The African Journal of Plant Science and Biotechnology ©2010 Global Science Books

Growth Performance of Three Kenaf Varieties Grown under Water Stress in Eastern Nigeria

Francis A. Nkaa* • **Chuks I. Ogbonnaya** • **Nwanma B. Onyike**

Department of Plant Science and Biotechnology, Abia State University, Uturu, Abia State, Nigeria

Corresponding author: * **nkafrank@yahoo.co.uk**

ABSTRACT

The effects of water deficit on the growth performance of three certified improved varieties of kenaf (*Hibiscus cannabinus* L. cvs. 'Tainung #2', 'SF 459' and 'Everglades 41') used for pulp and paper production were investigated. The plants, which were grown in the field on deep sandy-loam soil, were subjected to three irrigation regimes representing well-watered control, moderate stress and severe water stress. Water deficit profoundly reduced all aspects of vegetative growth including plant height, collar diameter, leaf development, branching, flowering and biomass accumulation. The moderate water stressed plants attained an average height of 126.44 cm and severely stressed 99.34 cm and thus reduced height by 23 and 39%, respectively of the control that attained a mean height of 163.44 cm. Collar diameter growth of severely stressed plants were retarded by 43% of the control having a basal diameter of 9.25 mm, moderately stressed retarded growth by 27% and the plants reached a radial diameter of 11.75 mm when compared with the control whose basal diameter growth was 16.14 mm. Although water stress affects all aspects of kenaf growth by reducing the biomass produced, it sometimes improves the quality of plants products.

Keywords: agro-morphology, *Hibiscus cannabinus*, water deficit, watering regime

INTRODUCTION

Kenaf (*Hibiscus cannabinus* L.) is an annual non-woody fibre crop that has received increased attention in the Western world during the past decade as a wood pulp supplement. The crop is a fast-growing herbaceous plant with a life-span of 100-150 days (Dempsey 1975).

Interest in kenaf as an annual pulp and biomass source has increased substantially with the gradually diminishing supplies of hardwoods and softwoods in the world and the increasing demands for cellulosic materials (White *et al.* 1970; Wood and Stewart 1981). A number of kenaf varieties for example 'Cuba 108', 'Everglades 71' and 'Guatemala 45'are agronomically suitable for production of paper pulp in the United States and other countries around the world (Robinson 1988; Sellers *et al*. 1993; Nkaa *et al*. 2007).

The species in wild or cultivated forms is found in many temperate and tropical areas of the world. Kenaf is reported to tolerate a wide range of soil conditions (White *et al.* 1970).

In Africa, kenaf is grown traditionally for cordage and has served as an important crop source of textile fibres. Wilson *et al.* (1965) reported that the fibre is used for the manufacture of twines, ropes, burlap bags and rug backing. In Nigeria, the crop is cultivated in the North where the leaves are eaten as vegetable. The plant tops, when ground, have high digestibility and can be used as feed for cattle and sheep (Killinger 1969; Swingle *et al.* 1978; Webber 1992).

There are few or no reports regarding the cultivation and growing of this all-purpose crop plant in the Eastern part of Nigeria. However, Ogbonnaya *et al.* (1997) carried out a pot experiment in which they investigated the growth and water relations of kenaf under water stress on a sandy soil. Hence this study is aimed at investigating the growth responses of kenaf cultivars grown in the field under moisture stress, to enable the scheduling of irrigation.

MATERIALS AND METHODS

Seed collection

Certified seeds of kenaf (*Hibiscus cannabinus* L.) were collected from the Agricultural Research Service of the United States of America Department of Agriculture (ARS-USDA). Three cultivars ('Tainung #2' (V1), 'SF 459' (V2) and 'Everglades 41' (V3)) were used for the study. These varieties were chosen on the basis of their high yield in terms of bast-core ratio, i.e. bark-wood ratio and resistance to diseases such as anthracnose, damping-off and nematodes.

Study area and cultural conditions

This experiment was conducted at the Abia State University, Uturu Botanical Garden (7° 6′ N, 6° 0′ E, 122X m asl) on a deep loam sandy soil. The characteristics of the soil were analysed using the method of Page *et al.* (1982).

The field was cleared of bush, ploughed and beds of 4 m × 4 m made. Five kenaf seeds per hole were planted at a soil depth of 3 cm in a spacing distance of 20 cm between plants and 50 cm between rows to give a total of 160 plants/plot (equivalent to 100,000 plants/ha). The seeds germinated within 2-4 days after planting given a germination rate of 90% for 'Tainung #2', 50% for 'SF 459' and 30% for 'Everglades 41'. The resulting seedlings were later thinned down at the two-leaf stage to one plant per stand, to obtain plants with uniform growth vigour and density.

In order to ensure optimum crop yield, all plots received 320 g of NPK fertilizer (12:12:17), equivalent to 200 kg/ha aimed at removing nutrient deficiency as a limiting factor. Plots were kept weed-free by hand hoeing. The test plants were ridded of insect pests by application of dimethylcyclopro-panecarboxylate insecticide following instruction on the label. The experiment lasted for a period of 5 months (15th Nov., 2002 – 10th March, 2003).

Received: 13 November, 2008. Accepted: 12 August, 2010.

