassava is a competitive crop, especially for the production of starch, animal feed, and alcohol production (Fuglie 2002; Oguntunde 2005).

Cassava is well known as a resistant crop, especially to climate and soil conditions. It can grow in places where cereals and other crops do not grow well. It can tolerate drought and can grow in low-nutrient soil. With a better planting material (stem) and improved input management, the productivity of cassava could be doubled (IFAD and FAO 2000). A study by El-Sharkawy (1993) shows that cassava can be cultivated in areas receiving less than 300 mm rainfall per year with a dry season of four to six months.

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Studies have indicated that, when water is available, cassava maintains a high stomata conductance and can keep the internal CO_2 concentration high, but when water becomes scarce, it closes stomata in response to even a small decrease in soil water potential. The rapid closure of cassava stomata and the resulting decline in transpiration lessens the decrease in leaf water potential and soil water depletion, thus protecting leaf tissues from turgor loss and desiccation (El-Sharkawy & Cock 1984; Palta 1984; Cock *et al.* 1985).

In recent years, there has been a tremendous increase in the research effort to improve the production of this important crop (Connor & Palta 1981; Mohammed *et al.* 2006). Most of the efforts (Hillocks 2002; Aina *et al.* 2004; Oguntunde 2005) were focused on enlargement of the in area under cultivation and the development of high yielding and drought tolerant varieties. It was also observed that the possibility of increasing the production per unit land area under cultivation using supplemental irrigation is little exploited. However, for the purpose of precise water applications, it is essential to understand fully cassava response to water deficit as well as to define the water use and its regulation under different field conditions. Most publications reporting on the response of cassava to water deficit were conducted under controlled environment (Oguntunde 2005). The results of those experiments require confirmation under natural environmental conditions.

Drip irrigation with its ability of small and frequent water applications have created interest in view of decreased water requirements, possible increased production, and better product quality (Connor *et al.* 1981; Mohammed *et al.* 2006). Edoga and Edoga (2006) reported that with drip irrigation, the soil is maintained continuously in a condition which is highly favourable to the crop growth. As the applications are located close to the plant root zone, the losses caused by through drainage or by wetting inter-rows and ridges are minimised. The report stated that drip irrigation generally compare favourably with other types of irrigation both in terms of crop yield and water conservation. Drip irrigation has proved to be a success in terms of water and increased yield (Bhardwaj 2001). Therefore, the objective of this study was to examine the water use, growth, and yield of cassava under different water regimes using the drip irrigation technology that can be easily transferred to the local farmers that are involved in the cultivation of cassava in Nigeria.

MATERIAL AND METHODS

Location of field experiment

This study was conducted at the Agricultural Engineering Experimental Farm of the Federal University of Technology, Akure (lat. 7°17'N, long. 5°8'E, and altitude of 388 m a.s.l.). It is a tropical rainforest zone of southern Nigeria, which is characterised by distinct wet and dry seasons. The soil of the experimental field is sandy clay loam soil, which is an alfisol classified as clayey skeletal oxic-paleustaif (USDA). (Agele 2003). The soil physical and chemical properties at the experimental site and the soil depth of 0.30–0.40 m are presented in Table 1.

Experimental treatments description

The field was planted with TMS 91934 cassava (*Manihot esculenta* Crantz) obtained from IITA, (International Institute of Tropical Agriculture), Ibadan, Nigeria on 1st December, 2006, and 25th October, 2007. The experiments were laid out in a randomised complete block design (RCBD) consisting

Table 1. Soil physical and chemical properties at the experimental field in the soil depth of 0.30–0.40 m

Parameters	Values
Sand (%)	47.7
Clay (%)	27.6
Silt (%)	23.7
Organic carbon (g/kg)	1.31
Organic matter (g/kg)	2.25
pH	6.22
Nitrogen (mg/kg)	0.13
Phosphorus (mg/kg)	5.69
Potassium (mg/kg)	0.65
Calcium (cmol/kg)	2.80
Magnesium (cmol/kg)	0.50
Iron (mg/kg)	17.94
Copper (mg/kg)	6.18
Manganese (mg/kg)	0.31
Zinc (mg/kg)	8.17
Silicon (mg/kg)	2.74
Chloride (mg/kg)	2.81
Boron (mg/kg)	0.65
Bulk density (mg/m^3)	1.29

of four treatments with three replicates. Each plot size was 4 × 3 m separated by 1 m wide spacing for demarcation between plots making twelve plots. Also twelve cassava stems with five to seven nodes were planted horizontally per each plot at a spacing of 1 m by 1 m. The crop was maintained at near field capacity for the first month to enhance good crop establishment.

Four different water regimes, three of which were based on fractions of available water (AW), are presented in Table 2. A simple drip irrigation technology with low gravity bucket was adopted for the experiment. Drip laterals were laid out at 1.0 m spacing between the rows. The drippers were placed at 1.0 m apart along the lateral line with a discharge capacity of 4 l/min each.

