CR000918

CER▲ S

TECHNICAL REPORT

July - November, 1996

CENTRE D'ETUDES REGIONAL

POUR L'AMELIORATION

DE L'ADAPTATION A

LA SECHERESSE.

The effect of water stress on the physiological and histo-chemical properties of kenaf *(Hibiscus cannabinus* L.) relevant to pulp and paper production.

Dr. Chuks I. Ogbonnaya

School of Biological Sciences
Plant Ecology Unit
Abia State University
PMB 2000, Uturu
Abia State
NIGERIA

ISRA - CNRA
B.P. 53 BAMBEY SENEGAL
TEL. (221) 73.61.97 - 73.60.50
FAX (221) 73.61.97 - 73.60.52

CG 30
PHYS 2

TECHNICAL REPORT

July - November, 1996

The effect of water stress on the physiological and histo-chemical properties of kenaf *(Wibiscus cannabinus* L.) relevant to pulp and paper production.

Dr. Chuks 1. Ogbonnaya

School of Biological Sciences
Plant Ecology Unit
Abia State University
PMB 2000, Uturu
Abia State
NIGERIA

SUMMARY

The effects of water stress on the physiological and histo-chemical properties of Kenaf (*Hibiscus cannabinus* L.) relevant to pulp and paper production were investigated. The plants were grown on a loose-textured sandy soil in the greenhouse at CERAAS, Bambey. Sénégal. Three watering regimes representing well watercd control, moderate stress and severe stress were imposed on the plants. Each watering treatment was replicated four time in a completely randomized design. Soil moisture stress significantly retarded vegetative growth as analysed by plant height, collar diamcter growth, Ieaf development, branching, flowering biomass acummulation and allocation. Kenaf tried to avoid drought by leaf rolling and stomatal closure. The water potential (ψ_w) went as low as -2.53 MPa under severe stress, and -0.50 MPa was bracketed as the most critical ψ_w, below which stomatal conductance and transpiration ceased or drastically reduced and Ieaf-air temperature differential became positive. Holistic analysis of the physical and histo-chemical properties of kenaf relevant to pulp and paper production indicated that water stress would no! significantly affect the quality of pulp and paper produced from this plant.

INTRODUCTION

Hibiscus cannabinus L., commonly known as Kenaf belongs to the family Malvaceae (the Mallows famiiy) and is native of East Centrai Africa. It is a fast-growing, multipurpose, herbaceous annuai with siender straight stems. It is traditionatly cultivated in Africa for cordage and has become an important crop source of textile fibres, world-over. It is used for the manufacture of twines, ropes, buriap bags and carpet backing (Wilson *et al.*, 1965), and has therefore become a jute fibre substitute. The fibres can be processed traditionally using retting ponds common in Africa, Asia and Latin America (Boulanger, 1990; Taylor, 1995). In Africa, the ieaves are eaten by man, and the plant tops, when ground, have high digestibiiity and can be used as a source of roughage and protein for cattle and sheep (Kiiinger, 1969: Swingie *et ai., 1978;* Hays, 1989, Webber, 1992).

Kenaf bast fibre can be used in making mats using severai textile and fibreglass technologies. Application for the mat ranges from seeded glass mats for instant lawns to moldabie mats for manufactured parts and containers. The core fibres are currentiy sized into severai markets inciuding oii absorbent, soii-iess potting mixes, animai bedding, packing material, organic fiiier for plastics, additives for driiiing muds and insuiation (Stein, 1990; Taylor, 1995). Kenaf also has a high potentiai as a board raw materiai with iow-density panels suitable for sound absorption and thermal resistance (Sellers *et al., 1993).*

The search for an annuai fibre crop as a source of raw materiai for puip and paper industry started a long time ago, and kenaf was favourabiy evaiuated as an annuai non-wood fibre source for puip and paper production (Nieschiag et *al.*, 1960). Anon (1953) reported that puip yieid. ranging from 45-54 % have been obtained from the hardwoods, whiie that from kenaf was in the range of 45-52 %. The amount of cellulose in kenaf compares favourabiy with rhose of hardwood, and the smaii amount of iignin, 9% compared with about 29% in pines, is also advantageous because less chemical is needed to release the fibres (Clark *et a/.* 1962).

The entire plant can be utiiized for paper production. The stem contains two distinct fibres, the bast or the outer bark fibres are comparable to softwood fibres. The inner core of short, woody fibres are comparable to hardwood fibres. Both could be used in puip production (Francio et *al.*, 1991). The paper produced from kenaf pulp has excellent ink-retention characteristics and its high tensiie strength is ideai for high-speed presses (Robinson, 1988) Kenaf papers are also as sturdy as woodpuip paper and are generaiiy brighter, require iess ink, and has iess ink rub-off (Sellers *et al.*, *1993).* After numerous researches, and triai runs, kenaf paper is now available from several commercial retailers and is being used by printing and graphics firms and publishers in the United States.

At present, there is an increasing demand for fibre products. About 95% of the world fibre used in the manufacture of pulp and paper is derived from forests, which must be conserved in the face of increasing CO_2 concentration and global warming. The other 5% cornes from bamboo, cereal straws, leaves and other fibrous annual plants. There is continuous reduction in forest resources each year and the increased demand for fibre would have to be met. The use of wood-based papers degrades the natural forests , destroys widelife habitats and pollutes the air, soil and water. if the cost of environmental conservation and restoration are taken into account, the use of this non-wood, annual source of fibres for pulp and paper production, therefore, makes "*ecological sense.*"

In addition, an annual pulp crop such as kenaf, has the advantage of considerably higher yield per hectare. Kenaf reaches an average of 3 meters in 150 days, while pines must grow for 14-18 years to be useful for pulp and paper production. It requires less land than most forest stands and it is not possible for forests to produce an annual quantity of fibre equal to that of a suitable annual crop like kenaf There is also less business risks and uncertainty with annuals than with long-term investments in timber production. Economic analysis of kenaf production shows that company land capable of growing the plant would provide raw material at roughly half the cost of producing pulpwood, and 3-5 times as much as pulpwood per hectare could be produçed annually. Kenaf also competes well with major crops, like corn, cotton and soybean with yields of 10 to 15 metric tons per hectare (Moore et ***al., 1976).*** The use of kenaf as a sou-ce of raw material for pulp and paper production, therefore, makes "*economic sense*"

Nigeria, for example, has two paper mills, and a third one is under construction. Plantations of gmelina (50,000 ha.), pines and eucalyptus (1,500 ha.) which have been established, cannot satisfy the demands of the three mills. The rotation period of some of these pulpwood being as much as 8 years. The two mills, thereeforee, operate below 50% capacity due to lack of pulping materials (Akinosho, 1987). Reliance of the paper mills on imported pulp has resulted in a shortfall in paper supply in the country (Idem and Adeoti, 1988).

Furthermore, Nigeria will be subjected to higher paper importation to the detriment of local paper producing industries in the future, since attempts to improve local paper production have not really succeeded. The country still imports about 90% of all its paper needs (FAO Report as cited by Business Concord, 1996). Oseni (1978) predicted consumption of paper and paper products in Nigeria at 1.80 to 5.25 million cubic meters of roundwood between 1985 and 1995. While Momoh (1980) evaluated paper and paper products consumption in 1980 at 160,000 tonnes as compared to 124,000 tonnes in 1975. With a population of 100 million, and a ccrnservative per capita paper consumption estimate of 5.0 kg, 500,000 tonnes of paper must be produced annually. This therefore creates the need for an annual pulp source, With a rotation period of only 0.25 years, kenaf can adequately fill the gap left by the long rotation pulp trees ,

Kenaf îs presently grown in the semi-arid narthern Nigeria at the peasant level, mainly for cordage, to produce sacs for the packaging and transportation of cocoa, palm kernel, groundnut, onions etc. Northern Nigeria has abundant land mass. The problem of comercialization of kenaf has been identified as lack of intensive planting (Anon., 1996). Large hectareages of kenaf could to be established in this part of the country to source the pulp and paper mills. Wowever, as in most West African Savanna (Owonubi, 1994), northern Nigeria experiences rainfall which could be as low as 520 mm. This low rainfall resources coupled with irregular rainfall pattern and the light-textured soil with low water-holding capacity, renders the region prone to drought. And before huge investments can be made on the growth of kenaf, there is need to understand its behaviour when grown in this kind of region.

From the literature survey so far made, much work has not been done on the water relations of this crop. The objective of this study, therefore, is to evaluate the effect of water deficit on some physiological and histo-chemical properties of kenaf relevant to pulp and paper production.

MATERIALS AND METHODS

Seed Collection: Certified seeds of Kenaf (*Hibiscus cannabinus* L) were obtained from the Obafemi Awolowo University, Institute of Agricultural Research, Moore Plantation, Ibadan, Nigeria. Cuba 108 cultivar was used for the study on the basis of its high bark-wood core ratio(Webber, 1993), since the harvest index for this experiment was the bast fibre.

Growth Conditions: Sandy soil was used as the potting medium. The characteristics of the soil were as previously described by Annerose (1990). The soil was sun-dried and undecomposed plant materials were removed by sieving. Twenty-eight kilogramme soil were packcd in plastic pots (ht. = 40 *cm,* diam. = 25 *cm*) with drainage holes at the bottom, to a bulk density of 1 .5852 $g\ cm^{-3}$. Ten kenaf seeds were planted at 0.5 cm depth and the resulting seedlings were later thinned down to one plant per pot at two-leaf stage, to obtain plants with uniform growth vigour. The soil was fertilized at the beginning of the experiment and two months later with compound N.P.K. (15-10-l 5) fertilizer at the rate of 200 kg/ha^{-} (White *et al.*, 1970) to remove nutrient deficiency as a limiting factor The pots were placed in a greenhouse at CERAAS, Bambey, Sénégal (Latitude 16”. 28’ West and Longitude 14”. 42’ North). At midday, maximum temperature was 35.5 ± 0.95°C; relative humidity was 46.25 ± 2.27 %, while Photosynthetic Photon Flux Density (PPFD) was 690.55 ± 135.44 $\mu mol\ s^{-1}\ m^{-2}$

Soit Moisture Treatment :Two weeks after germination at the four leaf stage, the following treatments were then imposed:

(1) Control (W1) - soil water was maintained at field capacity by daily watering, The daily water requirements of the plants were determined as the difference between the weight of a fully irrigated pot and the weight of the pot 24 hours later, after the day's evapotranspiration. This determination was done weekly to take care of changing water demands of the plants with age.
(2) Moderate stress (W2) - the plants were watered at 3 weeks intervals.
(3) Severe stress (W3) - they were watered at 4-week inter-vals. The choice of these watering regimes was based on the duration of short-term drought usually experienced by this crop in the field. At each watering session, soils *were* fully hydrated to field capacity.