Original Research Paper

Irrigation application

The experimental field was uniformly irrigated to field capacity by watering and allowed to drain before seeding. The seedlings were subjected to uniform irrigation at weekly intervals from sowing to 21 days after sowing. This was to ensure uniform seedling establishment before the imposition of the treatments.

Water deficit treatments were imposed on the test plants three weeks after germination when they had attained the four-leaf stage. A standard rain-gauge was mounted in the field in order to measure the quantity of water added to the plants through rainfall. The experimental plots were subjected to three levels of irrigation regimes as follows:

Control (L1): Control plants received a total of 650 mm of irrigation during the growth period. Under this regime, the crop plants received 20.3 mm of irrigation twice weekly throughout the experimental period. These numbers were chosen based on the records obtained from the Agrometrological Unit of the National Root Crops Research Institute (NRCRI), Umudike on the amount of rainfall per annum in the easthern region for the control and the amount of rainfall recorded in the northern region for the severe stress.

The quantity of water (litre) applied was obtained from the relationship:

1 mm of irrigation/rainfall = 1 litre/m^2. This implies that an area of 1 m^2 will receive a volume of 1 litre of water.

Mild water deficit (L2): The plants receive 14.1 mm of irrigation twice a week giving rise to a sum total of 450 mm of irrigation for the 4-month period.

Severe water deficit (L3): The plants under this regime were mostly stressed by subjecting them to 7.8 mm of irrigation twice a week, which amounted to a total of 250 mm of irrigation for the four-month duration.

Experimental design and statistical analysis

The experiment was based on a split plot design. The three irrigation regimes constituted the main plots and the three kenaf varieties as the sub-plots. The watering treatments were replicated three times to give a total of 27 experimental units. The experimental layout size was 660 m^2 consisting of three rows, each with a total of nine experimental plots/units of 4 m × 4 m. The biometric and productive determinations were performed on a minimal area of 4 m^2 in the inner part of each plot. The entire layout was surrounded with a row of border plants to protect the plants against external influences. Data obtained were subjected to analysis of variance using SPSS computer software (version 16) and means separated using Duncan's Multiple Range Test at $P \leq 0.05$.

Agro-morphological measurements

Three plants were randomly harvested at each sampling session from the experimental plots. The plants were cut at the ground level and the following growth parameters were measured:

Plant height was measured with the aid of a metre rule from the base of the stem at the root-collar to the terminal bud of the main stem. The root-collar diameter was measured at the collar to the nearest 0.01 mm with a calliper gauge (15-100-100 Manostat).

Dry matter production was obtained by carefully separating the shoot into leaves, bark, wood core and the floral parts when available. The bark was separated manually from the central wood core by peeling. The separation was made easier by cutting the stems into 10 cm lengths. The separated components were oven-dried at 85°C until constant weights were obtained. The dry weight of each component parts was determined to the nearest 0.01 g on a top-loading weighing balance (Metler P1200). The bark-wood ratio was determined as the ratio of the dry weight of the bark to the dry weight of the wood. These measurements were made fortnightly beginning from the date of the application of the treatments.

RESULTS

Growth

The effect of water stress on height growth and stalk diameter of the three kenaf cultivars grown in the field are shown in **Tables 1**, **2**. Water deficit reduced the cumulative height growth of the three kenaf plant cultivars when compared with the control. Kenaf plants under continuous irrigation vigorously increased plant height throughout the experimental period. Plant height increased slowly with the plants under stress, with severe stress having the most detrimental effect on plant height (**Table 1**). At the end of the growth period, the control attained an average height of 163.44 cm, moderate stress 126.14 cm and severe stress 99.34 cm. Moderate stress therefore, reduced height by 23% and severe stress by 39% of the control.

Table 1 Effect of watering regime on plant height of three kenaf cultivars ('Tainung #2' (V1), 'SF 459' (V2), and 'Everglades 41' (V3)) grown in the field.

Growth parameter / Age (weeks)	Variety	Watering regime			
		Well-watered (L1)	Moderate stress (L2)	Severe stress (L3)	Mean
Plant height (cm) at 4th week	'Tainung #2'(V1)	18.43	18.20	15.20	17.28 a
	'SF 459' (V2)	15.47	15.73	12.50	14.57 a
	'Everglades41'(V3)	17.93	13.40	12.40	14.61 a
	Mean	17.28 a	15.78 ab	13.39 b	
Plant height (cm) at 6th week	'Tainung #2'(V1)	51.60	44.05	39.62	45.09 a
	'SF 459' (V2)	46.03	39.13	34.60	39.92 a
	'Everglades41'(V3)	50.10	40.27	38.97	43.11 a
	Mean	49.24 a	41.15 b	37.73 b	
Plant height (cm) at 8th week	'Tainung #2'(V1)	84.42	73.42	57.67	71.83 a
	'SF 459' (V2)	70.53	62.25	58.13	63.64 a
	'Everglades41'(V3)	84.92	75.83	60.25	73.67 a
	Mean	79.96 a	70.50 a	58.68 b	
Plant height (cm) at 10th week	'Tainung #2'(V1)	101.33	76.33	63.58	80.42 ab
	'SF 459' (V2)	98.83	68.25	68.92	78.67 b
	'Everglades41'(V3)	104.83	87.75	73.25	88.61 a
	Mean	101.67 a	77.45 b	68.58 b	
Plant height (cm) at 12th week	'Tainung #2'(V1)	142.17	107.92	93.07	114.38 a
	'SF 459' (V2)	138.08	102.75	92.25	111.03 a
	'Everglades41'(V3)	142.08	105.92	103.58	117.19 a
	Mean	140.78 a	105.53 b	96.30 b	
Plant height (cm) at 14th week	'Tainung #2'(V1)	163.08	126.42	98.60	129.37 a
	'SF 459' (V2)	162.67	125.25	100.58	129.50 a
	'Everglades41'(V3)	164.58	126.75	98.83	130.06 a
	Mean	163.44 a	126.14 b	99.34 c	