Cultural practices and measurements

The experimental site was slashed manually, ploughed and harrowed in order to pulverise the soil. Cassava stems (Cultivar TMS 91934) were planted on December 1st, 2007, and October 25th, 2008. All plots were manually weeded on days 40, 90, 150, and 210 after planting (DAP). Soil moisture content was measured weekly at 0.1 m interval up to 0.5 m by gravimetric method. Agronomic parameters measured were the plant height, from the base of the plant to the apex of the youngest leaf by means of a meter rule, number of leaves by counting, stem girth, from the first node of every plant above soil level with the aid of Vernier Caliper, Harvest Index (HI, the tuber: total-biomass ratio), Leaf Area Index (LAI) observed monthly, biomass determination performed on days 120, 150, 180, 210, 240 and 270 (DAP); respectively. The yield and yield components were determined as the harvested plants were separated into leaves, stems, and tubers. Sub-samples of the plant parts were taken to determine the average dry matter content. The tuber length, root depth, number of tubers per plant, and tuber circumference were measured. The rainfall, evaporation, maximum and minimum air temperatures and relative humidity, shortwave solar radiation, and wind speed were monitored throughout the experiment at the meteorological station of the Meteorology department, FUT-Akure, at 500 m from the experimental site.

RESULTS

Meteorological conditions

The variations in the rainfall (mm), minimum and maximum temperatures (°C), minimum and maximum relative humidity (%), wind speed (km/h), solar radiation (MJ/m/day), mean temperature (°C), mean relative humidity and solar radiation for the period of experiments are shown in Figure 1. Total rainfall in 2007 and 2008 was 1350 and 1247 mm, respectively, as compared to the average of 1271 mm for a ten-year period (1997–2007) recorded at the site. Hence, the rainfall condition in 2007 was well above 10 years average while that in 2008 was below the average. A total of 872 and 795 mm of rainfall were recorded in 2006/07 and 2007/08 for the nine months of experimentation (i.e. 270 days after planting – DAP). Mean daily maximum temperatures ranged from 28 to 36°C and 26 to 35°C while minimum temperatures ranged from 15 to 24°C and 16 to 23°C, respectively, for the two cropping seasons. The highest maximum temperature was recorded in March for 2006/07 and 2007/08 cropping seasons, whereas the lowest minimum temperature was experienced in December for the two cropping seasons. The mean daily solar radiation for the two cropping seasons varied from 4 to 21 MJ/m^2/day and 3 to 19 MJ/m^2/day. The maximum daily relative humidity ranged from 55 to 100% and 67 to 100% while the minimum daily relative humidity ranged from 18 to 78% and 15 to 79%, respectively, for the two cropping seasons.

Table 2. Experimental treatment description for 2006/07 and 2007/08 cropping seasons

Treatment No.	Treatment label	Description
1	T_{100}	full water regime (i.e. 100% AW)
2	T_{50}	medium water regime (i.e. 50% AW)
3	T_{25}	low water regime (i.e. 25% AW)
4	T_0	control (i.e. rain-fed as practiced by local farmers)

AW – available water

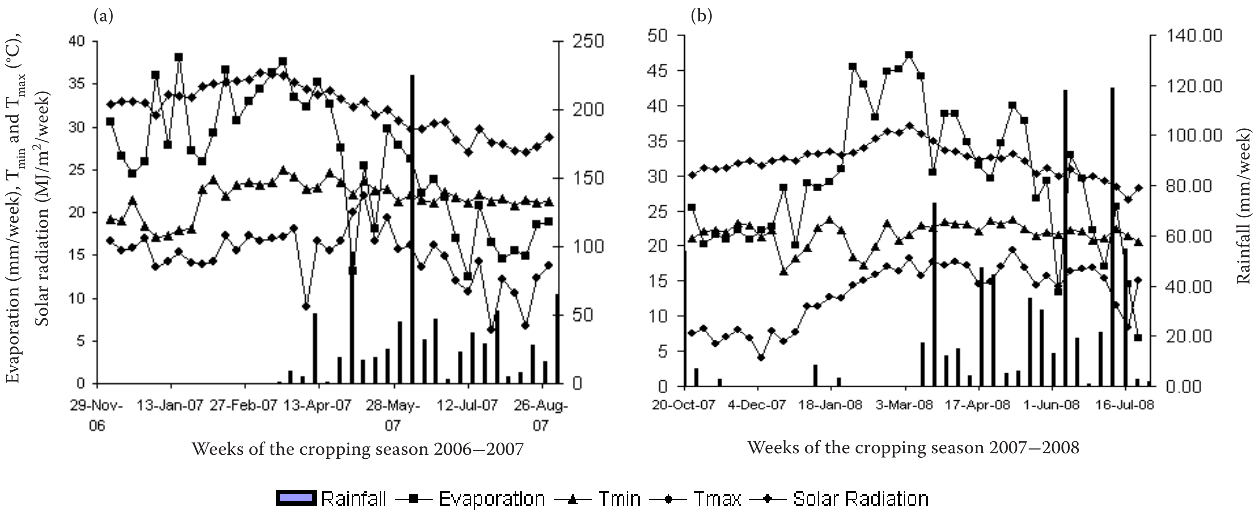

Figure 1. Weekly evaporation (Pan A) and rainfall, mean maximum and minimum temperatures, and mean solar radiation during (a) 2006/07 and (b) 2007/08 cropping seasons