Experimental Design and Statistical Analysis :
The experimental design was a completely randomized one with 3 watering treatments replicated 4 times. Each pot represented a subplot and a square of 9 subplots represented a whole plot. Whole plots were replicated four times to give a total of 12 experimental plots in a completely randomized design. The experimental plots were surrounded with a single row of border plants on all sides to receive external shocks. Data collected were subjected to analysis of variance and Duncan’s multiple range test was used in partitioning the means. ‘The SAS statistical software was used in carrying out the data analysis, using CERAAS Computing System

Measurements:

Physiological Measurements:

Growth Height growth was measured weekly with the aid of meter rule from the base of the stem at the soil level to the terminal bud of the main stem. Root-collar diameter was measured at the collar with a caliper guage (FACOM, 815A) to the nearest 0.001mm. Dry matter production was obtained by carefully uprooting the seedlings from the pot, Each plant was separated into roots, leaves, bark, wood core and the floral parts when available. The total weight of the stalk (bark and the wood), shoot and the total plant matter were also obtained. The plants were oven-dried at 88°C until constant weights were obtained. The dry weight of each component was determined to the nearest 0.01*g* on a top-loading meter balance (Mettler P-120). Leaf area was measured with leaf area meter (mode1 MK2, AT Area Meter Devices Ltd, England). The leaf area ratio (LAR) was obtained as the ratio of total area of leaf to whole plant dry weight. Root-shoot ratio was obtained as the ratio of the dry weight of root to the dry weight of the shoot, while bark-wood ratio was obtained as the ratio of the dty weight of the bark to the dry weight of the wood. These measurements were made every two weeks starting from the date of the application of the treatments.

Plant Water Relations: All water relations determination were made on the fifth leaf from the apex. Transpiration rate, ambient air temperature, leaf temperature and leaf stomatal conductance were measured using a steady state: porometer (Model LI-1600, LICOR Ltd; Lincoln, Nebraska, USA). Total water potential (ψ_w) was determined in the greenhouse using Scholander pressure chamber (Model 3000, Plant Water Status Console, Santa Barbara, Calif. USA) All measurements were made weekly between 11.00-l 3.00 *h*.

Leaf relative water content (LRWC) was determined gravimetically on a leaf disc and calculated from the following relationship: $[(W_{fresh} - W_{dry}) / (W_{turgid} - W_{dry})] \times 100$, where W_{fresh} is the weight of freshly harvested sample, W_{turgid} is the turgid weight after floating the sample for *4h* in water, and W_{dry} is the oven-dry (85°C for 24 *h.)* weight of the sample(Jensen, 1989). The same leaf was sampled for all the water relations measurements.

Soil Moisture Measurements:

Gravimetric measurement of soil moisture content were taken at weekly intervals after measuring the plant water stress parameters. Soil moisture content was determined at four depth intervals, O-7, 7-14, 14-21, and 21-28 cm. The gravimetric soil water contents were obtained as $[(W_{fresh} - W_{dry}) / (W_{dry})]$, where W_{fresh} is the fresh weight of soil sample, and W_{dry} is the oten-dry weight. These were converted to volumetric soil water contents by multiplying with the bulk density, 1.5852 g cm^{-2} of the potted soil. The average volumetric moisture content of the four soil levels was then obtained.

Fibre Dimensions and their Derived Values:

Fibre dimensions: Stern samples for the fibre studies were obtained from the second internode counting from the base. Small slivers were obtained from the bark and from the central wood core for maceration. The slivers were macerated with 10 *ml* of 60% nitric acid, boiled in a water bath for 10 *min*, (Ogbonnaya, 1990). Macerates were stained with 1: 1 phluroglucinol-glycerol mixture. Fibre samples were viewed under a calibrated microscope and the fibre walls presented a characteristic glistening nature, described as nacré or pearly luster. Twenty five fibres were measured for each sample to obtain an average fibre length (fl), fibre diameter (fd); fibre lumen diameter (fld), and fibre cell wall thickness (fwt) for each replicate.

Derived values: The following derived values were also calculated: coefficient of suppleness (CS) or Aexibility coefficient as fld/fd (Petri, 1952), slenderness ratio (SR) as fl/fd (Rydholm, 1965), and Runkel ratio (RR) as 2 x fwt/fld (Okereke, 1962).

Chemical Properties:

Alkali solubility: Alkali (1% NaOH) soluble substances content of the bark and wood core were dertermined by digesting 1 g of oven-dried ground material in *100 ml* of 1% NaOH in a water bath at 100 °C for 1 *h*, with three stirring periods. After digestion, the material was filtered and washed with water and 10% acetic acid solution. The residue was dried at 85°C until a constant weight was obtained. The weight of the extract expressd as a percentage of the total plant sample used for the extraction was the matter soluble in alkali (Casey, 1960).
Alkali soluble substances content (%) = $[(W_{sample} - W_{resid.}) / (W_{sample})] \times 100$, where W_{sample} was the oven-dry weight of the sample and $W_{resid.}$ was the oven-dry weight of the residue.

Alcohol-benzene solublity: TAPPI T6m-59 method was employed in the determination of alcohol - benzene soluble substances content of the bark and the wood (Grant, 1961). 1g of ground material was extracted in soxhlet apparatus with 100 *ml*. of a mixture of 33 ml 95% alcohol and 67 ml benzene for *8h*. At the end of the extraction, the alcohol-benzene solvent system was distilled off and the extract dried at 85 °C until a constant weight was obtained. The weight of the extract expressed as a percentage of the total plant sample used for the extraction was the matter soluble in alcohol-benzene solvent system.
Alcohol-benzene soluble substances content (%) = (Wt.of extract / Wt. of sample) x 100

Holistic Assessment of the Physical and Histo-chemical Properties

The results obtained were subjected to holistic assessment in order to obtain a conclusive vieu For each parameter measured the treatment effects were scored according to their relative performances. The scores ranged from 1 for the worst treatment effects to 3 (corresponding to the total number of treatments) for the best treatment effect. The total score for each treatment was obtained on the basis of which comparisons were made and conclusions drawn (Ogbonnaya, 1992).

RESULTS

Growth:

The effect of water stress on height, collar diameter growth, leaf area, number of branches, feaves and flowers are shown in Fig. 1. Water deficit reduced the cummulative height growth of kenaf plants when çompared with the control. Kenaf plants under continuous Irrigation vigorously increased plant height from the beginning of the experiment to its termination at the 10th week. Height increased slowly with the plants under stress, and severe stress had the most detrimental effect on height increases (Fig. 1A). At the end of the growth period, the control had attained a mean height of *2.47* m, moderate stress 1.3 1 m and severe stress 0.94 m. Moderate stress therefore reduced height by 47% and the severe stress by 62% of the control.

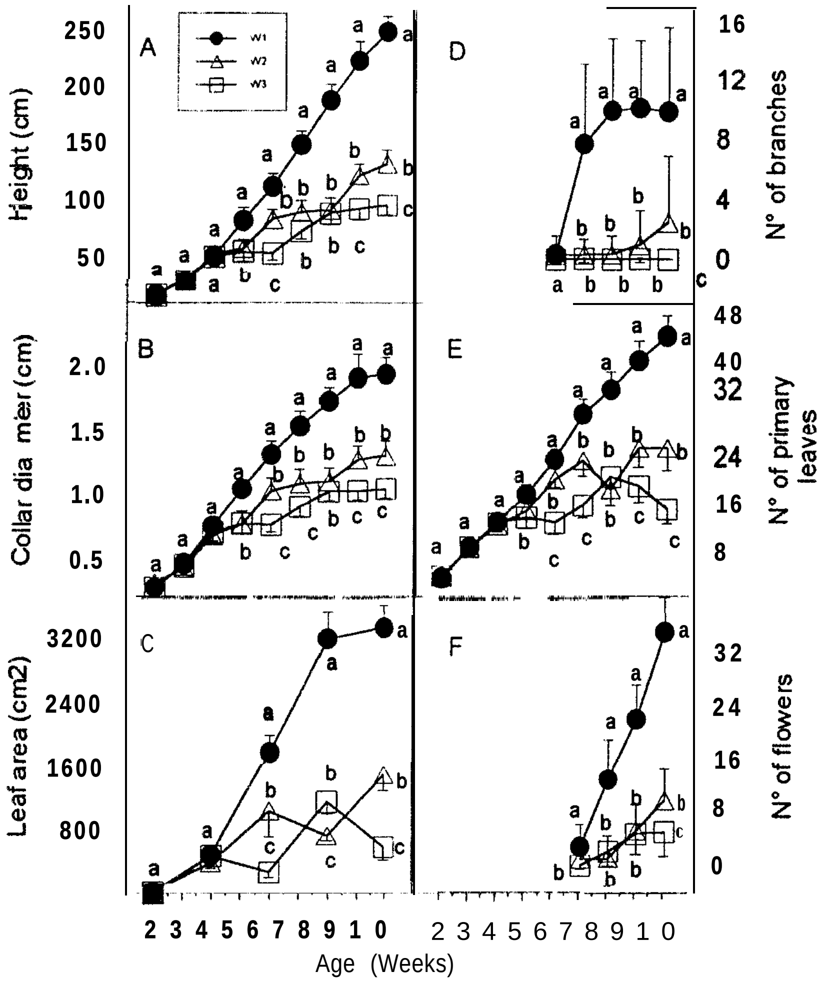

Fig. 1 Mean stalk height, root-collar diameter, leaf area, number of primary leaves, branches and flowers of kenaf under water stress. Means at each age followed by the same letter are not significantly different according to Duncan's multiple range test. W2 were watered on the 5th and 8th week. and W3 on the 6th week.

Collar diameter growth was significantly retarded by water stress. Moderate stress reduced growth by 32% and the plants attained radiai diameter of 1.3 cm, while severeiy stressed plants were rctarded by 45% having attained a basai diameter growth of 1.05 cm when compared with 1.94 cm growth recorded with the control at the end of the experimentai period (Fig. 1B).

Eeaf area growth (Fig. 1C) and primary ieaf production (Fig. 1E) were equaily affected by water stress. Primary ieaf number production siowed down at the 7th week of growth i.e during flowering, whiie that of the ieaf area growth was after the 4th week. Moderate stress reduced primary ieaf number by 43%, and ieaf area by 55%, whereas severe stress affected primary ieaf initiation and ieaf area deveiopment by 66 and 82% reductions respectiveiy.

Brarrching did not commence untii about the 6th week, and these were profuse in the control plants before flowering, after which ail the axiiiary buds were converted to flower buds. Moderate stress drasticaiiy reduced branching by 75% whiie severe stress completely inhibited it (Fig. 1E). Fiowering in ail the treatments started at the 7th week of growth, and was adversely affected by moderate and severe stress by 72 and 85% respectiveiy. The flower buds that were formed before the onset of stress got withered and dehisced. However, flower production recommenced when the plants were reiieved of stress (Fig. IF).

