African Journal of Biotechnology Vol. 10(50), pp. 10087-10094, 5 September, 2011
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB11.1278
ISSN 1684–5315 © 2011 Academic Journals

Full Length Research Paper

Growth, yield and fiber morphology of kenaf (*Hibiscus cannabinus* L.) grown on sandy bris soil as influenced by different levels of carbon

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Accepted 13 July, 2011

The effects of carbon levels on plant growth, yield and fiber morphological properties are not available for kenaf that is considered as a potential source of low cost natural fiber and feedstock for energy production as well. A pot-culture experiment was conducted in shade house to determine the effects of carbon levels on plant growth, yield and fiber morphology of different kenaf varieties. The plants of five kenaf varieties were grown in pots containing sandy beach ridges interspersed with swales (BRIS) soil. Organic carbons at the levels of 0, 10, 20, 30 and 40 t ha^{-1} were applied to pots using organic fertilizer. At harvest, stem diameter, plant height, leaf number, leaf area, plant components biomass, bast and core fiber yield and fiber dimensional properties were determined. Maximum growth, dry matter and fiber yield, and morphological characters were achieved at the carbon levels 20 t ha^{-1} but the values of these parameters decreased with additional increase in carbon levels. Among the varieties, HC2 had the highest plant height, leaf biomass, total dry matter and fiber yield. The longest bast fiber was observed in variety HC2. The variety G4 showed the widest fiber and higher lumen width among others. The bast fibers of all the kenaf verities were longer than core fiber. The core fiber was wider and higher in lumen width than the bast fiber. The above results keep a significant role and would be useful to select better varieties of kenaf for the purpose of making quality paper and paper products and to grow kenaf on BRIS soil with adequate yield and fibre quality using better management of organic carbon.

Key words: Kenaf varieties, carbon levels, growth, yield, fiber morphology, beach ridges interspersed with swales (BRIS) soil.

INTRODUCTION

Kenaf (*Hibiscuss cannabinus* L.) is one of the world's most potential sources of fiber in the cottage industry. Recently, the interest in growing kenaf has been increased throughout the world for its elevated fiber content (Alexopoulou et al., 2000). Kenaf is a fast growing crop and has high potential to be used as an industrial crop globally since it contains higher fiber materials or lignocellulosic material (Manzanares et al., 1996). The stalk of the plant is composed of two distinct fiber types; the bark of the kenaf stalk contains the long fiber strands that are composed of many individual smaller bast fibers. The woody core material of the stalk which is the portion remaining when the bark is removed contains core fibers. Whole stalk kenaf, bast and core fibers, have been identified as a promising fiber source for the production of pulp and paper, ropes, twine, coarse, burlap and fiberboard (Webber and Bledsoe, 1993; Petrini et al., 1994; Yu and Yu, 2007).

The bast fibers are of better quality than the core fibers; both of which can be utilized in various blends for the production of pulp (Petrini et al., 1994). The whole-stalk

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plant material can also be used in non-pulping products like building materials, such as particle board (Webber et al., 1999a) and within injection molded and extruded plastics (Webber and Bledsoe, 1993). The kenaf fibers can also serve as a virgin fiber for increasing recycled paper quality and paper strength. Due to high absorbency of the woody core material, researchers have investigated the use of kenaf as an absorbent (Goforth, 1994), as a poultry litter and animal bedding (Tilmon et al., 1988), as a bulking agent for sewage sludge composting (Webber, 1994) and as a potting soil amendment (Laiche and Newman, 1994; Webber et al., 1999b).

Due to the global demand for fibrous material, worldwide shortage of trees in many areas and environmental awareness, non-woods have become one of the important alternative sources of fibrous material for the 21st century. There is a wide variety of non-wood plant fibers that can be used for papermaking (Sabharwal et al., 1994). Non-woods, such as bagasse, wheat and rice straws, bamboo, and kenaf are being used in the manufacture of pulp and paper all over the world (Atchison, 1996). However, kenaf is being explored as a useful raw material for papermaking in developing and developed countries (Kaldor et al., 1990). With high adaptability with all ranges of soils, kenaf can be grown on sandy beach ridges interspersed with swales (BRIS) soil, which is poor in water holding capacity, low in cation exchange capacity and nutrient availability (Chen, 1985).