Agronomic growth

The patterns of the leaf number of cassava with time (DAP) in 2006/07 and 2007/08 cropping seasons were similar. At 74 DAP (i.e. Developmental stage) for the two cropping seasons, T_{100} had the highest average leaf number, with T_0 having the least value. The maximum values of the average leaf number for the two cropping seasons were recorded on day 186 (DAP) (i.e. late-season stage), with the reduction in the average leaf number noticed on days 193 to 270 (DAP) for all the treatments (Figure 2).

Figure 3 shows the changes of the stem diameter of cassava with time (DAP). The largest average stem diameters on day 74 (DAP) (developmental stage) for T_{100} and T_0 in the two cropping seasons were 0.013 and 0.009 m, respectively. During the mid-season (i.e. on days 86 to 166 DAP), all the treatments experienced a sudden increase in the average stem diameter. The increase in the average stem diameter was smaller towards the late-season (i.e. 172 to 270 DAP) as compared with the mid-season as shown in Figure 3. In all the treatments, T_{100} had the highest value of the average stem diameter in both seasons while T_0 had the least value.

The figures show that the average plant height increased with age (i.e. cassava growth stages) for all the treatments in the two cropping seasons. The highest average plant height of 2.745 m was obtained for T_{100} and the least value of 2.093 m was recorded for T_0 in both seasons, however, the differences in the average plant height for all the treatments were not significant. The average plant height increased rapidly from 158 to 270 DAP referred to as the final harvest, hence, at the end of the two cropping seasons, the highest average plant heights measured

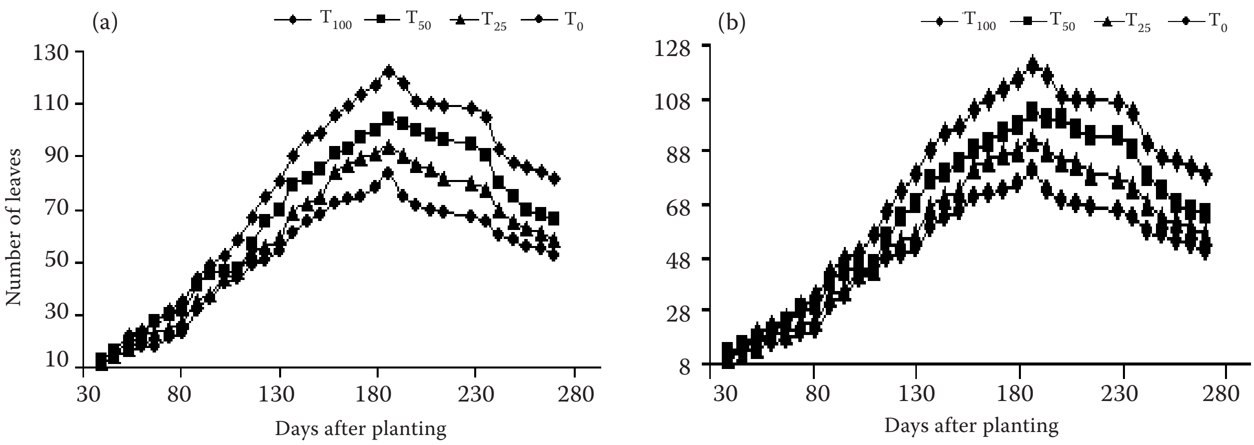

Figure 2. Leaf number of cassava with time (DAP) in (a) 2006/07 and (b) 2007/08 cropping seasons