Fig. 2 shows the effects of the treatments on the number of nodes and the iength of internodes at the end of the experimentai period. With node numbers of 41 and 27, moderate and severe stress reduced node initiation by 28 and 53% respectiveiy, when compared with 57 trodes produced by the adequately watered control. Internode length decreased with age in all the treatments. The effect of stress on the internode length for W2 and W3 were similar until about rhe 15th node when moderately stressed plants started branching due to earlier release of stress. The severe stress on the other hand continued a downward decline. The first flower buds were formed on the 29th nodes of the control and the moderate stress, while that of the severely stressed plants were on the 25th node. In the well watered control, long internodes altemated with short internodes more vigorously after the commencement of flowering.

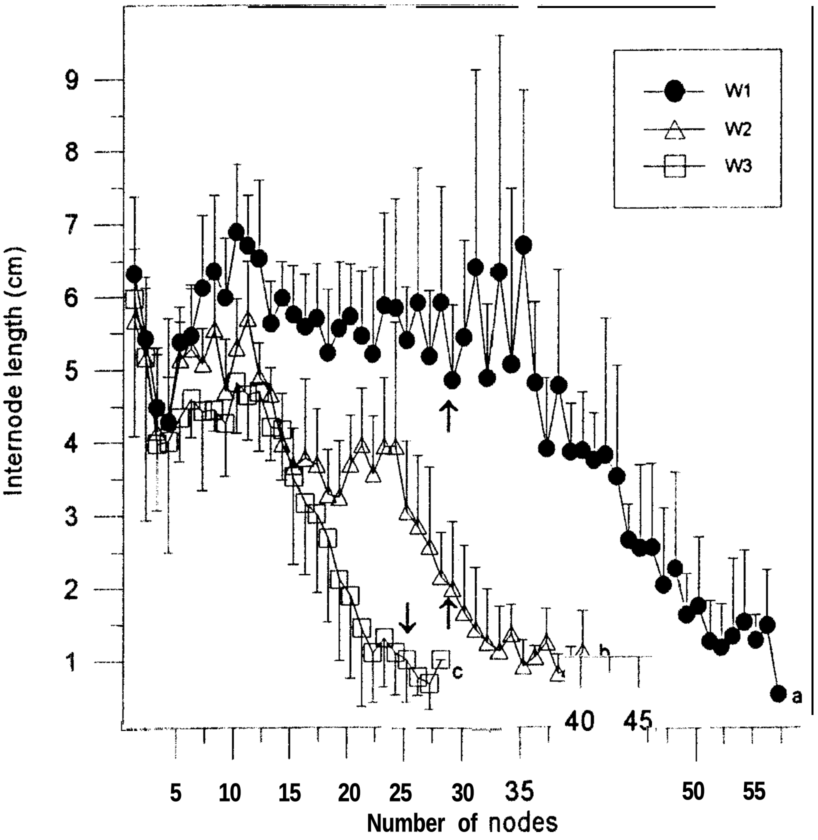

Fig. 2. Nodes and internode lengths of whole kenaf plants in the greenhouse under three soil moisture treatments. Terminal node numbers followed by the same letter are not significantly different according to Duncan's multiple range test. Arrows indicate the first flowering nodes.

Biomass accumulation

Biomass accumulation (Fig. 3) was also significantly affected by water stress, Leaf and root dry matter productions were highest after the 4th week of growth in the control plants. The difference between the moderate stress and the severe stress reponses were not significant. The pattern of growth in bark, wood, stalk, shoot and the overall plant production were similar With respect to the control, there were steep increases in biomass accumulation after the 6th week of growth. At the end of the experimental period, moderate stress reduced dry matter production of the leaf, root, bark, wood, stalk, shoot and total biomass (Fig. 4A) by 74%, and severe stress by of 86%.

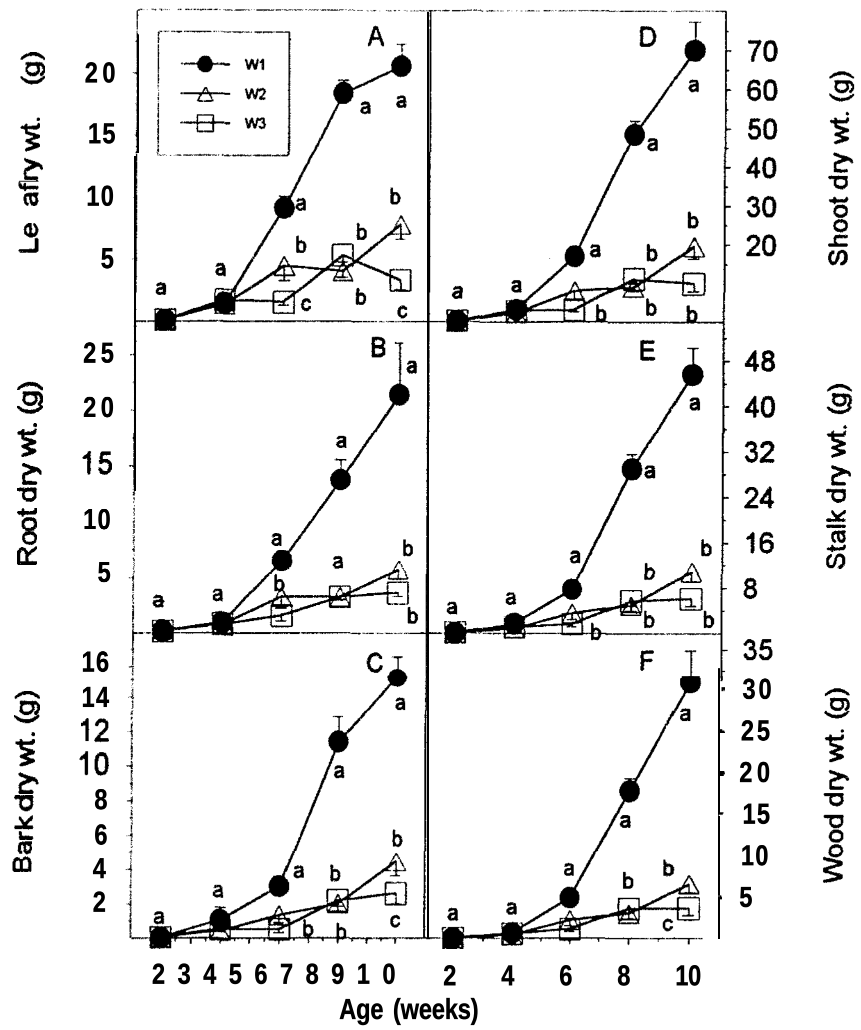

Fig. 3. Effect of water stress on dry matter accumulation of the leaf, root, bark, wood core, stalk and shoot of kenaf. At each age, means followed by the letter are not significantly different according to Duncan's multiple range test. W2 were watered on the 5th and 8th week and W3 on the 6th week.

Biomass allocation

Root-shoot ratio (Fig. 4B) and bark-wood ratio generally decreased with increase in age, and the steepest decline were at the 4th week of growth. Water stress had no effects on root-shoot ratio and bark-wood ratio (Fig. 4B and D). Leaf area ratio (LAR) increased by the 4th week before a downward decline (Fig. 4C). The stressed plants maintained relatively higher LAR throughout the experimental period.

Plant Water Relations

Leaf gas exchange. Stomatal conductance declined with age in the control treatment, and ail rhe treatments began a drastic decline after the 4th week of growth. Ail the levels of stress brought stomatal conductance to zero when watering was withheld. Upon rewatering there were rapid increases in stomatal conductance with a dramatic increase above the control by the severely stressed plants (Fig. 5A).

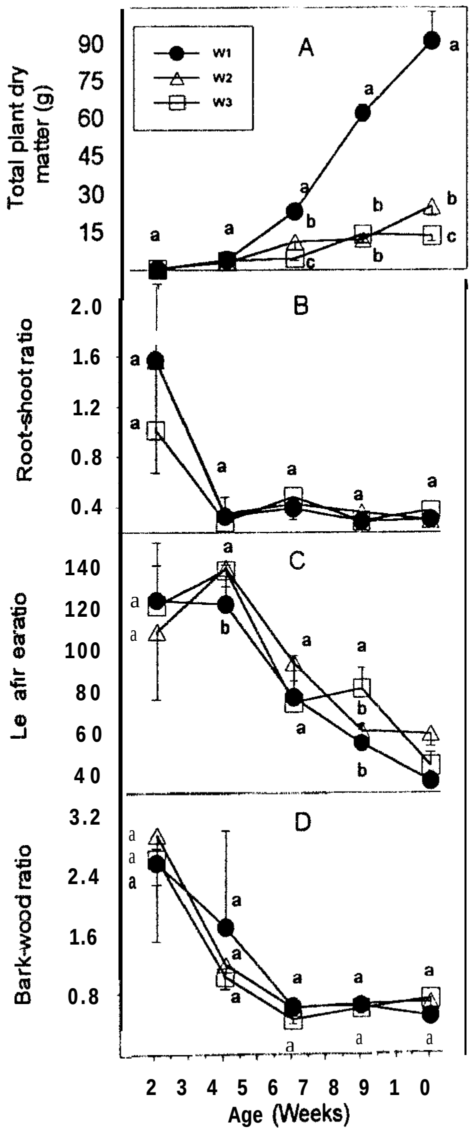

Fig. 4. Total dry matter accumulation, root-shoot ratio, leaf area ratio and bark-wood ratio of kenaf as influenced by water stress. Means along the column followed by the letter are not significantly different according to Duncan's multiple range test. W2 were watered at the 5th and 8th week, and W3 at the 6th week.

Similarly, transpiration rate fairly declined with maturity in the well watered control plants, after an initial increase by the 4th week of growth. Among the stressed plants, there was a steep fall in transpiration rate after the 4th week, that is, after only 2 weeks of stress. It reached 0.59 $\mu g\ cm^{-2}\ s^{-1}$ for both stressed plants as compared to 14.25 $\mu g\ cm^{-2}\ s^{-1}$ recorded with the control at the same period. Upon rehydration, transpiration rate rose rapidly, and in severely stressed plants transpiration went above the corresponding control value, only to fall sharply soon afterwards (Fig. 5B).

Leaf water status : LRWC began to drop two weeks after the initial withdrawal of watering, and moderate stress LRWC reached a value of 76 % after 2 weeks of stress, and in severely stressed plants 67% after 3 weeks of stress (Fig. SC). At the end of the experimental period, the LRWC of the moderate and severe stress had dropped to 58.57 and 55.10%, thereby representing 20.10 and 24.80% reductions of the LRWC of the corresponding, control respectively. An exponential regression of stomatal conductance (Fig. 6) indicated that stomata started closing at -0.5 Mpa, and finally closed at -1 .O MPa. Similarly transpiration rate (Fig. 7) started declining steeply below -0.5 MPa leaf water potential, and eventually ceased below -1.0 MPa.