Malaysia has a vast area of BRIS soil with 155,400 ha in Peninsular Malaysia and 40,400 ha in Sabah, respectively (Hazandy et al., 2009). Carbon is a key ingredient in soil organic matter (57% by weight) (Sundermeier et al., 2004), which is crucial for soil especially in less fertile sandy soil. Hence, the utilization of carbon is very important in BRIS soil to improve soil quality and for better growth of kenaf. To date, there are no reports on the effects of carbon levels on the growth, yield and fiber morphology of kenaf grown on sandy BRIS soil. We hypothesize that growth, yield and fiber morphology of kenaf differ in their responses to different carbon levels and varieties. To test our hypothesis, an experiment was conducted in 2010 in a shade house under pot-culture.

The general objective of the study was to examine the possibility for the cultivation of kenaf in BRIS soil. The specific objective of the study was to determine the effects of carbon levels on growth, yield and fiber morphology of five kenaf varieties.

MATERIALS AND METHODS

Experimental site and plant materials

The experiment was conducted at the Experimental Farm No. 2, University Putra Malaysia, Serdang, Selangor, Malaysia (2°59´ 20.56″N, 101°42´ 44.42″E) under a shade house during April to July 2010. Five kenaf varieties, namely V36, G4, KK60, HC2, and HC95 were used in the experiment as plant materials.

Growth conditions, treatments and experimental design

The kenaf plants were grown in pots containing sandy BRIS soil as the potting medium. The soil was air-dried and undecomposed plant materials were removed by sieving. Twenty-five kilograms of soil was packed in pots (height, 40 cm; diameter, 25 cm). Organic carbons at the levels of 0, 10, 20, 30, and 40 t ha^{-1} using organic fertilizer were applied to the pots. Ten kenaf seeds were planted at 0.5 cm depth and the resulting seedlings were later thinned down to three plants per pot at two-leaf stage, to obtain plants with uniform growth vigor.

Chemical fertilizers were applied at the rate of 300 kg ha^{-1} for N, and 150 kg ha^{-1} for P_2O_5 and K_2O, respectively. The chemical fertilizers used were urea for N, triple super phosphate for P and muriate of potash for K. The fertilizers P and K were applied to the soil surface and were incorporated before planting. Nitrogen fertilizer was applied in three splits at the interval of 20 days. The treatments were used following randomized complete block design (RCBD) with four replications. The plants were watered with sprinkler system during the crop growing season to maintain the soil moisture at field capacity measuring with tensiometer.

Soil samples and analysis

The soil samples were air-dried and sieved through a ≤ 2.0 mm sieve in the laboratory. The following physicochemical properties of the soil were determined: texture by pipette method (Day, 1965), moisture content by gravimetric method (Day, 1965), total organic carbon by LECO carbon analyzer (model CR-412; LECO Corp., St. Joseph, Mich.), total N by Kjeldahl method (Bremner, 1960), extractable P by Bray and Kurtz no. 2 procedure (Bray and Kurtz, 1945), micronutrients by the double-acid method (Mehlich, 1953), pH in water at soil: water of 1:5 and cation exchange capacity (CEC) by leaching with 1 M ammonium acetate (NH_4OAC), pH 7 (Piper, 1947).

The concentrations of nitrogen (N), phosphorus (P) and potassium (K) in the solution, were determined using an auto-analyzer (QuikChem, Series 8000, Lachat Instruments Inc., USA) and the concentrations of calcium (Ca), magnesium (Mg), Manganese (Mn), zinc (Z) and copper (Cu) were determined by atomic absorption spectrophotometer (Perkin-Elmer 5100 PC). The initial physical and chemical properties of the soil are presented in Table 1.

Growth and biomass measurements

Plant height, stem diameter and leaf numbers were determined on five plants in each replication. At harvest, plant height was measured using a steel ruler. The height was measured from cotyledon level up to the base at the terminal bud. Measurement of collar diameter was made using a digital caliper. Leaf number was counted when the main veins were first visible.

Leaf area was measured using the Li-3100 leaf area meter (LiCOR Inc., Lincoln, Nebraska, USA) from all treatments at harvest. Total leaf area was measured on five plants in each replication. For biomass, leaves, stems and roots were separated and dried in oven at 65°C for 48 h until the constant weight was obtained. Plant components dry matter and total dry matter yield were then determined.