Means followed by the same letter in the same row and column are not significantly different.

Table 2 Effect of watering regime on stalk diameter (mm) of three kenaf cultivars ('Tainung #2' (V1), 'SF 459' (V2), and 'Everglades 41' (V3)) grown in the field.

Growth Parameter / Age (weeks)	Variety	Watering Regime			
		Well-watered	Moderate stress	Severe stress	Mean
		(L1)	(L2)	(L3)	
Stalk diameter (mm) at 4th week	'Tainung #2'(V1)	2.51	2.50	2.45	2.49 a
	'SF 459' (V2)	2.80	2.75	2.49	2.68 a
	'Everglades41'(V3)	2.91	2.52	2.20	2.54 a
	Mean	2.74 a	2.58 a	2.38 a	
Stalk diameter (mm) at 6th week	'Tainung #2'(V1)	4.95	3.89	4.19	4.34 a
	'SF 459' (V2)	5.08	4.62	4.25	4.65 a
	'Everglades41'(V3)	5.72	4.90	4.62	5.08 a
	Mean	5.25 a	4.47 b	4.35 b	
Stalk diameter (mm) at 8th week	'Tainung #2'(V1)	7.83	6.00	5.47	6.43 b
	'SF 459' (V2)	8.13	6.84	6.48	7.15 b
	'Everglades41'(V3)	9.84	8.21	6.60	8.22 a
	Mean	8.60 a	7.02 b	6.18 b	
Stalk diameter (mm) at 10th week	'Tainung #2'(V1)	9.07	6.03	5.66	6.92 b
	'SF 459' (V2)	11.23	7.71	7.52	8.82 a
	'Everglades41'(V3)	11.35	9.65	7.99	9.66 a
	Mean	10.55 a	7.80 b	7.06 b	
Stalk diameter (mm) at 12th week	'Tainung #2'(V1)	12.62	8.13	7.94	9.56 a
	'SF 459' (V2)	16.23	9.97	9.17	11.79 a
	'Everglades41'(V3)	15.28	12.23	10.45	12.65 a
	Mean	14.71 a	10.11 b	9.18 b	
Stalk diameter (mm) at 14th week	'Tainung #2'(V1)	14.53	9.77	7.72	10.67 b
	'SF 459' (V2)	17.58	11.93	9.68	13.06 a
	'Everglades41'(V3)	16.31	13.55	10.36	13.41 a
	Mean	16.14 a	11.75 b	9.25 c	

Means followed by the same letter in the same row and column are not significantly different.

Analysis of variance showed no significant differences ($P \leq 0.05$) on the height attained among the three varieties of kenaf as affected by the variety effects except those at the 10th week of harvest. There were significant differences on the height of the plants as influenced by the treatment effects.

Moderate and severe water deficits significantly reduced the plant height when compared with the control. However, there were no significant differences on height between those of moderate and severe levels except at the 8th and 14th week of growths.

Stalk diameter growth was significantly retarded by water stress. The severely stressed plants were reduced by 43% of the control having a basal diameter of 9.25 mm, whereas the moderately stressed plants retarded growth by 27% and the plants attained a radial diameter of 11.75 mm when compared with the control that recorded a basal diameter growth of 16.14 mm at the termination of the experiment (**Table 2**).

Statistical analysis revealed that there were significant differences ($P \leq 0.05$) among the varieties on radial growth. The highest collar diameter growth was produced by 'Everglades 41' (V3) and this was not statistically different from that of 'SF 459' (V2) but statistically different from that recorded for 'Tainung #2' (V1).

There were also significant differences on the radial growth of the three kenaf varieties as brought about by the treatment applications. The basal diameter growth recorded by the severely stressed plants were significantly different from those of moderately stressed and control.

Biomass accumulation

The effects of variety and the various levels of treatment applications on dry matter production of the dry weight of leaf and the total weight of shoot are shown in **Tables 3, 4** whereas those of the dry weight of bark and wood core are shown in **Tables 5, 6**.

The dry weight of leaf was significantly affected by moisture stress. Leaf production was highest from the 4th week to the 14th week of growth in the control hence plants attaining a total mean weight of 17.68 g. The moderately stressed plants attained a mean weight of 9.31 g indicating that biomass accumulation was retarded by 47% while severely stressed plants recorded an average weight of 5.83 g having reduced dry matter production of leaf by 67% with reference to the control (**Table 3**).