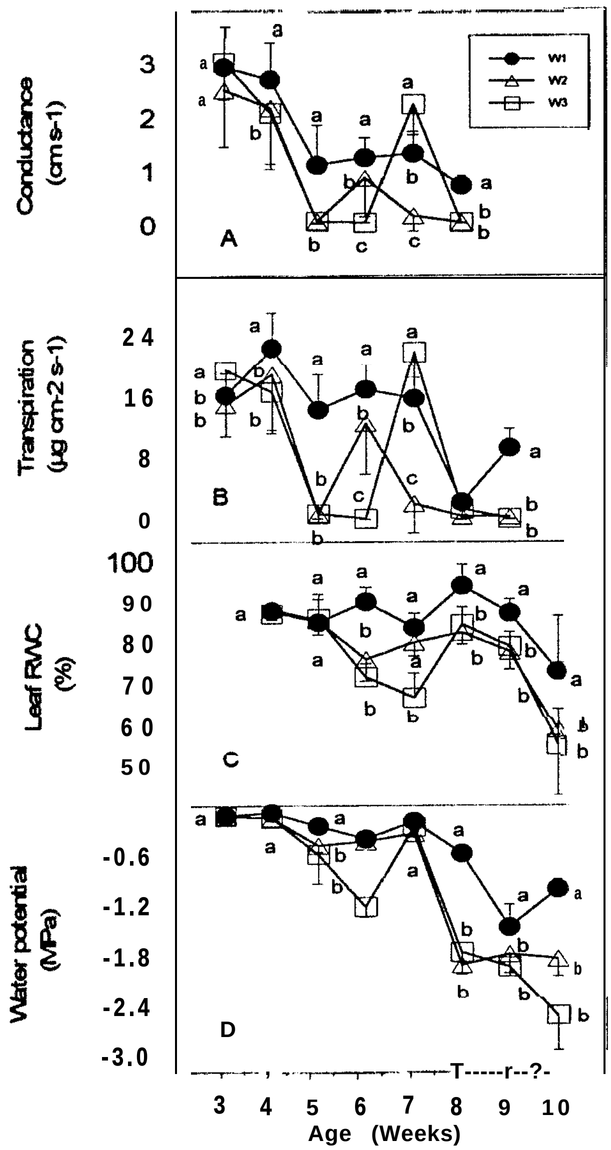

Fig. 5. Stomatal conductance, transpiration rate, leaf RWC and water potential of kenaf as influenced by water stress. At each age, means followed by the same letter are not significantly different according to Duncan's multiple range test. W2 were watered on the 5th and 6th week and W3 on the 6th weeks.

The leaf water potentials (Ψ_w) during the drying and recovery cycles are show in Fig. 5D The Y, in the control plants fairly decreased as the plants aged, while droughted plants began to show sharp decrease in Y, after 2 weeks of stress. Before the first watering session at the 5th week, the severely droughted plants had reached Y, of -1.21 MPa. Upon rewatering, the recovery of Y, of the Ieaves was almost as rapid as the rate of drying, in that, Y, got very close to the control value of -0.4 MPa.

At the second watering session at the 8th week, the Y, of moderately droughted plants also dropped sharpely to -1.91 MPa after 2 weeks of stress. The severely stressed plants dropped drastically to -1 76 MPa after only one week of stress, these are when compared with -0.58

MPa attained by the the adequately watered control at the same period. At the end of the experimental period, Y, of -1.01, -1.84, and -2.53 MPa had been attained by the adequately watered control, moderately and, severely stressed plants respectively. There was no significant difference in the values obtained with the stressed plants.

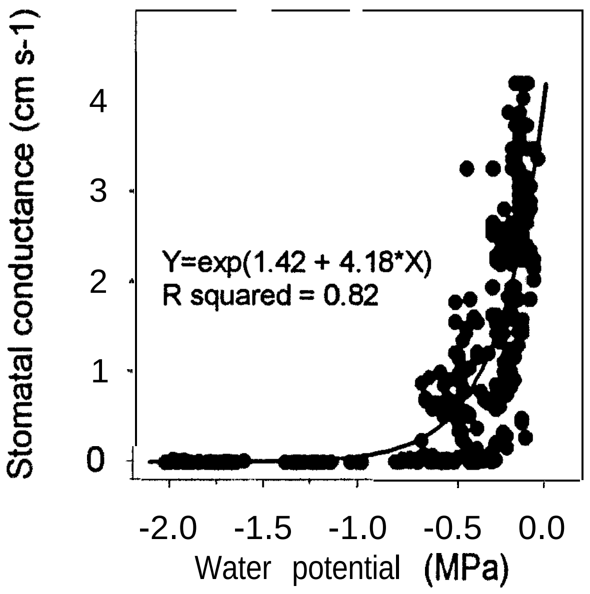

Fig. 6. Stomatal conductance of kenaf as a function of water potentiai. The curve was fitted by an exponential equation.

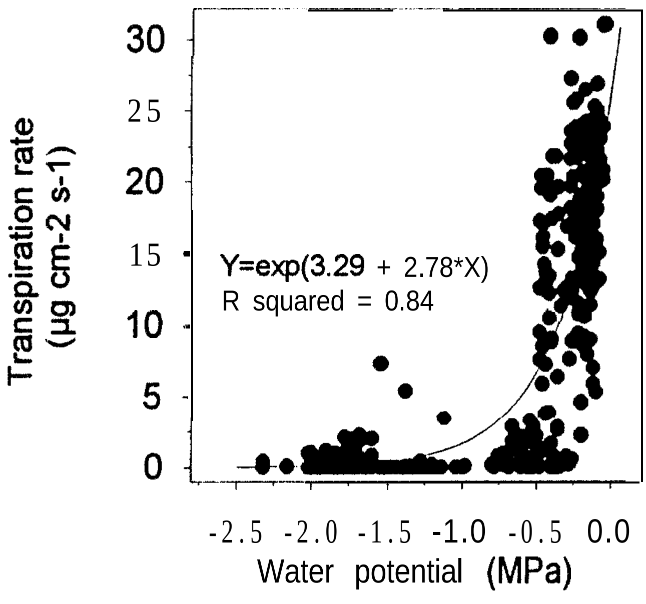

Fig. 7. Relationship between transpiration rate and water potential in kenaf. The curve was fitted by an exponential equation.

Plant microclimate: Plant leaf-air temperature differential in the control increased with time up to rhe 5th week before a gradual decline thereafter. Similar results were obtained with plants under stress, except after watering sessions when they sharply dropped. As stress increased, temperature of the stressed plant increased above air temperature and temperature differential became positive, indicating that the leaves were hotter than the air The leaf-air temperature differential of the well watered control remained negative indicating that the leaves were cooler than the ambient air (Fig. SA). A polynomial regression of leaf-air temperature differential on water potential showed that leaf temperature would rise above air temperature at about Y w below -0.5MPa (Fig. 9).

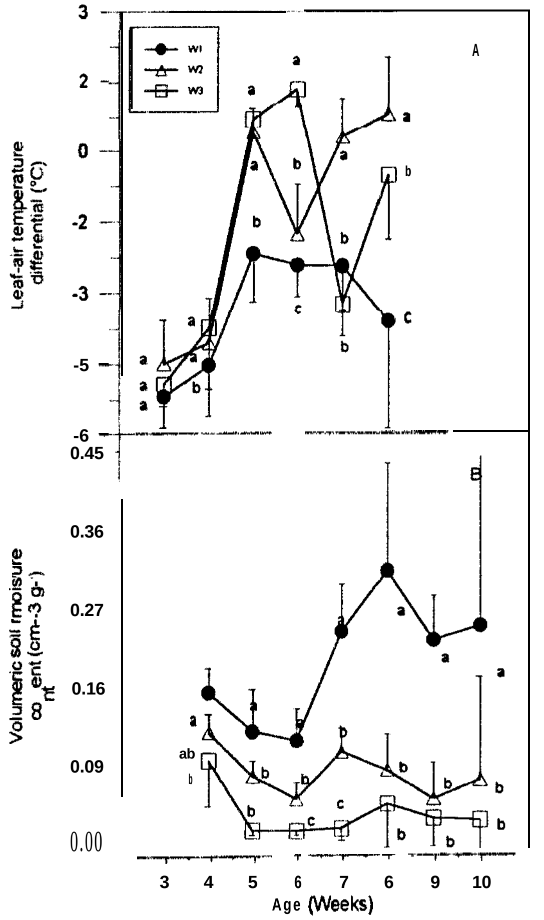

Fig. 8. Leaf - air temperature differential and soil volumetric water content as variously affected by water stress with kenaf. Within the age, means followed by the same letter are not sigificantly different according ta Duncan's multiple range test. W2 were watered on the 6th and 8th week. and W3 on the 6th week.

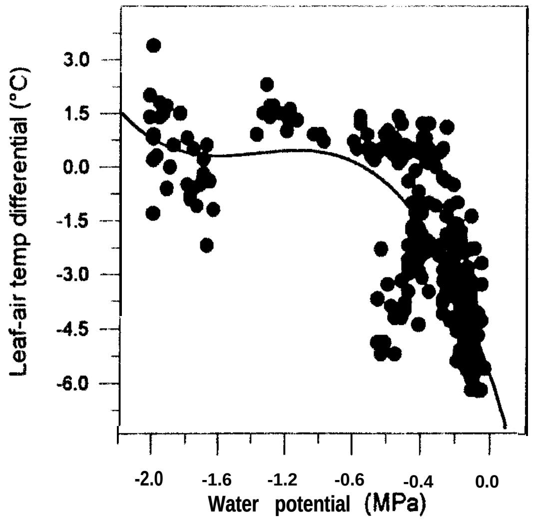

Fig 9. Relationship between leaf-air temperature differential and water potential in kenaf. The curve was fitted by three-term polynomial.

Soil water status: Average volumetric water content (cm" g^{-1}) of the experimental soil obtained at O-7, 7-14, 14-21 and 21-28 cm soil depth are shown in Fig. 8B. The soil water content went high after the 6th week in the well watered control, corresponding to the peroid of commencement of flowering. Volumetric soil water content in the stressed pots remained relatively low even after the periodic watering.

Stalk Physical Properties

Stalk specific gravity. Stalk specific gravity was not a variable factor within the first 6 weeks of growth of kenaf. There was a steep increase at the 8th week of growth, and gradual increase thereafter. All levels of stress severely checked this attribute throughout the growth period. The difference in stalk specific gravity among the stressed plants was not found to be statistically significant (Fig. 10).