Fiber yield determination

After harvesting, the kenaf stems were subjected to retting for fiber yield determination. Five plants were sampled and submerged in water for 14 days. The fibers were then washed with running water, dried and weighed for bast and core yield determination.

Table 1. The initial physical and chemical properties of sandy BRIS soil used in the experiment.

Soil variable	Content
Sand (%)	96.4
Silt (%)	2.4
Clay (%)	1.2
pH (H_2O)	4.6
CEC [cmol (+) kg^{-1})]	9.64
Organic carbon (%)	0.44
N (g kg^{-1})	0.2
P (g kg^{-1})	0.05
K (g kg^{-1})	0.09
Ca (mg kg^{-1})	10.3
Mg (mg kg^{-1})	7.6
Mn (mg kg^{-1})	5.7
Cu (mg kg^{-1})	4.9
Zn (mg kg^{-1})	4.2

Fiber morphology determination

Maceration process was used to determine the morphology of fibers. The process of maceration was carried out according to the technical association of pulp and paper industry (TAPPI) standard T233-Su-64 (Smook, 2003). The process involved splitting of bast and core separately into matchstick size of 2 mm in width and 10 to 20 mm in length. This was followed by the addition of 25 ml distilled water with 1.5 g sodium chlorite and 8 drops of acetic acid into each test tube. The test tubes were boiled in water bath for 24 h. Subsequently, the bast and core fibers were washed gently using distilled water and shaken in distilled water to get the individual fibers. One drop of safranine was added into the fiber and stained for 15 min. A small amount of fibers were then transferred into a slide.

The measurement of bast and core fibers for their fiber morphology was carried out using Quantimeter Image Analyzer equipped with Leica microscope. Fiber length, fiber width, fiber lumen width and fiber cell wall thickness were measured. Thirty fibers were measured from each maceration slide to obtain the average value of fiber length, fiber width, fiber lumen width and fiber cell wall thickness.

Statistical analysis

Data on stem diameter, plant height, leaf number, leaf area, dry matter yield, fiber yield and morphology were subjected to statistical analysis (ANOVA) using SAS statistical package (SAS, 2007). Mean comparisons were performed by Duncan's multiple range test (DMRT) at $P \leq 0.05$.

RESULTS

Effect of carbon levels and variety on stem diameter, plant height, leaf number and leaf area of kenaf

The mean comparisons of growth parameters of kenaf at different carbon levels and varieties are shown in Table 2. The results indicate that carbon levels had significant effects on all the measured characters. The highest values for stem diameter, plant height, leaf number and leaf area were obtained from the carbon level 20 t ha^{-1}. Additional carbon levels showed decreasing trends.

All the evaluated traits were significantly influenced by the variety. The highest stem diameter, plant height, leaf number and leaf area were observed in the variety HC2, while the lowest values for all these parameters were obtained from HC95.

Effect of carbon levels and variety on dry weight of root, stem and leaf, and total dry weight of kenaf

The dry weight of root, stem and leaf, and total dry weight of kenaf were significantly affected by carbon levels and variety (Table 3). The highest values for the dry weight of root, stem and leaf, and total dry weight were obtained from 20 t ha^{-1} carbon levels. The values for these parameters were reduced with further increases in carbon levels. All the traits measured were significantly influenced by the variety. The variety HC2 had the highest values for all these parameters, whilst the variety HC95 showed the lowest values of the measured traits.

Effect of carbon levels and variety on bast and core fiber yield of kenaf

Figure 1 shows the effect of carbon levels and variety on bast and core fiber yield of kenaf. Bast and core fiber yield were significantly influenced by carbon levels. Both the yield parameters were significantly increased with an increase in carbon levels but the values decreased with

Table 2. Growth parameters of five varieties of kenaf at different carbon levels.