There were significant differences on the performances of the kenaf varieties on the basis of leaf biomass accumulation as affected by variety effect. 'Everglades 41' recorded the highest value and this was found to be statistically different from those produced by 'SF 459' and 'Tainung #2' from the 6th week to the 14th week of growth. However, no significant differences were found between that produced by 'SF 459' and 'Tainung #2' except those harvested at 10th week of growth where the three varieties were found to be statistically different with respect to leaf dry matter production.

Analysis of variance showed significant differences ($P \leq 0.05$) among the three kenaf cultivars as influenced by the different watering regimes. When compared with the control, all the levels of treatment applications significantly reduced leaf dry matter production of leaf.

The total biomass accumulation of the three kenaf varieties was drastically retarded by water deficit when compared with the control (**Table 4**). The control had an average weight of 42.64 g at the termination of the experiment. The severely stressed plants were reduced by 71% of the control having attained a mean weight of 12.38 g whereas the moderately stressed plants retarded total biomass by 49% with a mean weight of 21. 67 g.

There were significant differences among the various varieties of kenaf on the total biomass accumulation as brought about by the effect of the variety. 'Everglades 41' performed best among the three varieties in terms of overall accumulation and this was found to be statistically different from the mean weights of 'SF 459' and 'Tainung #2' during the periods of 6th, 8th and 10th week of harvests. However, these differences were not found to be significant at the 12th and 14th week of harvests.

Similarly, differences among the various levels of treatment applications on the total biomass accumulation of the three kenaf varieties were found to be highly significant. The total dry matter production of shoot of the severely

Table 3 Effect of watering regime on dry weight of leaf (g) of three kenaf cultivars ('Tainung #2' (V1), 'SF 459' (V2), and 'Everglades 41' (V3)) grown in the field.

Growth Parameter / Age (weeks)	Variety	Watering Regime			
		Well-watered	Moderate stress	Severe stress	Mean
		(L1)	(L2)	(L3)	
Dry weight of leaf (g) at 4th week	'Tainung #2'(V1)	0.38	0.33	0.26	0.32 a
	'SF 459' (V2)	0.43	0.40	0.31	0.38 a
	'Everglades41'(V3)	0.53	0.30	0.25	0.36 a
	Mean	0.44 a	0.34 ab	0.27 b	
Dry weight of leaf (g) at 6th week	'Tainung #2'(V1)	2.32	1.55	1.48	1.78 b
	'SF 459' (V2)	2.52	2.03	1.55	2.03 b
	'Everglades41'(V3)	3.33	2.38	2.25	2.66 a
	Mean	2.72 a	1.99 b	1.76 b	
Dry weight of leaf (g) at 8th week	'Tainung #2'(V1)	5.28	3.20	2.50	3.66 b
	'SF 459' (V2)	5.40	4.02	3.53	4.32 b
	'Everglades41'(V3)	8.21	6.34	4.17	6.24 a
	Mean	6.30 a	4.52 b	3.40 b	
Dry weight of leaf (g) at 10th week	'Tainung #2'(V1)	7.45	3.37	3.23	4.68 c
	'SF 459' (V2)	9.62	4.73	5.48	6.61 b
	'Everglades41'(V3)	10.80	6.88	6.27	7.98 a
	Mean	9.29 a	4.99 b	4.99 b	
Dry weight of leaf (g) at 12th week	'Tainung #2'(V1)	10.13	4.09	3.68	5.97 b
	'SF 459' (V2)	18.68	5.99	5.21	9.96 a
	'Everglades41'(V3)	16.58	9.35	7.35	11.10 a
	Mean	15.13 a	6.48 b	5.42 b	
Dry weight of leaf (g) at 14th week	'Tainung #2'(V1)	14.60	6.10	4.50	8.40 a
	'SF 459' (V2)	20.87	8.82	6.43	12.04 a
	'Everglades41'(V3)	17.57	13.00	6.57	12.38 a
	Mean	17.68 a	9.31 b	5.83 b	

Means followed by the same letter in the same row and column are not significantly different.

Table 4 Effect of watering regime on total dry weight of shoot (g) of three kenaf cultivars ('Tainung #2' (V1), 'SF 459' (V2), and 'Everglades 41' (V3)) grown in the field.

Growth Parameter / Age (weeks)	Variety	Watering Regime			
		Well-watered	Moderate stress	Severe stress	Mean
		(L1)	(L2)	(L3)	
Total dry weight of shoot (g) at 6th week	'Tainung #2'(V1)	3.63	2.38	2.15	2.72 b
	'SF 459' (V2)	3.77	2.87	2.15	2.93 b
	'Everglades41'(V3)	4.83	3.34	3.08	3.75 a
	Mean	4.08 a	2.86 b	2.46 c	
Total dry weight of shoot (g) at 8th week	'Tainung #2'(V1)	11.36	6.97	5.46	7.93 c
	'SF 459' (V2)	10.61	7.70	6.90	8.40 b
	'Everglades41'(V3)	15.91	13.02	7.96	12.20 a
	Mean	12.63 a	9.23 b	6.77 c	
Total dry weight of shoot (g) at 10th week	'Tainung #2'(V1)	16.07	7.47	6.96	10.17 c
	'SF 459' (V2)	21.26	8.93	10.26	13.48 b
	'Everglades41'(V3)	22.91	14.66	11.90	16.49 a
	Mean	20.08 a	10.35 b	9.71 b	
Total dry weight of shoot (g) at 12th week	'Tainung #2'(V1)	25.03	10.29	8.86	14.73 a
	'SF 459' (V2)	41.03	13.25	11.79	22.02 a
	'Everglades41'(V3)	38.89	20.54	17.00	25.48 a
	Mean	34.98 a	14.69 b	12.55 b	
Total dry weight of shoot (g) at 14th week	'Tainung #2'(V1)	35.78	14.43	9.95	20.05 a
	'SF 459' (V2)	48.84	18.99	13.66	27.16 a
	'Everglades41'(V3)	43.29	31.58	13.52	29.46 a
	Mean	42.64 a	21.67 b	12.38 c	