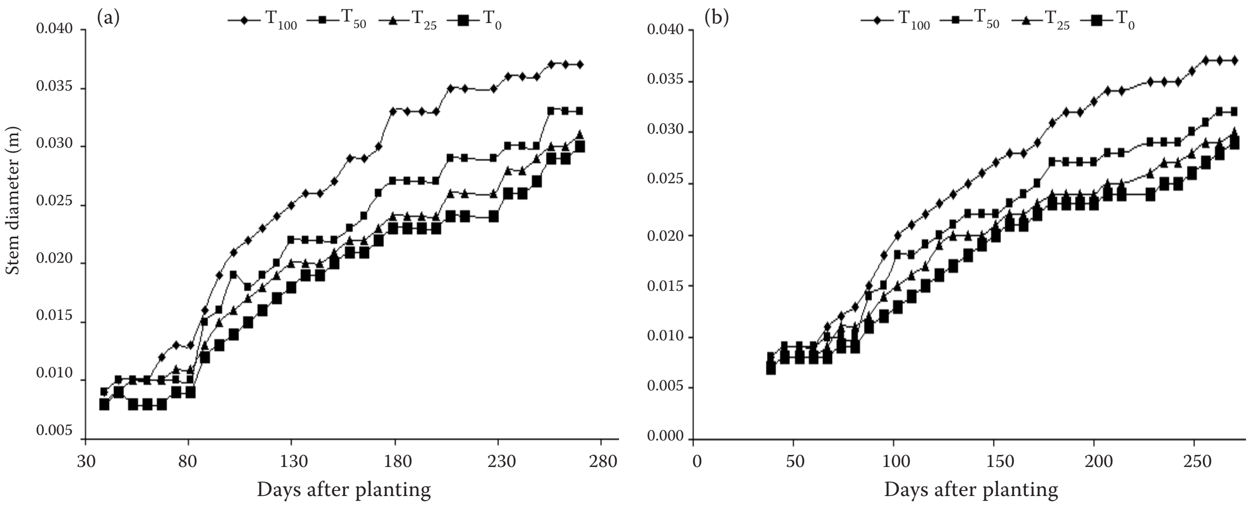

Figure 3. Stem diameter of cassava with time (DAP) in (a) 2006/07 and (b) 2007/08 cropping seasons (stem diameter observed in meters)

were 209.30, 236.20, 255.20, and 274.50 cm for the treatments T_{100}, T_{50}, T_{25}, and T_0, respectively

The average changes in the leaf area index of cassava with time (DAP) in 2006/07 and 2007/08 cropping seasons are presented in Figure 5. The average leaf area indexes for the two cropping seasons were similar, with the values 4.30, 3.95, 3.26, and 2.52 for T_{100}, T_{50}, T_{25}, and T_0, respectively at the final harvest (i.e. 270 DAP).

Biomass production

The average values of dry matter production of leaf, stem, and tuber based on T_{100}, T_{50}, T_{25}, and T_0, can be compared by calculating the average dry matter production per treatment per replicate during the cropping seasons of 2006/07 and 2007/08. The results are presented in Table 3. The average cassava tuber yields of 28.15 and 15.36 t/ha were obtained with T_{100} for the two cropping seasons, while those of 4.56 and 2.98 t/ha were recorded with T_0 for 2006/07 and 2007/08, respectively.

The average total dry matter production (ATDMP) for all the treatments in the period from 120 days after planting to the final harvest for 2006/07 and 2007/08 cropping seasons is shown in Table 4. ATDMP was significantly influenced by the irrigation treatments, and the irrigation with T_{100} at 100% of available water (AW) registered the highest ATDMP of 49.12 and 37.62 t/ha for the two cropping seasons, while the lowest ATDMP

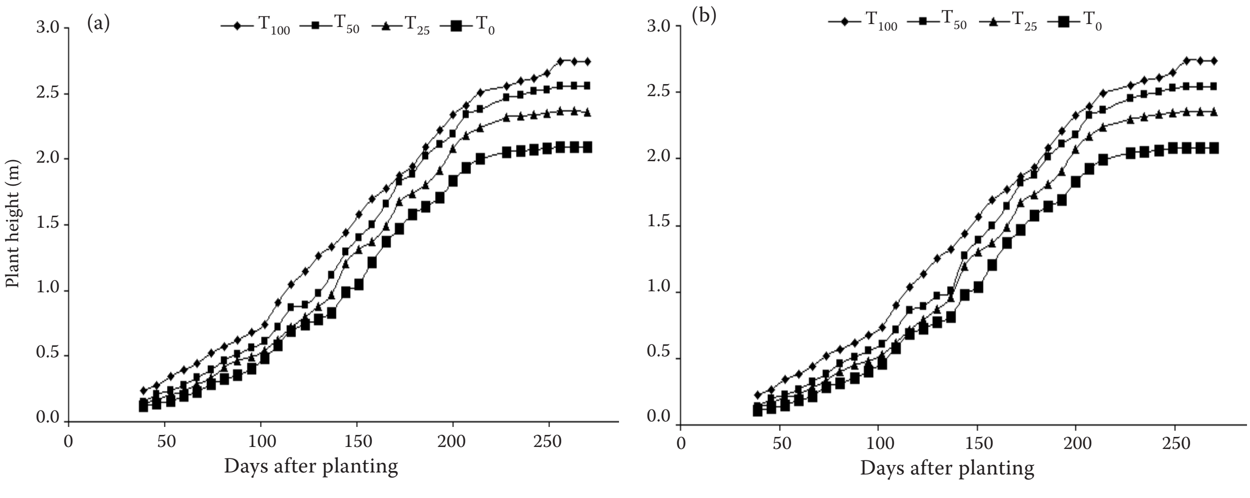

Figure 4. Plant height of cassava with time (DAP) in (a) 2006/07 and (b) 2007/08 cropping seasons (plant height measured in meters) not reffered to in the text