Treatment	Stem diameter (mm)	Plant height (cm)	Leaf number	Leaf area (cm^2 $plant^{-1}$)
Carbon levels (t ha^{-1})				
0	3.94±0.05^e	84.40±1.10^e	21.86±0.20^e	166.95±4.56^e
10	9.89±0.08^d	165.17±2.17^d	61.48±0.62^d	950.17±9.65^d
20	14.30±0.17^a	219.30±3.20^a	77.13±0.76^a	1428.62±10.45^a
30	13.22±0.18^b	208.01±3.25^b	74.81±0.82^b	1326.57±9.57^b
40	12.16±0.34^c	197.38±2.18^c	71.12±0.84^c	1223.52±9.68^c
Variety				
KK60	10.84±0.31^d	160.91±4.10^d	61.25±1.64^d	1168.06±30.23^d
HC2	12.54±0.35^a	204.74±4.81^a	68.54±1.79^a	1121.25±23.17^a
V36	11.97±0.43^b	197.90±4.60^b	65.92±1.69^b	1092.18±38.12^b
G4	11.57±0.29^c	189.11±3.50^c	62.79±1.61^c	1041.58±17.89^c
HC95	10.31±0.56^e	149.43±2.87^e	59.40±1.59^e	985.85±28.32^e

Means within the column that have same letter are not significantly different (DMRT, P ≤ 0.05). Values are means ± standard error of the mean.

Table 3. Dry matter yields of kenaf as affected by carbon levels and varieties.

Treatment	Root dry weight (g $plant^{-1}$)	Stem dry weight (g $plant^{-1}$)	Leaf dry weight (g $plant^{-1}$)	Total dry weight (g $plant^{-1}$)
Carbon levels (t ha^{-1})				
0	1.46±0.08^e	2.46±0.11^e	1.52±0.09^e	5.45±0.22^e
10	9.34±0.24^d	31.95±1.14^d	8.47±0.24^d	49.76±1.45^d
20	14.76±0.44^a	52.85±2.08^a	14.18±0.56^a	81.79±0.75^a
30	13.74±0.54^b	51.76±2.32^b	13.16±0.54^b	78.66±1.87^b
40	12.79±0.87^c	50.40±1.24^c	12.00±0.38^c	75.19±0.78^c
Variety				
KK60	10.77±0.41^e	38.73±1.50^d	10.36±0.40^d	59.90±2.32^d
HC2	11.89±0.32^a	40.51±1.59^a	10.77±0.29^a	64.38±2.38^a
V36	11.53±0.53^b	39.35±2.12^b	10.56±0.44^b	62.90±2.39^b
G4	10.91±0.67^c	38.65±1.56^c	10.43±0.52^c	60.92±2.35^c
HC95	10.55±0.39^d	37.81±1.37^e	10.22±0.36^d	58.64±2.27^e

Means within the column that have same letter are not significantly different (DMRT, P ≤ 0.05). Values are means ± standard error of the mean.

additional increase in carbon levels up to 40 t ha^{-1}.

Measured traits were significantly influenced by the variety. The highest bast and core fiber yield were obtained from the variety HC2 whilst the lowest yields of bast and core fiber were observed in variety HC95.

Effect of carbon levels and variety on morphological properties of bast and core fiber of kenaf

Comparison of morphological traits of kenaf bast and core fibers at different carbon levels are presented in Table 4. The measured morphological traits on bast and core fibers were significantly influenced by carbon levels. The lengths of fibers producing from the bast and core tissues differed markedly. The highest bast and core fiber lengths were observed at carbon levels of 20 t ha^{-1} and the lowest lengths of bast and core fibers were at 0 level of carbon. The carbon level 20 t ha^{-1} had the highest values for fiber width, lumen width and cell wall thickness of bast and core fiber and the lowest values for all these morphological properties of kenaf were observed at 0 level of carbon. Further addition of carbon levels significantly decreased all the morphological traits of kenaf fibers.

Fiber morphological traits were found to vary significantly among different kenaf varieties. The results indicate that the longest bast fiber among the five

Table 4. Morphological properties of kenaf bast and core fibers as affected by different carbon levels and varieties.