Means followed by the same letter in the same row and column are not significantly different

stressed plants was significantly different from those of the control throughout the experimental period. However, this was found not to be significantly different from those of moderately stressed plants at 10th and 12th week of harvests.

Kenaf bark dry matter production like other components analysed indicated that water deficit had adverse effects on its bark biomass accumulation. With reference to the control, the three varieties improved on their dry matter production of bark with 'Everglades 41' having the highest (**Table 5**). The average dry weight of bark attained by the control plants at the end of the experiment was 10.77 g. The moderate and severe stressed plants had a mean weight of 4.90 g and 2.96 g respectively thus retarding dry matter production of bark by 55% by the moderate stress and 73% by the severe stress when compared with the control.

Similarly effect of variety revealed that there were significant differences among the three varieties at 10th week of harvest. The differences between 'Everglades 41' and 'Tainung #2' were significant whereas, that between 'Everglades 41' and 'SF 459' were not statistically different with the exception of the harvest at 10th week of growth.

Statistically, there were high significant differences ($P \leq 0.05$) among the kenaf varieties following the treatment applications. The differences between the control and the stressed plants were significant but that between the moderate and the severe stress were not except those harvested at 14th week of study.

Like the dry weight of bark, water deficit adversely retarded the dry matter production of kenaf wood core (**Table 6**). 'Everglades 41' had the highest performance. At

Table 5 Effect of watering regime on dry weight of bark (g) of three kenaf cultivars ('Tainung #2' (V1), 'SF 459' (V2), and 'Everglades 41' (V3)) grown in the field.

Growth Parameter / Age (weeks)	Variety	Watering Regime			
		Well-watered (L1)	Moderate stress (L2)	Severe stress (L3)	Mean
Dry weight of bark (g) at 6th week	'Tainung #2'(V1)	0.60	0.33	0.31	0.42 a
	'SF 459' (V2)	0.57	0.38	0.26	0.41 a
	'Everglades41'(V3)	0.68	0.44	0.40	0.51 a
	Mean	0.62 a	0.39 b	0.32 b	
Dry weight of bark (g) at 8th week	'Tainung #2'(V1)	2.73	1.63	1.32	1.89 b
	'SF 459' (V2)	2.43	1.58	1.53	1.85 b
	'Everglades41'(V3)	3.31	2.55	2.59	2.48 a
	Mean	2.83 a	1.92 b	1.48 b	
Dry weight of bark (g) at 10th week	'Tainung #2'(V1)	3.72	1.73	1.68	2.38 c
	'SF 459' (V2)	5.03	1.90	2.23	3.06 b
	'Everglades41'(V3)	5.33	3.58	2.50	3.81 a
	Mean	4.69 a	2.41 b	2.14 b	
Dry weight of bark (g) at 12th week	'Tainung #2'(V1)	6.78	2.72	2.13	3.88 b
	'SF 459' (V2)	10.45	3.33	3.08	5.62 a
	'Everglades41'(V3)	9.98	5.16	4.27	6.47 a
	Mean	9.07 a	3.74 b	3.16 b	
Dry weight of bark (g) at 14th week	'Tainung #2'(V1)	8.75	3.65	2.43	4.94 b
	'SF 459' (V2)	12.52	4.67	3.28	6.82 a
	'Everglades41'(V3)	11.05	6.38	3.17	6.87 a
	Mean	10.77 a	4.90 b	2.96 c	

Means followed by the same letter on the same row and column are not significantly different.

Table 6 Effect of watering regime on dry weight of core (g) of three kenaf cultivars ('Tainung #2' (V1), 'SF 459' (V2), and 'Everglades 41' (V3)) grown in the field.