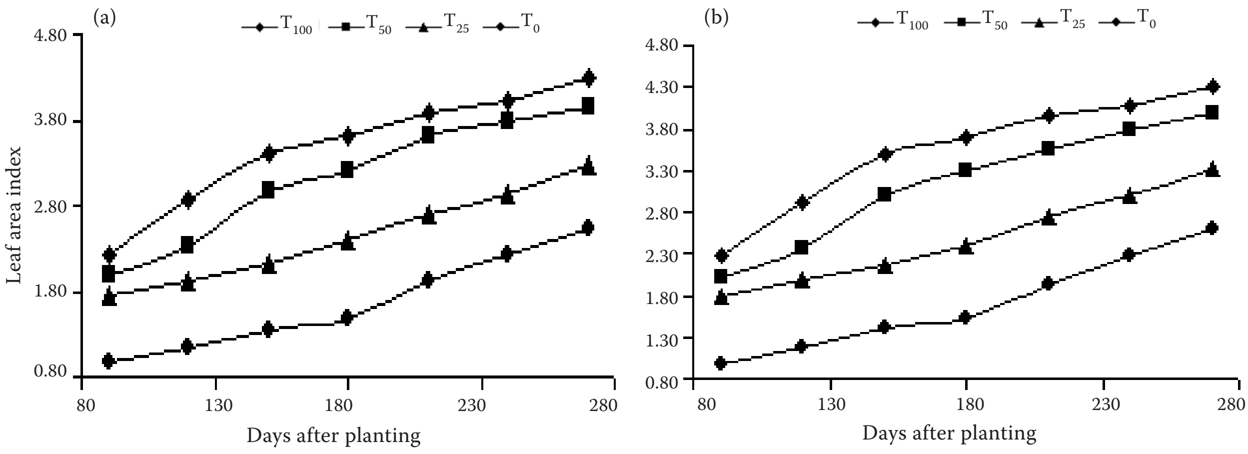

Figure 5. Average leaf area index of cassava with time (DAP) in (a) 2006/07 and (b) 2007/08 cropping seasons

of 7.12 and 5.92 t/ha were obtained for the two cropping seasons.

The average total dry matter production (ATDMP) and average tuber yield increased with the crop age for all the treatments with T_{100} giving the highest values of 49.12 and 37.62 t/ha in the two cropping seasons followed by T_{50}, and the least values of 7.12 and 5.92 t/ha with T_0 in the two cropping seasons, respectively. During the periods of cropping season, average total dry weight increase was high in T_{100} and similar for T_{50}, T_{25}, and T_0. Cassava with the treatment T_{100} produced the average total biomass of 49.12 t/ha with the tuber yield of 28.15 t/ha, while T_{50}, T_{25}, and T_0 produced the average total biomass and tuber yields of 27.47 and 13.11 t/ha; 14.56 and 8.53 t/ha and 7.12 and 4.56 t/ha, respectively, in

Table 3. Leaf, stem and tuber productivity (t/ha dry weight) under different irrigation water regimes from 120 days after planting (DAP) to final harvest

Treatment	2006/07							2007/08						
	120	150	180	210	240	final harvest	STD	120	150	180	210	240	final harvest	STD
Leaf productivity														
T_{100}	1.83	2.81	3.32	3.20	2.64	6.07^a	0.01	1.64	2.70	3.07	3.07	2.53	5.77^a	0.16
T_{50}	1.11	1.63	2.46	3.01	2.07	7.07^b	0.05	1.03	1.51	2.57	2.83	1.93	3.66^b	0.20
T_{25}	0.55	1.19	2.06	1.67	1.97	1.98^c	0.01	0.51	1.11	1.94	1.52	1.82	2.75^c	0.08
T_0	0.42	0.78	1.25	1.04	1.32	1.20^d	0.03	0.35	0.64	1.16	0.91	1.32	1.44^d	0.10
Stem productivity														
T_{100}	0.82	1.55	2.16	5.12	6.17	15.47^a	0.04	0.73	1.65	2.01	4.96	6.07	16.50^a	0.37
T_{50}	0.54	1.56	1.22	3.95	4.94	7.29^b	0.03	0.45	1.46	1.18	3.81	4.77	9.28^b	0.28
T_{25}	0.41	1.40	1.35	1.65	4.16	4.55^c	0.02	0.37	1.30	1.13	1.53	4.16	4.60^c	0.06
T_0	0.33	0.90	0.80	1.26	1.94	1.36^d	0.01	0.30	0.77	0.70	1.15	1.94	1.50^d	0.08
Tuber productivity														
T_{100}	1.52	3.15	3.38	4.16	16.03	28.15^a	0.02	1.45	3.02	3.22	4.02	15.89	15.36^a	0.43
T_{50}	0.71	2.98	1.77	1.75	10.33	13.10^b	0.03	0.65	2.77	1.57	2.55	10.22	9.20^b	0.15
T_{25}	0.37	2.72	0.97	2.78	4.23	8.53^c	0.04	0.33	2.58	0.86	1.64	4.23	6.43^c	0.16
T_0	0.34	0.52	0.69	0.98	1.37	4.66^d	0.05	0.30	0.47	0.63	0.89	1.38	2.98^d	0.17