Treatment	Fiber length (mm)		Fiber width (µm)		Lumen width (µm)		Cell wall thickness (µm)	
	Bast	Core	Bast	Core	Bast	Core	Bast	Core
Carbon levels (t ha^{-1})								
0	2.27±0.26^{e}	0.69±0.16^{e}	17.39±4.68^{d}	21.87±4.56^{e}	7.56±2.55^{e}	14.61±3.45^{d}	4.92±1.67^{d}	3.60±0.92^{e}
10	2.65±0.29^{d}	0.75±0.15^{d}	20.75±6.52^{c}	23.50±5.86^{c}	9.27±4.37^{d}	15.82±3.37^{c}	5.80±1.58^{c}	4.11±0.80^{d}
20	2.74±0.37^{a}	0.80±0.14^{a}	24.20±6.89^{a}	25.64±6.72^{a}	11.41±5.19^{a}	16.90±3.67^{a}	6.43±1.88^{a}	4.34±0.96^{a}
30	2.70±0.33^{b}	0.78±0.16^{b}	23.78±7.60^{ab}	24.30±4.54^{b}	11.03±5.87^{b}	16.19±2.49^{b}	6.12±1.79^{b}	4.18±0.98^{b}
40	2.68±0.36^{c}	0.76±0.17^{c}	23.11±7.25^{b}	22.67±6.25^{d}	10.21±4.34^{c}	15.89±4.31^{c}	5.76±1.67^{c}	3.96±0.93^{c}
Variety								
KK60	2.52±0.40^{c}	0.71±0.11^{d}	20.63±6.89^{c}	23.02±4.30^{c}	8.43±4.22^{d}	14.54±3.26^{d}	6.07±4.22^{a}	4.21±0.69^{bc}
HC2	2.72±0.35^{a}	0.83±0.15^{a}	22.30±6.53^{b}	25.75±3.66^{ab}	11.08±3.49^{b}	16.94±2.64^{b}	5.57±3.49^{b}	4.25±0.68^{b}
V36	2.71±0.36^{a}	0.80±0.16^{b}	22.07±8.15^{b}	25.52±3.51^{b}	10.03±4.07^{c}	16.11±2.17^{c}	5.98±4.07^{a}	4.79±1.09^{a}
G4	2.62±0.38b^{b}	0.76±0.15^{c}	24.73±6.54^{a}	25.85±3.81^{a}	13.59±6.65^{a}	19.21±3.57^{a}	5.88±6.65^{a}	3.29±0.66^{d}
HC95	2.47±0.37^{c}	0.68±0.14^{e}	19.79±6.42^{d}	21.25±3.39^{d}	7.54±4.12^{e}	12.95±2.47^{e}	6.10±4.12^{a}	4.12±0.67^{c}

Means within the column that have same letter are not significantly different (DMRT, P ≤0.05). Values are means ± standard error of the mean.

varieties was observed in HC2, while HC95 had the shortest bast fiber. The core fiber was found longest in HC2 and the shortest core fiber was obtained from variety HC95. The variety G4 had significantly widest bast and core fiber and higher lumen width among the five varieties. The varieties HC2 and V36 had similar bast fiber length and bast and core fiber width. The varieties V36, G4, KK60 and HC95 did not significantly differ in the bast cell wall thickness. V36 showed the highest core cell wall thickness compared to other varieties.

DISCUSSION

Stem diameter, plant height, leaf number and leaf area determine the growth and yield of kenaf. Results presented in this study demonstrate that carbon levels had significant effect on all the growth parameters monitored in this study. Stem diameter and plant height fairly increased with every increase in carbon level from 0 to 20 t ha^{-1} and both control and higher carbon levels adversely affected these important plant growth parameters.

The stem diameter and plant height varied at the different carbon levels and among the different varieties of kenaf. Our results are in accordance with those of Agbaje et al. (2008) who reported significant differences in plant height of different kenaf varieties. They found that Cuba 108 and Ifeken 400 were taller than Ibadan local varieties. Plant height extension that included all growing internodes, leaf area expansion of all leaves capable of growth and leaf addition on all branches and main-stem were recognized as basic phenomena of shoot morphogenesis and growth. As internodes elevate other organs such as leaves (Alm et al., 1991; Morrison et al., 1994; Reddy et al., 1997b) any factor that affected growth process of these organs would affect overall canopy development (Reddy et al., 1997a, 2004; Gerik et al., 1998).