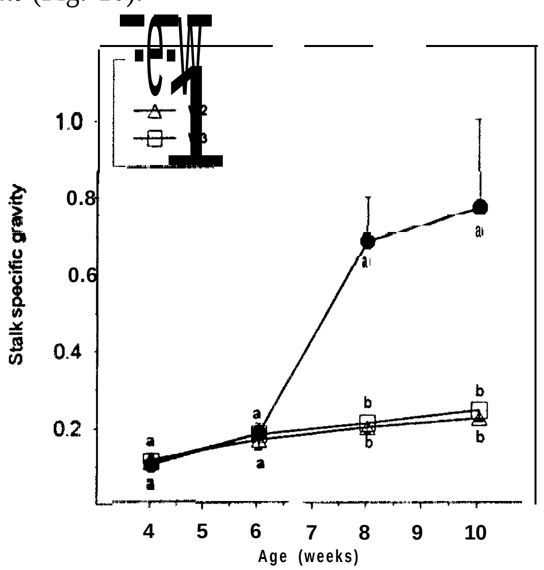

Fig. 10. Stalk specific gravity of kenaf under three soil moisture regirnes Means at age followed by the letter are significantly different according to Duncan's multiple range test.

Fibre Dimensions and the Derived values:

Fibre dimensions. The effects of water stress on the fibre dimensionai properties are shown in Fig. 11. Bark and wood fibre length fairly increased with maturity and both moderate and severe water deficit adversely affected this important fibre dimension. Optimal values of fibre elongation were obtained by the 8th week of growth for both bark and wood, for the adequately watered control and moderate stress. The fibre length of the severely stressed plants continued to rise after an initial decrease. The bark fibre length ranged from 1.63 mm for the stressed plants to 2.19 mm for the well watered control, while that of the wood was in the range of 0.53 mm to 0.8 mm for the severely stressed plants and the adequately watered control respectively (Fig. 1 IA and B). At the end of the grow-th period, there were no significant differences between the bark fibre lengths. The differences between the bark and the wood fibre lengths were significant at P=O.O 1.

In contrast with the fibre length, Fibre diameter (fd) decreased with maturity in both the bark and the wood. Severe stress reduced fd. of the plants, while moderate stress enhanced it above the control in the bark (Fig. 11C and D). At the end of experimental period, water stress had significant effect on fd of both the bark and the wood. The result of the fibre lumen diameter (fld) was similar to that of the fd, in that fld decreased with age and stress produced higher fld after the 6th week in the bark. The differences between the fld of the wood were not significant at the end of the growth period, whereas stress sgnificantly (P=0.05) increased it in the bark (Fig. 11E and F). The differenes between the bark fd and fld and those of the wood were statistically significant.

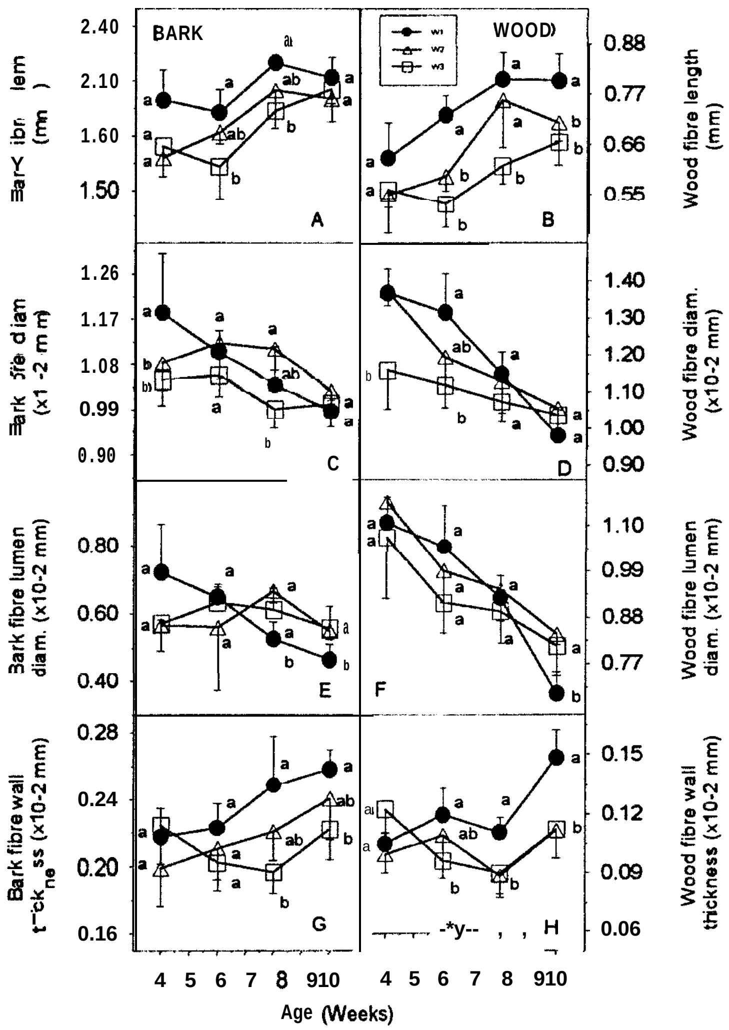

Fig. 11. Effect of water stress on bark and wood fibre length. fibre diameter, fibre lumen diameter. and fibre wall thickness. Means within the age. followed by the same letter are not significantiy diierent according to Duncan's multiple range test. W2 were watered on the 5th and 8th week, and W3 on the 6th week.

Fibre wall thickness (fwt), on th other hand, increased with maturity in the well watered control of both the bark and the wood, whereas stress reduced it with age, but this began to increase after the 8th week of growth. At the end of the experiment, water stress had significantly reduced fwt of the wood, and only those of the severely stressed plants in the bark (Fig. 11G and H). The values between the wood and the bark were significantly different (P-0.01) at the end of the period.

The **fibre derived** values. The difference between the wood and bark derived values were statistically different (P=0.05) at the end of the growth period. The slenderness ratio (SR) increased with maturity, except that in the bark water stress reduced this value at the 6th week, that is, after the first cycle of drought. The optimal SR in both bark and wood were obtained at the 8th week of growth. At the end of the experiment, water deficit had no effect on the bark SR, but it significantly reduced those of the wood (Fig. 12A and B). Coefficient of suppleness (CS) or flexibility coefficient decreased with maturity in the control for both the bark and the wood. In the wood this value was consistently higher with stress, and similarly so in the bark, after an intial decrease with severe stress at the 6th week. At the termination of the experiment. water deficit had significantly enhanced CS in both the wood and bark (Fig. 12C and D)

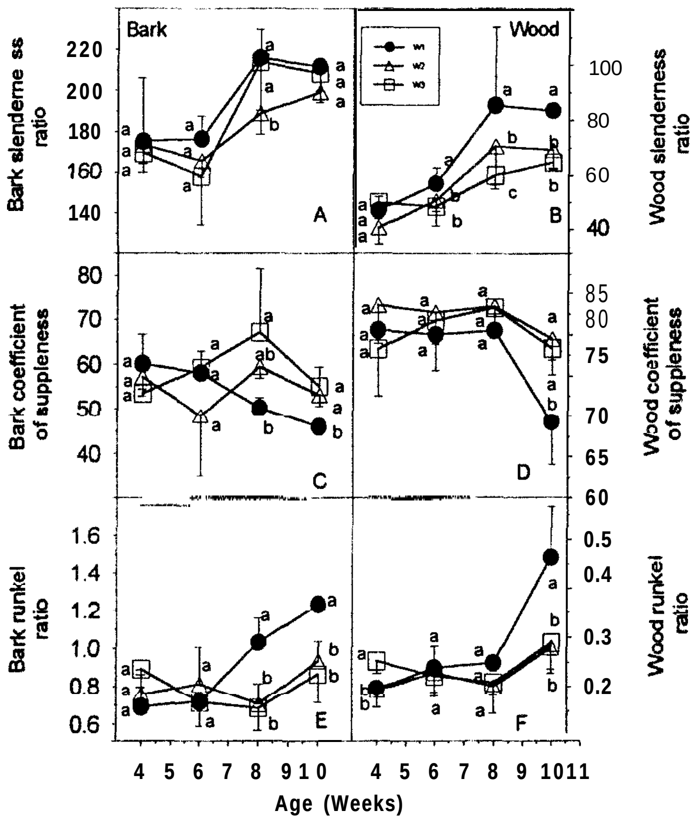

Fig. 12. Effects of water stress on bark and wood slenderness ratio, coefficient of suppleness and runkel ratio. At each age, means followed by the same letter are not significantly different according to Duncan's multiple range test. W2 were watered on the 5th and 8th week and W3 on the 6th week.

Runkel ratio (RR) increased with age in the well watered control. The response with the stressed plants was rather erratic, but were significantly lower than the control at the end of the growth period (Fig. 12E and F).

Chemical properties

Alkali soluble substances content (1% alkali solubility): Alkali soluble substances content decreased with age, and increased with stress in bath the bark and wood core. The wood alkali solubility varied from 23.78% in the adequately watered control to 33.68% with severe stress. while that of the bark ranged from 24.71% with the control to 43.24% under severe stress (Fig. 13A and B). Whereas, water stress significantly increased alkali solubility in both the bark and the wood, the differences between the wood and the bark were not significant.

Alcohol-benzene soluble substances content: Alcohol-benzene solubility increased witb stress in both the bark and the wood, and the values ranged from 8.64% with adequately watered control in the bark, to 15.76% with severely stressed plants in the wood. At the end of the growth period, severe stress had significantly increased alcohol-benzene solubility in the bark, and with moderate stress in wood (Fig. 13C and D). Alcohol-benzene soluble substances of the bark and the wood were not statistically different.

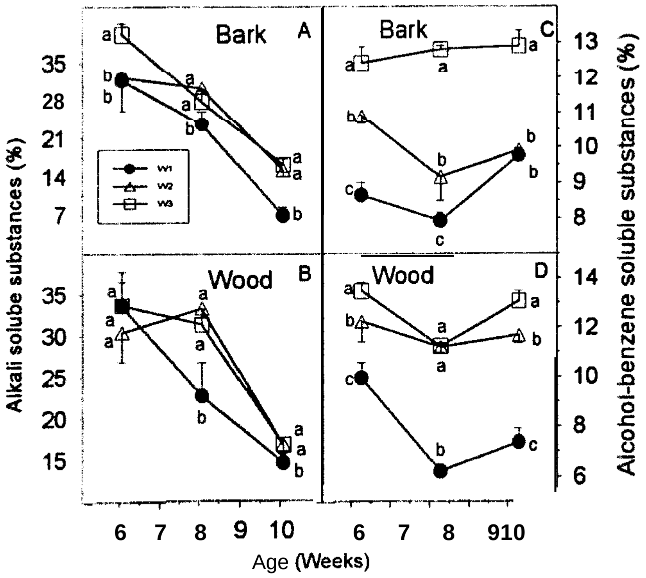

Fig. 13. Alkali and alcohol - benzene soluble substances content of kenaf bark and wood as affected by water stress. Means followed by the same letter within age are not significantiy different according to Duncan's multiple range test. W2 were watered on the 5th and 8th week and W3 on the 6th week.