Table 4. Effects of different water regimes on the average total dry matter production (t/ha) of cassava in 2006/07 and 2007/08 cropping seasons, from 120 days after planting (DAP) to final harvest

Treatment	2006/07							2007/08						
	120	150	180	210	240	final harvest	STD	120	150	180	210	240	final harvest	STD
T_{100}	4.17	7.74	8.86	12.49	24.84	49.12[a]	0.49	3.83	7.37	8.30	12.05	24.48	37.63[a]	0.52
T_{50}	2.35	6.18	5.66	8.70	17.34	27.47[b]	0.10	2.13	5.73	5.31	9.19	16.73	22.13[b]	0.38
T_{25}	1.37	5.31	4.38	6.11	10.36	14.56[c]	0.05	1.21	4.99	4.02	4.69	10.22	13.78[c]	0.20
T_0	1.08	2.20	2.75	3.28	4.64	7.12[d]	0.08	0.94	1.88	2.49	2.96	4.64	5.92[d]	0.30

2006/07 cropping season (Table 4). Harvest Index (HI, the tuber: total-biomass ratio) of 0.64 and 0.42 were recorded for T_{100} in the first and second seasons, respectively, while HI for T_{50} to T_0 ranged from 0.69 to 0.38 in the two cropping seasons.

Yield attributes

Among the yield attributes, the average number of tubers per plant was favourably influenced by the percentage of water applied. The highest values throughout the cropping seasons (Table 5) were observed with the treatment T_{100}.

Average total soil water storage

Figures 6a and b show the average total soil water storage in 2006/07 and 2007/08 cropping seasons with time (DAP). The total water storage in the root zone at the developmental stage of cassava (i.e. 60 DAP) ranged between 4.76 and 6.67 mm with T_{100} and 1.84 and 2.58 mm with T_0 for the two cropping seasons. The highest average total water storage of 18.59 and 3.39 mm in T_{100} and T_0 on day 144 (DAP) (i.e. mid-season stage) was recorded in 2006/07 cropping season. Towards the late-season, that is, 242 DAP, the highest average total water storage of 15.33 and 6.21 mm were observed for T_{100} and T_0 in 2007/08, respectively. It was generally observed that the average total water storage was high in T_{100}, followed by T_{50} and with T_0 showing the least value as shown in Figures 6a and b for the two cropping seasons.

Water use efficiency

The treatment T_{100} consumed 1491.75 and 1701.13 mm of water in 2006/07 and 2007/08 cropping seasons, respectively, while the treatments T_{50}, T_{25}, and T_0 consumed 1100.50 and 1097.19 mm; 856.21 and 792.57 mm and 729.25 and 751.13 mm, respectively, in the two cropping seasons. For the two cropping seasons, the values of water use efficiency ranged from 4.58 to 18.87 kg/ha (Table 6). The percentage of total water applied from the total water use ranged from 14.83 to 61.72% for the seasons. Also, the fractional increase in water use efficiency demonstrated the highest value of 2.02 in 2006/07 and the lowest value of 0.30 in 2007/08 for the two seasons (Table 6).

Table 5. Effects of different water regimes on yield attributes

Treatments	2006/07				2007/08			
	tubers per plant	tuber length (m)	tuber circumference (m)	root depth (m)	tubers per plant	tuber length (m)	tuber circumference (m)	root depth (m)
T_{100}	7	0.435	0.300	0.500	7	0.403	0.252	0.401
T_{50}	5	0.355	0.266	0.392	5	0.321	0.198	0.324
T_{25}	4	0.275	0.220	0.347	4	0.238	0.168	0.291
T_0	3	0.226	0.170	0.310	3	0.191	0.142	0.251