Leaf number and leaf area varied significantly due to variation in carbon levels and among varieties. The variety of HC2 had the highest values of these parameters. Leaf number, total leaf area and plant height were the major factors determining PAR interceptions by row crops and any factor that affected these processes would affect canopy light interception and thus biomass production. In this study, plants grown in 20 t ha^{-1} carbon level developed almost nine times more whole plant leaf area than plants grown at 0 carbon level. The decreased leaf area development at 0 carbon level could be attributed to insufficient nutrient supply and a decrease in nutrient supply may lead to large reductions in leaf area expansion rate resulting smaller leaf sizes

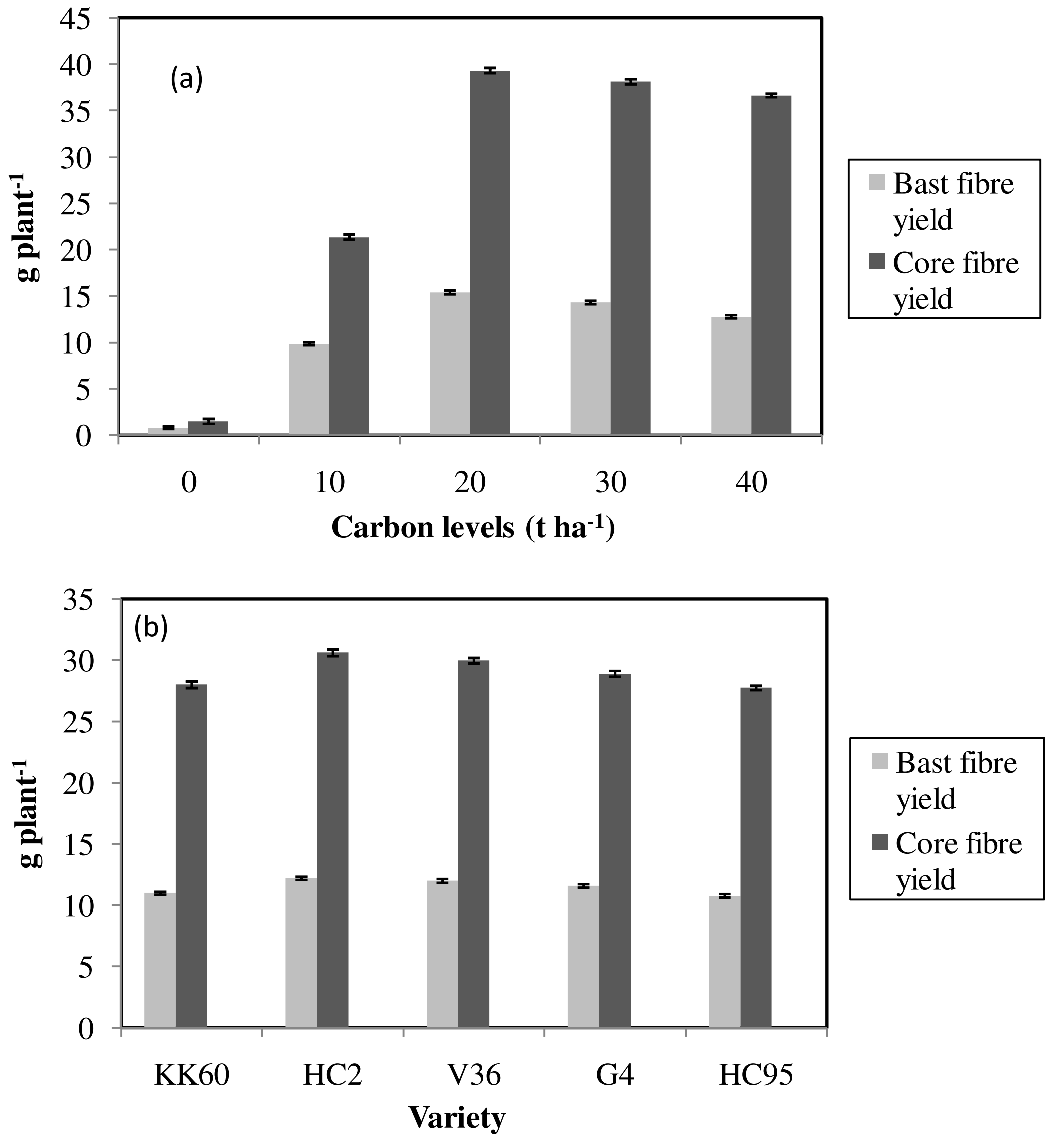

Figure 1. Effect of carbon levels (a) and variety (b) on bast and core fibre yield of kenaf. Values are means ± standard error of the mean.

(Terry et al., 1983; Ingestad and Lund, 1979; Mcdonald and Davies, 1996; Roggatz et al., 1999).