Table 1: Holistic assessment of the effects of water deficit on kenaf stalk physical properties, fibre dimensions and their derived values.

S/N°	Parameters	Treatments		
		W1	w2	w3
	Stalk Physical Properties			
1	**Specific gravity**	3	2	2
	Histo-chemieal Properties			
	Wood			
2	Fibre length	3	2	2
3	Fibre diameter	3	3	3
4	Fibre lumen diameter	3	3	3
5	Fibre wall thickness	2	3	3
6	Sienderness ratio	3	2	2
7	Coefficient of suppleness	2	3	3
8	Runkel ratio	2	3	3
9	1%Alkali solubility	3	2	2
10	Alcohol-benzene solubility	3	2	2
	Bark			
11	Fibre length	3	3	3
12	Fibre diameter	3	3	3
13	Fibre lumen diameter	2	3	3
14	Fibre wall thickness	1	2	3
15	Slenderness ratio	3	3	3
16	Coefficient of suppleness	2	3	3
17	Runkel ratio	2	3	3
18	1%Alkali solubilitv	3	2	2
19	Alcohol-benzen solubility	3	3	2
	Total	49	50	50
	Percentage performance	85.96%	87.12%	87.72%

Holistic assessment: A holistic assessment of the effect of water stress treatments on kenaf stalk physical properties, fibre dimensions and their derived values are shown on Table 1 Severely and moderately stressed plants had the highest scores of 50 respectively, when compared with 49 obtained with the control. Thus, representing 87.72% performances for plants under stress and 85.96% for the well watered control. The differences between these performances were not statistically significant.

DISCUSSION

Physical Growth:

Stern development and elongation are the critical components of the growth process (Schulze and Matthew, 1993). Physiological efficiency of any particular fibre species is manifested in the increment of plant height and increase in basa1 diameter. These parameters which result from the respective activities of apical growth and intercalary growth are generally considered dependable yield components of a bast fibre crop.

Water deficit was observed to have significantly reduced height and collar diameter growth of kenaf That drought reduces plant height and vigour is well known. The alteration of these growth parameters under water deflcits are due in part to the role of water in turgidity maintenance necessary for cell enlargement (Kramer, 1963). Cell division also decreases with increased water deficits, because cells apparently must attain a certain size before they çan divide (Doley and Leyton, 1968). As there is no direct method for assessing the fibre yield from a standing crop, plant height and basa1 diameter are considered as the general guiding criteria for efficient production of fibres in a particular species (Maiti and Chakravarty, 1977) It can rherefore be concluded that, drought affects the efficient production of fibres in kenaf.

Leaf growth is the most sensitive of plant processes to water deficits and is frequently inhibited in field crops (Hsaio, 1973; Schulze and Matthew, 1993). For a given location and growth duration, the amount of light intercepted is primarily dependent on leaf area development, and these have been shown to be directly linked to leaf turgor (Bunce, 1977; Wenkert et *al.*, 1978). Water deficit adversely affected the number of nodes and leaves produced in kenaf, leaf dry matter, and leaf area due to of poor leaf expansion and defoliation.

Kenaf usually grows straight and unbranched in dense stands. In this experiment, branching started at the 6th week of growth. However, it stopped when flowering fully commenced at the 8th week, since all the axillary buds had become flower buds. Branching was highly reduced by moderate stress and completely inhibited by severe moisture stress. High branching is an unwanted luxury under drought because it would be wasteful of soil moisture (Keim and Kronstad, 1981). Inhibition of branching under drought conditions observed in kenaf could therefore be considered an adaptive mechanism, as it tried to conserve water which could be needed in the more critical stages of development, like flowering.

Flowering of Kenaf in the greenhouse started on the 7th week of growth in all the treatments. Water stress, however, reduced flower production by more than 70%. Within a range of germplasms, most of the drought resistance of high yielding crops under drought stress could be attributed to earliness (Chinoy, 1961; Derera, 1969). This characteristic wauld allow a genotype to escape, in relative terms, a gradually increasing drought stress. Kenaf did not employ this escape mechanisms in order to resist drought, since flowering started at the time in all the treatments.

Biomass accumulation

Soil moisture stress reduced biomass accumulation in all components of kenaf that were nvestigated, namely; the leaf, root, bark, wood core, stalk, shoot and consequently,total dry natter It is hypothesized that an important result of mild drought stress would be a decrease in rhe efficiency with which solar radiation is used to accumulate biomass. The loss of accumulation efficiency is associated with a decline in photosynthetic capacity which might have resulted from decreases in leaf gas conductances (Muchow *et al.*, 1986). It has been shown in this study that kenaf closes its stomata almost completely at the onset of drought (see Fig. 5A and B). Though this was an efficient drought avoidance mechanism, it was at the expense of carbon accumulation (Nwalozie and Annerose, 1996).

Biomass allocation

High root-shoot ratios are generally a response to water stress in the rooting zone. The root-shoot ratio in kenaf decreased with age, and it was not influenced by water deficit. Root growth depends on supply of carbohydrate from the shoot and reduction in leaf area usually reduces root growth (Kramer, 1983), this would have been the case with kenaf. LAR in kenaf deçreased with maturity. However, the variations among the stress treatments were not statistically significant at the end of the experimental period, but were signiftcantly reduced with respect to the control. The importance of leafiness as a component of overall growth is well known. For most plants the LAR decreases with age as the plant size increases (Blackman and Wilson, 195'1). A reduction of LAR with age has been observed as a usual feature in annuals (Higgs and James, 1969), and this can be related to their shorter life span (Sharma and Ogbonnaya, 1990). The reduced LAR with stress would have been caused, in part, by the high defoliation observed with stressed plants.

Bark-wood ratio, like root-shoot ratio was not affected by water deficit in kenaf, and this decerased with maturity. Fibre-wood ratio is generally considered a dependable yield component and selective index of bast fibre crops (Maiti and Chakravarty, 1977). These two components are direct derivatives of secondary cambium. A higher fibre-wood ratio indicates the plant's efficiency in the production of higher yield of fibres than of wood. This criterion is utilized as a measuring stick in the production of fibres of different species or varieties. This finding agrees with the report of Francois *et al.* (1992), that saiinity had on significant effect on the proportion of the stem that is bark in kenaf. They reported that bast fibres accounted for approximately 36% of the stem weight at all salinity treatments. This percentage also agrees with kenaf bast fibre percentage reported by Muchow (1979) in Australia. Cuba 108 has been shown to have the least percentage wood core material (62%), and greatest bark to wood ratio (0.61), among all the kenaf varieties (Webber, 1993).

Plant Water Relations

Water status

Drought tolerance levels in plants varies widely among species. Dehydration of sunflower plants to -1.5 Mpa, for example, caused injury to about 10% of the cells, while dehydration below -2.0 MPa caused so much injury to organelles and membranes that recovery was impossible (Fellows and Boyer, 1978). Giles *et al.* (1976) observed irreversible changes in cell structure of 25% of maize mesophyll cells at -1.8 MPa. Injury has been ascribed to mechanical rupture of protoplasm, degradation of cell membranes, protein denaturation, and accelerated gene mutations (Kramer, 1983, Roy-Macauley *et al.*, 1992).

Dehydration is usually accompanied by severe damage and disorganization of membranes and organelles. However, dessication-tolerants retain most of their structure and capacity for physiological activities, and resume normal growth processes soon after rehydration (Kramer, i983). The results presented in this study showed that kenaf was able to recover after a deficit of -2.54 MPa, after four weeks of drought. In addition, it retained more than 50% of its

LRWC. The fact that kenaf was able to recover after a water deficit corresponding to -2 54 MPa indicates that it is relatively desiccation-tolerant. The results of this study are not at variance with the reports of Maas and Hoffman (1977), Curtis and Lauchli (1985, 1986), Francois *et al.*(1992) that placed kenaf as a moderately salt-tolerant non-halophyte, on the basis of its response to salt stress. Plant breeders and physiologists agree that, there is a very high carrelation between drought tolerance and salt tolerance, afterall, in both cases the plant is subjected to moisture stress.

Leaf gaseous exchange

A common response to water stress is stomatal closure, which reduces both flux of CO_2 and water vapour. Ahernatively, stomates may remain open while turgor is maintained through osmotnc adjustment. Stomatal conductance and transpiration rate in kenaf progressively declined with age in the adequately watered control. All the levels of stress brought stomatal conductance and transpiration to zero. Kenaf was also observed to roll its leaves during drought, These two mechanisms employed by kenaf could be described as drought tolerance by dehydration postponement (Kramer, 1983), equivalent to drought avoidance by Levitt (1980). Upon rewatering there were rapid increases, with a dramatic increase above the control obsened in the severely stressed plants (Fig. 6). This buttresses the earlier assertion that kenaf is desiccation tolerant. An exponential regression of stomatal conductance indicated that stomata started closing at -0.5 MPa, and finally closed at -1 .O MPa. Similarly transpiration rate started declining steeply below -0.5 MPa leaf water potential, and eventually ceased below -1.0 MPa.

Cowpea shows a similar response (Hall and Schulze, 1980; Nagarajah and Schulze, 1983). fhis response enables plants to avoid desiccation by maintaining leaf water potential at relatively high levels. While osmotic adjustment is minimal in such species (Shackel and Hall, 1983), it cannot be ruled out for kenaf which has been hypothesized to have a high desiccation tolerance capacity. This might be due to membrane resistance and/or osmotic adjustment mechanisms triggered when water deficit surpasses the critical point of -0.5 MPa.

Kenaf could therefore be described as opportunistic in relation to water availability, with high rate of stomatal conductance and transpiration when soil water is available but with markedly reduced leaf conductance and transpiration rate when water is limited. This contrasts with wheat, which utilizes water sparingly when it is available but has only a gradua1 decrease in photosynthesis as water deficits develop (Hensen *et al.*, 1989).

Plant microclimate:. Leaf temperature relationships are used to estimate water stress in plants, because leaf temperature and ambient air temperature differentials are functions of transpiration rates (Halim *et al.*, 1989). The temperature of the stressed plants increased above air temperature and air-tempreature differential became positive, indicating when the plants were stressed. At this point, the leaf was hotter than the ambient air. This could be linked up to the stomatal closure, poor gas exchange and decreased transpirational cooling of the plants, Water potential of -0.5 MPa was bracketed as the critical water potential, below which the plant would be stressed and the leaf temperature would rise above ambient air temperature.