Growth Parameter / Age (weeks)	Variety	Watering Regime			
		Well-watered (L1)	Moderate stress (L2)	Severe stress (L3)	Mean
Dry weight of core (g) at 6th week	'Tainung #2'(V1)	0.71	0.49	0.36	0.52 a
	'SF 459' (V2)	0.67	0.46	0.28	0.47 a
	'Everglades41'(V3)	0.82	0.51	0.43	0.59 a
	Mean	0.73 a	0.49 b	0.36 b	
Dry weight of core (g) at 8th week	'Tainung #2'(V1)	3.35	2.13	1.64	2.37 b
	'SF 459' (V2)	2.78	2.10	1.84	2.24 b
	'Everglades41'(V3)	4.39	3.16	2.20	3.25 a
	Mean	3.51 a	2.46 b	1.90 b	
Dry weight of core (g) at 10th week	'Tainung #2'(V1)	4.90	2.37	2.05	3.11 b
	'SF 459' (V2)	5.95	2.30	2.55	3.60 b
	'Everglades41'(V3)	6.78	4.20	3.13	4.70 a
	Mean	5.88 a	2.96 b	2.58 b	
Dry weight of core (g) at 12th week	'Tainung #2'(V1)	8.12	3.48	3.05	4.88 b
	'SF 459' (V2)	11.90	3.93	3.50	6.44 ab
	'Everglades41'(V3)	12.33	6.03	5.38	7.91 a
	Mean	10.78 a	4.48 b	3.98 b	
Dry weight of core (g) at 14th week	'Tainung #2'(V1)	8.75	4.82	3.02	6.76 b
	'SF 459' (V2)	12.52	5.50	3.95	8.30 a
	'Everglades41'(V3)	11.05	6.97	3.78	8.47 a
	Mean	10.77 a	5.76 b	3.58 b	

Means followed by the same letter on the same row and column are not significantly different.

the termination of the experiment, the control attained a mean dry weight of 14.18 g, moderate stress 5.76 g and severe stress 3.58 g. When compared with the control, it became evident that water deficit retarded the dry matter production of kenaf wood core of moderately stressed plants by 59% and of severely stressed plants by 75%.

Varietal responses indicated that differences were not significant apart from those at the 10th week of harvest where 'Everglades 41' varies significantly from 'SF 459' and 'Tainung #2'.

Treatment application indicated that differences between the three kenaf varieties on the basis of dry matter production of wood core were significant at $P \leq 0.05$. But the differences between the moderate stress and the severe stress were not statistically significant.

Biomass allocation

The bark-wood ratio (**Table 7**) generally decreased with increase in age. Analysis of variance showed that there were significant differences on the bark-wood ratio as influenced by both variety and treatment effects at the 8th week of growth. The steepest decline also occurred at the 8th week of growth. Water stress and variety had no drastic effects on bark-wood ratio except that observed at the 8th week of growth.

DISCUSSION

Growth

The study demonstrated that height growth was significantly reduced by water deficit in all the varieties. That drought reduces plant height and vigour is well known. Water stress and salt stress are the most severe environmental stresses to which plants may be subjected to. Kramer (1963) reported that the alterations witnessed by growth parameters under water stress are due in part to the role of

Table 7 Effect of watering regime on bark-wood ratio of three kenaf cultivars ('Tainung #2' (V1), 'SF 459' (V2), and 'Everglades 41' (V3)) grown in the field.

Growth Parameter /Age (weeks)	Variety	Watering Regime			
		Well-watered	Moderate stress	Severe stress	Mean
		(L1)	(L2)	(L3)	
Bark-wood ratio at 6th week	'Tainung #2'(V1)	0.84	0.86	0.83	0.84 a
	'SF 459' (V2)	0.68	0.84	0.86	0.79 a
	'Everglades41'(V3)	0.68	0.91	0. 92	0.90 a
	Mean	0.79 a	0.87 a	0.87 a	
Bark-wood ratio at 8th week	'Tainung #2'(V1)	0.81	0.68	0.80	0.76 a
	'SF 459' (V2)	0.87	0.75	0.83	0.82 b
	'Everglades41'(V3)	0.75	0.62	0.72	0.70 c
	Mean	0.81 a	0.68 a	0.78 a	
Bark-wood ratio at 10th week	'Tainung #2'(V1)	0.76	0.73	0.82	0.77 a
	'SF 459' (V2)	0.85	0.83	0.87	0.85 a
	'Everglades41'(V3)	0.79	0.85	0.80	0.81 a
	Mean	0.80 a	0.80 a	0.83 a	
Bark-wood ratio at 12th week	'Tainung #2'(V1)	0.83	0.78	0.86	0.82 a
	'SF 459' (V2)	0.88	0.85	0.88	0.87 a
	'Everglades41'(V3)	0.81	0.86	0.79	0.82 a
	Mean	0.84 a	0.83 a	0.84 a	
Bark-wood ratio at 14th week	'Tainung #2'(V1)	0.70	0.78	0.80	0.76 a
	'SF 459' (V2)	0.81	0.85	0.83	0.83 a
	'Everglades41'(V3)	0.75	0.77	0.84	0.79 a
	Mean	0.75 a	0.80 a	0.82 a	

Means followed by the same letter on the same row and column are not significantly different.

water in turgidity maintenance necessary for cell enlargement. Kenaf plant though non-halophyte has been shown to tolerate moderately saline soil (Curtis and Làuchli 1985, 1986; Francois *et al.* 1992). Physiological studies indicate that both photosynthetic capacity and carbohydrate metabolism are altered in response to stress. Cell division has been shown to decrease as water deficit increases, because cells apparently must attain a certain size before they can divide (Doley and Leyton 1968).

Due to unavailability of any direct method that can be used in the assessment of fibre from a standing crop for now, plant height and basal diameter are still considered as the general guiding criteria for measuring efficient production of fibres in a particular species (Maiti and Chakravarty 1977; Alexopoulou *et al*. 2000). Our results show that drought affects the efficient production of fibres in kenaf. These observations are in agreement with the work of Kramer (1983); Muchow (1992) and that of Ogbonnaya *et al.* (1997) who reported that water deficits adversely affect all aspects of plant growth including plant height and root-collar diameter.