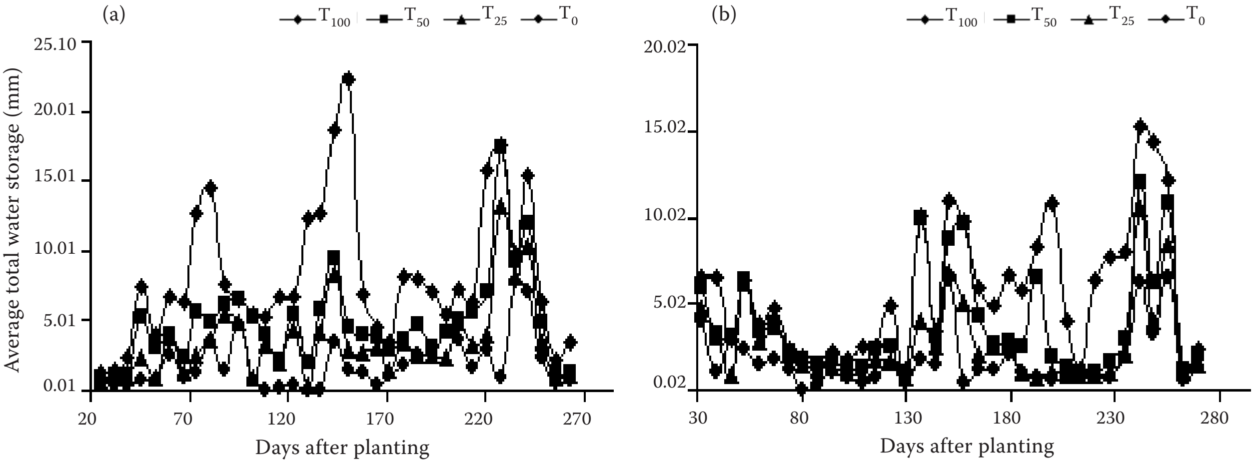

Figure 6. Average change in total soil water storage with time (DAP) in (a) 2006/07 and (b) 2007/08 cropping seasons

DISCUSSION

Total amounts of rainfall during the field experiment for the two cropping seasons (i.e. 2006/07 and 2007/08) were 872 and 795 mm, respectively. This amount of rainfall falls below the annual rainfall of more than 1000 mm reported by IITA (2007) for high yield production. However, supplemental irrigation is inevitable in order to increase the cassava yield rather than the expansion of cultivated lands. The mean daily maximum temperature oscillated between 28 and 36°C in the first season and 26 and 35°C in the second one while the mean daily minimum temperature ranged between 15 and 24°C and 16–23°C, respectively, for the two seasons. The highest mean daily maximum temperature values were recorded in March, while the highest mean daily minimum temperatures occurred in December in the two cropping seasons. Comparing the ten years daily maximum and minimum temperature values at the study site with the highest mean daily maximum and minimum temperatures obtained followed the same trend. The highest mean daily minimum temperature observed in December may be due to harmattan. The general environmental conditions resembled those in the experiments reported by Ekanayake (1993) and IITA (2007). It was noted that the evaporation, temperature, and solar radiation showed little variation, while the rainfall pattern varied greatly between the cropping seasons during the experiments as illustrated in Figure 1. Rainfall was low in 2007/08 compared to 2006/07 cropping season, the difference in the average total dry matter production having been due to the availability of more water in 2006/07 cropping season than in that of 2007/08, which shows that cassava may have

Table 6. Total water use, water use efficiency and fractional use in water use efficiency in different irrigation treatment

	2006/07				2007/08			
	T_{100}	T_{50}	T_{25}	T_0	T_{100}	T_{50}	T_{25}	T_0
Irrigation water applied (mm)	762.50	381.25	126.96	0.00	1050.00	446.06	141.44	0.00
Effective rainfall (mm)	729.25	729.25	729.25	729.55	651.13	651.13	651.13	651.13
Total water used (mm)	1491.75	1110.50	856.21	729.55	1701.13	1097.19	792.57	651.13
Total applied water to TWU (%)	51.11	34.33	14.83	0.00	61.72	40.65	17.85	0.00
Tuber yield (kg/ha)	28150	13100	8530	4550	15350	9200	6420	29860
Relative yield (%)	100	46.54	30.30	16.16	100	59.93	41.82	19.41
Water use efficiency (kg/ha/mm)	18.87	11.80	9.96	6.24	9.02	8.39	8.10	4.58
Fractional increase in WUE	2.02	0.89	0.60		0.45	0.34	0.03	

been affected by soil water deficit, (Table 4). Similar results were found by Baker (1986).

The leaf development was observed right from the crop establishment/development (i.e. 1–35 DAP/36–85 DAP) to the crop mid-season stage (i.e. 86–166 DAP). Also, the decrease in the leaf number was observed from the crop late-season stage (i.e. 167–270 DAP) (Figure 2). This result was similar to that in the experiment reported by IITA (2007). The sudden increase in the average stem diameter was due to the onset of rainfall at the crop mid-season stage; while the smaller increase in the average stem diameter towards the crop late-season stage shows that the water intake by cassava was not used during the late-season for the stem development, but for the tuber formation, (Mabrouk *et al.* 1987 and Matthews & Hunt 1994). The average plant height values recorded for the two seasons were similar (Figure 4). The rapid increase in the average plant height discovered 158 DAP (i.e. mid-season stage) to 270 DAP (i.e. late-season stage) may be the result of additional water coming from precipitation that relieved the crop from the stress condition in all the treatments (Mabrouk *et al.* 1987). The average values of the leaf area index for the two cropping seasons were in the same range as the values obtained 120 DAP with the same cultivar planted in IITA, Ibadan (IITA 2007). In the non stressed plots (i.e. T_{100}), the average leaf area index reached 4.30, whereas T_0 (stressed plots) hardly reached 2.52 in 2006/07 cropping season, (Mabrouk *et al.* 1987; IITA 2007).