The stressed plants, therefore, began to face another kind of stress, heat stress And that is why breeders seldom attempt to separate heat from drought tolerances, probably because drought is usually accompanied by high temperature. High temperature accompaning drought causes release of ammonia fi-om decomposition of protein that injures plant tissues (Weiland and Stuttle, 1980).

Physical Properties

Stalk specific gravity Specific gravity determines the strength properties of wood, its resistance to breakage, and its elasticity, durability and yield. The specific gravity of kenaf was adversely affected by water stress. This could be linked up to unfavourable carbon balance observed during drought, leading to the starvation of the plants, and the under-developmem of the cellwall (Ogbonnaya et *al.*, 1992). On the basis of the result obtained, kenaf would yield more fibres after the 6th week of growth, and may therefore not be harvested before then.

Fibre dimensional properties

Warer stress adversely influenced the fibre dimensional properties of both kenaf bark and wood core. The fibre length (fl), fibre diameter (fd), fibre lumen diameter (fld) and fibre wall thickness (fwt) were decreased, except in the bark where fibre lumen diameter was significantly increased. The reduced fibre dimensions by water stress would be due, in part, to the role of water in turgidity maintenance necessary for cell enlargement (Kramer, 1963), because cell expansion is achieved when loosening of the cell wall yeilds under stress of the interna1 turgor pressure (Schulze and Matthew, 1993).

The higher lumen size in the bark due to stress would be due to reduction of the fibre wall shickness by dehydration rather than growth. Thickening of fibre walls apparently results from an unusually high degree of hydration of their constituents (Swanson, 1959). At the end of the experimental period, water deficit had no significant effect on the bast fibre length and diameter, wood fibre diameter and lumen size, similar to the earlier observation of Francois et *al.* (1992) on salinity.

Derived values of fibre dimensions

The true relevance of fibre dimensions is better evaluated in terms of slenderness ratio, coefficient of suppleness and runkel ratio. The usefulness of fibre length to paper quality is measured in terms of its slenderness ratio. The higher the slenderness ratio, the stronger the resistance to tearing (Rydholm, 1967). The results of this work showed that bark SR of kenaf was not affected by water deficit at the end of the experimental period.

Guidelines by Petri (1952), Okereke (1962) and Rydholm (1967) showed that a higher coefficient of suppleness (≥ 50 but preferably > 60) is necessary for fibres used in paper-making. This is because paper strength tends to improve with increasing CS. Fibres with high CS are flexible, collapse readily and produce good surface contact and fibre-to-fibre bonding. They yield low bulk paper with excellent physical characteristics (burst, tensile and fold). Water deficit enhanced this property in both the. bark and the wood core as a result of increased fibre lumen diameter due to reduced fibre wall thickness.

Runkel ratio determines the suitability of fibre for paper production. The guidelines by Okereke (1962) and Rydholm (1967) show that for good paper characteristics, the RR will be ≤ 1, because paper strength tends to improve with decreasing RR. The present showed.that water stress decreased RR of the bark and the wood core of kenaf, indicating that water stress would enhance kenaf paper strength. Earlier studies on a tree species (Ogbonnaya et *al*, 1992) indicated no significant effect of water stress on the quality of pulp and paper produced from *Gmelina arborea*

Chemical properties

The result of this study showed that 1% alkali soluble substances content of kenaf was tncreased by water deficit in both the bark and the wood. The alkali soluble substances are made up of pentosans, hexosans and lignin, which are mainly carbohydrates and their derivatives (Casey, 1960). The increased carbohydrates and their derivatives is easily understood, since reduced moisture decreases growth, without having as much effect on photosynthesis (Levitt, 1956). Consequently, carbohydrates (soluble or insoluble) accumulate with stress. Soluble carbohydrates can also increase due to the conversion of insoluble carbohydrates like starch to soluble substances like sugar among others, as result of starvation (Adjahossou and Vieira da Silva, 1978). High percentage of alkali solubility is, however, undesirable in pulping; it predisposes wood to decay and in sulphite pulping process, yields are reduced and more alkali is consumed (Casey, 1960).

Alcohol-benzene soluble substances (lipids, waxes, and resins) are mainly lipids or their derivatives. High values of alcohol-benzene solubles adversely affect the pulping process by frothing and clogging of pipes, and the quality of the resulting pulp (Grant, 1961). In kenaf, these substances increased with increase in water deficit. Iljin (193 1) showed very early that. elimination of the vacuole by contraction or thickening of the protoplasm or by filling with these nondrying substances accompanies the development of extreme drought hardiness Schmidt (1939) reported an increase in alcohol permeability in droughted plants which was explained as an increase in lipid permeabihty. On the basis of conclusions of other workers he suggested that the surface lipids are more basic in the droughted plants, more acid in the moist-grown plants.

Holistic assessment

Holistic analysis of the effect of water deficit on the physical and histo-chemical properties of kenaf relevant to pulp and paper production revealed that water deficit tended to improve the resulting pulp and paper quality of kenaf A similar result was obtained with *Gmelina arborea* (Ogbonnaya et *al.*, 1992), in which water stress affected growth but not the resulting pulp and paper quality,

Water stress is not always injurious. Although it reduces vegetative growth, it sometimes improves the quality of plant products (Kramer, 1983). Mild water stress has been found to kncrease the rubber content of guayule and the desirable aromatic properties of Turkish tobacco (Wolf, 1962). It can be generally hypothesized, therefore, that some level of stress may be required ta improve the fibre qualities of crop plants. This level of stress which does not affect growth, however, has to be worked out for each plant.

CONCLUSIONS

1. The most critical water potential was -1.5 to -1 .0 MPa, below which stomata closed, leaves rolled up and transpiration ceased.
2. Kenaf might be employing drought avoidance mechanisms
3. Kenaf recovered after a decrease in the water potential to -2.53 MPa.
4 Kenaf might also be employing drought tolerance mechanisms.
5. Water deficit caused reduction in growth of kenaf and pulp yield by implication,
6. From the holistic assessement water deficit does not affect the quality of pulp and paper produced from kenaf,

ACKNOWLEGEMENT

I am immensely grateful to Dr. Daniel. J. M. Annerose, the Director of CERAAS, for the oppurtunity given to me to use the expertise and the material resources of his Center to carry out this study, and also for his personal interest and appreciation of my work. It was pleasurable working with every member of the Centre. I am equally grateful to my colleague, Dr. Marcel. C. Nwalozie for encouraging me to apply for the Research Fellowship at CERAAS, and for all his care and assistance during my stay in Sénégal. Dr. Harold Roy-Macauley, the Assistant Scientific Director, made sure the experiment succeeded. He was a wonderful host, it was nice meeting him.

David Boggio, the biometrician, was very resourceful with the experimental design and the statistical analysis. Jennifer Baciuska, the documentalist, was very helpful in the search for literature. Jean-Marc Lacape's constant interest in the experiment was helpful. Couna Sylla, rhe computer analyst/programmer, was always ready to help out with computer problems even at odd hours. I am grateful to the technicians and particulariy Ibrahim Ndong and Papa Samba Dia for their assistance and work ethics in data collection. 1 am equally grateful to the administrative crew led by Mons. Kandji Mamoudu, for their quick responses to my material needs. To the European Union (EU) that provided the fund for this research (Grant N" FED 342 RPR), 1 am no less indebted.

I owe a debt of thanks to my Vice Chancellor, Prof S. 0. Igwe for his goodwill and interest in my joumey, and for granting me Fellowship Leave to undertake the research. I wish to appreciate the assistance of my friends Prof B. E. B. Nwoke and Engr. Sam. Iwuh for my stay in Lagos. And finally, to my wife, Commie and my kids, Dozie, Ihuoma and Bukkie who had to bear the burden of my absence, 1 owe them all.

REFERENCES

Akinosho, T. 1987. Forestry, Long green struggle for paper. *Agronomy Journal* 67, 57-59.

Annerose, D. J. M. 1990. Recherches sur les mécanismes physiologiques d'adaptation à la secheresse: Application au cas de l'arachide (*Arachis hypogaea* L.) cultivée au Sénégal. Doctorat These, Science Naturelles, Universite Paris VII.

Auonymous. 1953. Density, fibre length, and yield of pulp for various species of wood. 'fechnical Note N° 191, Forest Product Laboratory, Madison, Wisc.

Anonymous, 1996. L'avenir des fibre végétales: Le cas du kénaf Nigeria. *Spore 65,* 5.

Bagby, M. 0. 1977. A practical fibre resource. In. *Non-woodplant fibre pulping* - Progress Report, N° 8, Atlanta. Technical Association of the Pulp and Paper Industry.

Bagby, M. O., Adamson, T. F.,and White, G. **A. 1975.** Kenaf stem yield and composition: Influences of maturity and field storage. TAPPI CA Report No. 58, Non-wood Plant Fibre Pulping Progress Report No. 6, pp. 69

Blackman, G. E. and Wilson, G. **L.** 1951. An analysis of the differential effects of light intensity on the net assimilation rate, leaf area ratio and relative growth rate on different species. *Ann. Bot* 15, 373.

Boulanger, J. 1990. Les Hibiscus textile en Arique Tropicale, 2éme partie: production de la textile du kénaf et de la roselle. IRCT-CIRAD, France.

Bunce, J. A. 1977. Leaf elongation in relation to leaf water potential in soybean. *Journal of Experimental Botany 28,* 156- 16 1.

Business Concord. 1996. Global paper demand rises as Nigeria's recedes (an FAO Report) *National Concord Newspaper,* Nigeria. July 22, 1996.

Casey, J. P. 1960. *Pulp andpaper chemistry and chemical technology,* Vol. 1 (2nd edition). London; Edward Amold.

Chinoy, J. J. 1961. Physiology of drought resistance in wheat. II. Evaluation of drought resistance in eight varieties of wheat on the basis of growth analysis. *Phyton. 16.* 13 1-139.

Clark, T. F., Nelson, G. H., Nieschlag, H. **J. and Wolff, I. A. 1962.** A search for new fibre crops. V. Pulping studies on kenaf. *TAPPI 45,* 780-786.

Curtis, P. S. and Làuchli, A. 1985. Response of kenaf to salt stress: Germination and vegetative growth. *Crop Science* 25, 944-949.

Curtis, P. S. and Làuchli, A. 1986. The role of leaf area development and photosynthetic çapacity in determining growth of kenaf under moderate salt stress. *Aust. Journal Plant Physiology* 13, 553-565.