Biomass accumulation

The performance of any plant in terms of dry matter production is directly dependent on the pattern of its leaf area development in response to solar energy and carbon dioxide intake. This means that the amount of light intercepted for any given location and growth duration is primarily dependent on leaf area development, which has been shown to be directly linked with leaf turgor (Bunce 1977; Wenkert *et al.* 1978; Muchow 1992; Danalatos and Archontoulis 2010). Leaf growth is the most vulnerable of plant responses to water stress and is regularly inhibited in field crops (Hsaio 1973; Schulze and Matthew 1993). Different plants develop different strategies for environmental stress adaptation. In this study, kenaf was observed to adopt the mechanism of leaf rolling and stomatal closing to avoid or limit water loss. Though this was an efficient way of managing drought stress in terms of water loss, however, it was disadvantageous to the plant in the sense that it leads to a decline in photosynthetic capacity as a result of complete stoppage of CO_2 assimilation (Muchow *et al.* 1986; Muchow 1992; Nwalozie and Annerose 1996).

Water deficit drastically reduced the leaf area and overall dry matter of kenaf leading to poor leaf expansion and defoliation. This was found pronounced among the plants that were severely starved of soil moisture. It has been established that kenaf plants usually grow erect and unbranched when densely planted (Higgins and White 1969; Muchow and Wood 1983; Webber and Bledsoe 2001). In the present study branching was drastically retarded by moderate stress and completely inhibited by severe moisture stress. It has been reported that inhibition of branching in kenaf grown under drought conditions is an adaptation mechanism (Ogbonnaya *et al.* 1997).

Flowering in this experiment was observed to commence on the 6th week of growth in the adequately watered control and the moderate stress whereas, the severely stressed plants started flowering on the 8th week of growth. Moisture stress, however affected flower production by more than 80% in the severely stressed plants. The effect was so strong that most of the flowers initiated were aborted. Although Chinoy (1961) and Derera *et al.* (1969) reported that within a range of germplasms, most of the drought resistance of high yielding crops under drought stress could be attributed to earliness. However, kenaf has not been known to employ escape mechanisms in order to overcome drought, flowering did not start in the stressed plants earlier than unstressed ones or control. The overall reduction in the biomass accumulation could be attributed to the loss of accumulation efficiency which is associated with a decrease in carbon dioxide intake into the leaf due to leaf stomatal closure at the on set of drought (Ogbonnaya *et al.* 1997; Alexopoulou *et al*. 2000).

Biomass allocation

It has been reported that bark-wood ratio is generally considered a dependable yield component and selective index of bast fibre crops (Maiti and Chakravarty 1977; Tsakonas *et al*. 2005). The bark-wood ratio was found not to be adversely affected by water stress in kenaf, and it was also observed to decrease with increase in age. This finding agrees with the report of Ogbonnaya *et al.* (1997), who reported that water deficit had no significant effect on bark-wood ratio and that it decreased with maturity.

A higher bark-wood ratio is an indication of the plant's efficiency in the production of higher yield of fibres than of wood. This criterion is employed as a yardstick for determination of fibre production in different species. In the present work, it has been shown that 'SF 459' (V2) cultivar recor-

ded the highest percentage of bark – wood ratio out of the three cultivars investigated. However differences between them were not significant. On the other hand, 'Everglades 41' (V3) variety had the highest mean weight on the basis of total dry matter of the shoot when compared with the other varieties. This report is in agreement with the report of Webber (1993), who reported that 'Cuba 108' had the least percentage wood core material, and greatest percentage of bark to wood ratio among all the kenaf varieties investigated.

ACKNOWLEDGEMENTS

We sincerely remain grateful to the Association of African Universities (AAU) who provided the fund for this research. The assistance of Dr. C. L. Webber III who sent the certified seed used in this study is highly appreciated.

REFERENCES

Alexopoulou E, Christou M, Mardikis M, Chatziathanassiou A (2000) Growth and yields of kenaf varieties in central Greece. *Industrial Crops and Products* **11**, 162-172

Bunce JA (1972) Leaf elongation in relation to leaf water potential in soybean. *Journal of Experimental Botany* **28**, 156-161

Chinoy JJ (1961) Physiology of drought resistance in wheat II. Evaluation of drought resistance in eight varieties of wheat on the basis of growth analysis. *Phytoagronomy* **16**, 131-139

Curtis PS, Làuchili A (1985) Response of kenaf to salt stress. Germination and vegetative growth. *Crop Science* **25**, 944-949

Curtis PS, Làuchili A (1986) The role of the leaf area development and photosynthetic capacity in determining growth of kenaf under moderate salt stress. *Australia Journal Plant Physiology* **13**, 553-565

Danalatos NG, Archontoulis SV (2010) Growth and biomass productivity of kenaf (*Hibiscus cannabinus* L.) under different agricultural inputs and management practices in central Greece. *Industrial Crops and Products* in press