The comparison of the growth under T_{100} observed in the present study with other results found under similar experimental conditions and reported by Keating *et al.* (1982), Fukai *et al.* (1984) and Baker (1986) revealed closely similar values of ATDMP, average tuber yield per plant, average tuber length, and average tuber circumference. For example, ATDMP of 49.12 and 37.62 t/ha obtained in 2006/07 and 2007/08 cropping seasons with T_{100}, were close in values to the values of 49.40 and 38.10 t/ha obtained by Lilley *et al.* (1988) and Mohammed *et al.* (2006). On the other hand, average total dry matter production of 49.12 and 37.62 t/ha with dry tuber yield of 28.15 and 15.35 t/ha obtained in 2006/07 and 2007/08 cropping seasons with T_{100} were higher than total dry biomass of 25.00 and 24.10 t/ha obtained by Mohammed *et al.* (2006) for the same growth period. It was also observed that the average dry tuber yield of 15.35 t/ha obtained at T_{100} in 2007/08 cropping season was in the same range with the average dry tuber yield of 16.00 t/ha recorded by Lilley *et al.* (1988). The variations in the average total dry matter production and tuber yield (dry matter) were due to the soil nutrients, regime of water application, environmental conditions and cassava cultivar (Manickasundaram *et al.* 2002; Lincoln 2005; Mohammed *et al.* 2006; IITA 2007). The decrease experienced in ATDMP in the second season compared to the first season in Table 4 was due to the reduction of nutrients in the soil, and this result is similar to that reported by Lincoln (2005). The increments in the ATDMP based on DAP and water application were noticed in all the treatments with T_{100} showing average increments of total dry matter production of 4.17, 7.14, 8.86, 12.49, 24.84 and 49.12 t/ha and 3.82, 7.36, 8.30, 12.05, 24.48 and 37.62 t/ha for 120, 150, 180, 210, 240 and 270 days after planting, respectively, for the two cropping seasons (Table 4). The low average total dry matter production in T_{50}, T_{25}, and T_0 may have been caused by the effect of different water regimes applied (Table 4). Mohammed *et al.* (2006) recorded higher values in total dry matter production with 100% of water application in drip irrigation system. The mean differences in dry leaf, stem, tuber, and total dry matter production at final harvest (270 days after planting) for the two seasons shown in Tables 3 and 4 between the treatments in each of the plot were highly significant. Also standard tests showed in each treatment that there significant differences in dry leaf, stem, tuber and total dry matter production. Harvest Indexes (HI, the tuber: total biomass ratio) of 0.64 and 0.42 were recorded with T_{100} in the first and second seasons, while HI with T_{50} to T_0 ranged from 0.69 to 0.38 in the two cropping seasons. The decrease in HI values in the second season as compared with the first season was due to the decrease in the average total dry matter production and dry tuber yield experienced in the second season, which resulted from the low nutrient level of the soil during the second cropping season (Lincoln 2005; IITA 2007). The differences in the yield attributes and average total dry matter production occurring 270 DAPS in all the treatments as shown in Tables 4 and 5 were apparently associated with the differences in the water regime. It was noted that T_{100} had the highest yield attributes and ATDMP followed by T_{50}, T_{25}, and T_0. Manickasundaram *et al.* (2002) and Mohammed *et al.* (2006) reported similar improvement in the yield attributes and total dry biomass of cassava on using drip irrigation at 75% of surface irrigation and continuous application of water at optimum level under varying water regimes. The variation in water storage resulted from the differences in water amount applied in the respective treatments. The highest average values of total water storage of 18.59 and 3.39 mm determined at T_{100} and T_0 144 DAP (mid-season stage) in 2006/07 cropping season were due to the differences in the water application. Also, at the late-season stage of cassava growth, with T_{100} was recorded the highest average total water storage (Figure 6). The water use efficiency was 18.87 and 9.02 kg/ha/mm in T_{100} with 51.11% and 61.72% of total applied water from total water use, in the two cropping seasons. T_{25} revealed the least water use efficiency and percentage of applied water from total water use. A higher fractional increase in water use efficiency was also recorded in T_{100} (Table 6). These results are in conformity with the findings of Mohammed *et al.* (2006) in cassava production.

CONCLUSION

The results of this study confirmed earlier findings and added new clear field evidence of cassava response to different water regimes through supplemental irrigation. From this study, it can be recommended that in moderate water scarcity area, drip irrigation with T_{50} could be used for achieving higher yields of cassava. Also, in areas where water is very scarce, drip irrigation with T_{25} can be applied to obtain yields higher than under $T_{0,}$ with zero irrigation.

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