Derera, N. F. , Marshal, D. R. and Balam, L. N. 1969. Genetic variabîlity in root development in relation to drought tolerance in spring wheats. *Exp., Agric*. 5, 327-337

Doley, D. and Leyton, L. 1968. Effects of growth regulating substances and water potentîal on the development of secondary xylem in *Fraxinus*. *New Phytol. 67, 579-594.*

Fellows , R J. and Boyer, J. S. 1978. Altered ultrastructure of cells of sunflower leaves having low water potentials. *Protoplasma 93, 3* 8 l-395.

Francois, L. E., Donovan, T. J. and Maas, E. V. 1992. Yield, vegetative growth, and fibre length of kenaf grown on saline soil. *Agronomy Journal* 84, 592-598.

Giles, K. L., Cohen, D. and Beardsell, M. F. 1976. Effects of water stress on the ultrastructure of leaf cells of *Sorghum bicolor*. *Plant* Physiol. 57, 1 1- 14.

Grant, J. *1961. A laboratory handbook of pulp and paper manufacture* (2nd edition). London; Edward Amold.

Halim, R A., Buxton, D. R., Hattendorf', M. J. and Carlson, R. E. 1989. Water-deficit effects on alfalfa at various growth stages. *Agron. J.* 81, 765-770.

Hall, A. E. and Schulze, E. D. 1980. Drought effects on transpirattion and leaf water status of cowpea in controlled environment. *A ust. J. Plant Physiol.* 7, 14 1 - 147.

Haskell, G. **and Millis, A..** 1963. Ideograms for exploring the taxonomy, evolution and genetics of plants. *Nature* 198, 1072-1074.

Hays, S. M. 1989. Kenaf tops equal high-quality hay. USDA-ARS, Agric. Res. 37(6), 18.

Henson, I. E., Jensen, C. R and Turner, N. C. 1989. Leaf gas exchange and water relation of Lupins and Wheat. 1. Shoot responses to soil water deficits. *Aust. J. Plant Physiol* 16, 401-413

Higgs , D. E. D. and James, D. B. 1969. Comparative studies on the biology of upland grasses. 1. Rate of dry matter production and its control grass species. *J. Ecology* 57, 553-563.

Hsaio, T. C. 1973. Plant responses to water stress. *Annual Review of Plant Physiology*, 24 5 19-570.

Idem, N. U. A. and Adeoti, A. A. 1988. Kenaf - A potential pulp source for Nigeria A paper presented at the 2nd Annual Conference of the Botanical Association of Nigeria, 10-14th April, 1988, at ABU Zaria.

Iljin, W. S. 1930. Die orsache der ressistenz *von* pflanzenzellen gegen Austrocknung *Protoplama 7,* 59-7 1.

Jensen, C. **R** 1989. Plant water relations approaches and measurements. In: Persson, R. and Wredin, A. eds. *Vuttninsbehov och Narings- tillforsel. Foredrag presenterude vid NJF-seminarium* nr. 15 1 Landskrona, l-3 augusti 1989, pp. 45-63.

Jordan, W. R; Dugas, W. A. and Shouse P. J. 1983. Strategies for crop improvement for drought-prone regions. *Agric. Water Manage*. 7, 28 l-299.

Keim, D. L. and Kronstad, W. E. 1981. Drought response of winter wheat cultivars grown under field stress conditions. *Crop Sci. 2* 1, *Il* - 14.

Killinger, C.B. 1969, Kenaf (*Hibiscus cannabinus* L.), a multipurpose crop. *Agronomy J.* 61 734-736.

Kramer, P. J. 1963. Water stress and plant growth. *Agronomy Journal* 55, *3* l-35.

Kramer, P. J. 1983. *Wuter relations of Plants.* New York: Academic Press.

Levitt, J. 1956. *The hurdiness of plants*. New York: Academic Press Inc., Publîshers

Levitt, J. 1980. *Responses of plants to environmental stresses. New* York: Academic Press

Ludlow, M. M. 1980. Adaptive inflences of stomatal responses to water stress (pp. 123-138) Bn: N. C. Turner andP. J. Kramer, Eds *Adaptation of plants to water and high temperature stress.* New York: Wiley Interscience.

Maas, E. V. and Hoffman, G. J. 1977. Crop salt tolerance - current assessment. *J. Irrig Drain. Div. Am.* Soc. *Civ. Eng.* 103, 115-134.

Maiti, R. K. and Chakravarty, K. 1977. A comparative study of yield components and quality of common Indian bast fibres. *Economic Botany 3 1*, 55-60.

Momoh, Z. 0. 1980. Meeting the wood requirement for pulp and paper mills in Nigeria Forestry Research Institute Seminar, October, 1990.

Muchow, R., C. 1979. Effects of plant population and season on kenaf (*Hibiscus cannabinus* L.) grown under irrigation in tropical Australia. 1. Influence on the components of yield Field Crop Res., 2: 55-66.

Muchow, R. C , Sinclair, T. R., Bennett, J. M. and Hammond, L. C. 1986. Response of leaf growth, leaf nitrogen, and stomatal conductance to water deficits during vegetative growth of field-grown soybean. ***Crop Science 26,*** 1190-1 195.

Nagarajah, S. and Schulze, E. D. 1983. Responses of *Vigna unguiculata* ('L) Walp. to temperature and soil drought. ***Aust. J. Plant Physiol. 10, 385-394.***

Nieschlag, H. J., Nelson, G. H. and Wolff, 1. A. 1961. A search for new fibre crops. Part IV. kenaf composition. ***TAPPI 44,*** 5 15-5 16.

Nwalozie, M. C. and Annerose, D. J. M., 1996. Stomatal Behaviour and water status of cowpea and peanut at low soil moisture levels. Acta Agronomica Hungarica, 44(3): 229-336

Ogbonnaya, C. 1. 1990. Aspects of the minera1 nutrition ecology of *Gmelina arborea* seedlings . Ph. D Thesis, Department of Botany, University of Port Harcourt, Nigeria

Ogbonnaya, C. **I.** 1992. N and P nutrition of *Gmefina arborea* Roxb. seedlings on latasolic soil. II: Effects of N and P fertilizers and their combinations on histo-chemical properties ***Pertanika*** 15(3), 207-216.

Ogbonnaya, C. I., Nwalozie, M. C. and Nwaigbo, L. C. 1992. Growth and wood properties of *Gmeiina arborea* (Verbenaceae) seedlings grown under five soil moisture regimes ***American Journal Botany*** 79(2), 128- 132.

Okereke, 0. 0. 1962. Studies on the fibre dimensions of some Nigerian timbers and raw rnaterials, Part 1: Research Report N° 16. Fed. Ministry of Commerce and Indusary, Lagos, Nigeria.

Oseni, A. M. 1978. An assessment of Nigerian wood balance situation. A paper presented at the 8th Annual Conference of the Forestry Association of Nigeria, Ilorin, December, 1978.

Owonubi, J. J. 1994. Rainfall analysis for agricultural production in the Nigerian savanna. In F. N. Reyniers and Netoyo, L. eds. ***Bilan hydrique agricole et sécheresse en Afrique tropicale.*** Paris: John Libbey Eurotext, pp57-66.

Petri, R 1952. Pulping studies with African tropical woods. ***TAPPI 35,*** 157-I 60.

Robinson, F. E. 1988. Kenaf: A new fibre crop for paper production. *Calif. Agric*. ***42, 3*** 1-32.

Roy-Macauley, H. Zuily-Fodil, Y., Kedric, M., Pham Thi, A. T. and Vierra da Silva, J. 1992. Effects of drought stress on the proteolytic activities in *Phaseolus* and *Vigna* leaves from sensitive and resistant plants. ***Physiologia Plantarum 85, 90-96***

Rydholm, S. A. ***1967. Pulpingprocess.*** New York, Wiley and Sons.

Schmidt, H. 1939. Plasmazustand und wasserhaushalt bei *Lamium maculatum*. *Protoplasma* 33, 25-43.

Schulze, H. R and Matthew, M. A. 1993. Growth, osmotic adjustment, and cell-wall rnechanics of expanding grape leaves during water deficits. ***Crop Sci., 33: 287-294***

Sellers, T., Miller, G. D. and Fuller, M. J. 1993. Kenaf core as a board raw material. *For Prod. J.* ***43, 69-7*** 1.

Shackel, K. A. and Hall, A. E. 1983. Comparison of water relations and osmotic adjustment in sorghum and cowpea under field conditions. *Aust. J. Plant Physiol.* ***10,*** 423-435.

Sharma, B. M. and Ogbonnaya, C. I 1990. Growth analysis of ***Seturia barbata*** (Lam.) Kunth in South-west Nigeria. *Zizaniology* ***2, 19*** 1 - 196.

Stein, H. D. 1994. Kenaf A promising plant for the pulp and paper industry, Extension Forestry Notes, VPI&SU Department of Forestry.

Swanson, C. A. 1959. Translocation of organic solutes. In. Steward, F. C. ed. ***Plant Physiology: A Treaties***. New York: Academic Press, pp. ***48 l-545.***

Swingle, R S., Urias, A. R., Doyle, J. C. and Voigt, R L. 1978. Chemical composition of kenaf forage and its degestibility by lambs and in vitro. ***J. Anim. Sci. 46,*** 1346-1350.

Taylor, C. S. 1995. Kenaf. Kenaf International Ltd., McAllen, TX (based on Dempsey, 1975).

Webber, C. L. 1992. Crude protein and yield components of six kenaf cultivars as affected by crop maturity. Industrial Crops and Products, 2: 27-3 1.

Webber, C. **L.** 1993. Yield components of five kenaf cultivars. ***Agronomy Journal 85,*** 533-535

Weiland, R T. and Sttutle, C. A. (1980). Concomitant determination of foliar nitrogen loss, net carbon uptake, and transpiration. ***Plant Physiol. 65,403"406.***

Wenkert, W., Lemon, E. R and Sinclair, T. R. 1978. Leaf elongation and turgor pressure in field-grown soybean. ***Agronomy Journal*** 70, ***76 l-764.***

White, G. A., Cummins, D. G., Whitely, E. L., Fike, W. T., Grieg, J. K., Martin, J. A., Killinger, G. B., Higgins, J. J. and Clark, F. T. 1970. Cultural and harvesting methods for kenaf - an annual crop source of pulp in the southeast. ARS, U. S; Department of Agric. Prod. Res. Report, 113.

Wilson, F. D., 1965. F. D., Summers, T. E. , Joyner, J. F., Fishler, D. W. and Seale, C. C., 1965. Everglade 4 1 and Everglade Il, two new varieties of kenaf (*Hibiscus cannabinus* L.) for the fibre and seed. Florida Agr. Exp. Sta. Cir. S-168.

Wolf, *F.* A. 1962. *"Aromatic or oriental tobaccos."* North Carolina: Duke University Press.