Dempsey JM (1975) *Fibre Crops*, The University Press of Florida, Gainesville

Derera NF, Marshal SR, Balam LN (1969) Genetic variability in root development in relation to drought tolerance in spring wheats. *Experimental Agriculture* **5**, 327-337

Doley D, Leyton L (1968) Effects of growth regulation substances and water potential on the development of secondary xylem in *Fraxinus*. *New Phytologist* **67**, 579-594

Enukwesi L, Nwalozie MC, Anyanwu DI (1986) Effects of pre-sowing hydration – dehydration on germination, vegetative growth and fruit yield of *Abelmoschus esculentus* grown under two moisture regimes. *Tropical Agriculture* **63**, 181-184

Francois LE, Donovan TJ, Maas EV (1992) Yield vegetative growth, and fibre length of kenaf grown on saline soil. *Agronomy Journal* **84**, 592-598

Higgins JJ, White GA (1969) Effects of plant populations and harvest date on stem yield and growth components of kenaf in Meryland. *TAPPI* **52 (II)**, 667-668

Hsaio TC (1973) Plant responses to water stress. *Annual Review of Plant Physiology* **24**, 519-570

Killinger CB (1969) Kenaf (*Hibiscus cannabinus* L.) - a multi-purpose crop. *Agronomy Journal* **61**, 736

Kramer PJ (1963) Water stress and plant growth. *Agronomy Journal* **55**, 31-35

Kramer PJ (1983) *Water Relations of Plants*, Academic Press, New York

Maiti RK, Chakravarty K (1977) A comparative study of yield components and quality of common Indian bast fibres. *Economic Botany* **31**, 55-60

Muchow RC (1992) Effect of water and nitrogen supply on radiation interception and biomass accumulation of kenaf (*Hibiscus cannabinus* L.) in a semi-arid tropical environment. *Field Crops Research* **28**, 281-293

Muchow RC, Sinclair TR, Benneth JM, Hammond LC (1986) Response of leaf growth, leaf nitrogen, and stomatal conductance to water deficits during vegetative growth of field-grown soybean. *Crop Science* **26**, 11901195

Muchow RC, Wood IM (1983) Effect of sowing date on the growth and yield of kenaf (*Hibiscus cannabinus* L.) grown under irrigation in tropical Australia I. Phenology and seed production. *Field Crops Research* **7**, 81-90

Nkaa FA, Ogbonnaya CI, Onyike NB (2007) Effect of differential irrigation on physical and histochemical properties of kenaf (*Hibiscus cannabinus* L.) grown in the field in Eastern Nigeria. *African Journal of Agricultural Research* **2 (6)**, 252-260

Nwalozie MC, Annerose DJM (1996) Stomatal behaviour and water status of cowpea and peanut at low soil moisture levels. *Acta Agronomica Hungarica* **44 (3)**, 229-236

Ogbonnaya CI, Nwalozie MC, Roy-Macaulay H, Annerose DJM (1997) Growth and water relations of kenaf (*Hibiscus cannabinus* L.) under water deficit on a sandy soil. *Industrial Crops and Products* **8**, 65-76

Page AC, Miller RH, Keaney DR (1982) *Methods of Soil Analysis. Part 2* (2nd Edn), American Society of Agronomy, Madison, Wisconsin, USA

Robinson FE (1988) Kenaf: A new fibre crop for paper production. *Califonia Agriculture* **42**, 31-32

Schulze HR, Mathew MA (1993) Growth, osmotic adjustment and cell – wall mechanics of expanding grape leaves during water deficits. *Crop science* **33**, 287-294

Sellers T, Miller GD, Fuller MJ (1993) Kenaf core as a board raw material. *Forage Production Journal* **43**, 69-71

Webber CL (1992) The influence of metalochlor and triflaralin on kenaf (*Hibiscus cannabinus* L.) yield components. *Industrial Crops and Products* **1**, 17-20

Webber CL (1993) Yield components of five kenaf cultivars. *Agronomy Journal* **85**, 533-535

Webber CL, Bledsoe VK (2001) Kenaf yield components and plant compositions. *Proceedings of the 5th National Symposium, New Crops and New Uses: Strength in Diversity*, Atlanta, GA, pp 315-327

Wenkert W, Lemon ER, Sinclair TR (1978) Leaf elongation and turgor pressure in field – grown soybean. *Agronomy Journal* **70**, 761-764

White GA, Cummins DG, Whitely EL, Fike WT, Grieg JK, Martin JA, Killinger GB, Higgins JJ, Clark FT (1970) Cultural and harvesting methods for kenaf – an annual crop source for pulp in the south-east. ARS, USDA Products Research Report, 113. Washington, DC, pp 1-38

Wilson FD, Summers TE, Joyner JF, Fishler DW, Seale CC (1965) 'Everlades 41' and 'Everlades 71' two new cultivars of kenaf *(Hibiscus cannabinus* L.) for the fibre and seed. Florida Agricultural Experimental Station Cir. S-168. Available online: http://edis.ifas.ufl.edu

Wood IM, Stewart GA (1981) Kenaf as a potential source of pulp in Australia, Commonwealth Scientific Industrial Research Organization; Division of Tropical Crops and Pastures; Division of Chemical Technology CSIRO, Melbourne, Australia, 144 pp. Available online: http://catalogue.nla.gov.au/Record/43144