The dry weight of the whole plant and its components were significantly influenced by carbon levels and decreased with further increases in carbon levels after 20 t ha^{-1}. The dry weight of the different plant components differed markedly between varieties. The variety HC2 had the highest total dry matter yield, which could be attributed to the highest plant height of this variety. As the plant height increased, the stalk biomass yield increased. Our results are in accordance with the results of Webber and Bledsoe (2002) who found increased stalk biomass yields of kenaf with the increase in plant height. These results are in consistent with Ching et al. (1993) who reported the same trend with full season kenaf for fiber production. The stalk and biomass yields are important factors in selecting cultivars to be used for kenaf fiber production (Webber and Bledsoe, 2002).

Different carbon levels and variety had a significant effect on leaf biomass yield. The highest values for leaf biomass yield were at carbon level 20 t ha^{-1} and in variety HC2. Leaf biomass yields are important consideration when selecting cultivars for kenaf forage production, because the leaves are the primary source of protein (Webber, 1993a). Our results are in agreement with those of Webber (1993a, b), who reported differences among the cultivars for leaf biomass yield. Webber reported that ‘Guatemala 51’ had the greatest leaf biomass yield among five cultivars (Webber, 1993a) and ‘Guatemala 45’ had the greatest leaf biomass among six cultivars (Webber, 1993b).

Fiber yield was significantly influenced by carbon levels from 0 to 20 t ha^{-1} and thereafter it was decreased. In our study, different kenaf varieties showed significant difference in terms of fiber yield. Among the varieties, HC2 had the maximum bast and core fiber yield. In this study, the stem diameter, plant height, leaf number, leaf area and total plant biomass were found highest in variety HC2 which contributed to produce maximum fiber yield of this variety as compared to other varieties. The difference in fiber yields among kenaf varieties was crucial for kenaf breeding program. The majority of the breeding programs in the US have developed cultivars that are suitable for fiber yield (Webber and Bledsoe, 2002).

Comparison of mean morphological characters showed that carbon levels and variety had a significant effect on the kenaf bast and core fibers. The highest values for these fibers were obtained from the carbon level 20 t ha^{-1} and variety HC2. From this study, it was observed that the length and thickness of the bast fiber were different from that of the core fiber. All the varieties produced longer bast fiber and thicker fiber cell wall than the core fiber. However, the core fiber had higher fiber and lumen width than the bast fiber.

Average lengths of kenaf bast and core fibers found in this study were 2.61 and 0.76 mm, respectively. Similar results were reported by Ashori et al. (2006) who found the average bast and core fiber length 2.48 and 0.72 mm, respectively. The length of the bast fiber is comparable to that of softwood fibers (2.7 to 4.6 mm) and longer than the hardwood fibers (0.7 to 1.6 mm) (Ates et al., 2008). However, the core fibers are shorter than softwood fiber and very close to the lowest value of hardwood fibers. The width of kenaf fiber of different varieties in our experiment was in range of 19.79 to 25.85 µm which was in normal range of hardwood fiber width (20.0 to 40.0 µm) observed by Ates et al. (2008).

Kenaf fibers are the important raw materials in pulp as well as other industries. Physical dimensions of the kenaf fibers are very crucial for pulp and other industries. Long fiber can produce better fiberboard and paper tensile strength properties. The felting coefficient should be more than 70 for softwoods and 40 for hardwoods to produce quality paper and fiberboard (Akgul and Tozluoglu, 2009). The felting coefficients of bast and core fibers of all the varieties in this study were 105 to 127 and 29 to 32, respectively. This result indicates the suitability of bast fiber for the production of pulp over the core fiber.

Conclusion

Our results demonstrate that carbon levels enhanced plant growth, yield and fiber dimensional properties of kenaf until a certain level, as indicated by the enhanced stem diameter, plant height, leaf number, leaf area, fiber yield and fiber morphological traits. At 20 t ha^{-1} carbon level, plant growth, yield and fiber morphological properties were maximum and at 0 t ha^{-1} carbon level, the values of these parameters were minimum, indicating the potential beneficial application of organic carbon to the BRIS soil for better growth and yield of kenaf. Reduced plant growth, fiber yield and morphological properties at additional carbon level after 20 t ha^{-1}, indicated that the use of carbon should be up to 20 t ha^{-1} for better growing of kenaf in BRIS soil.

The fiber morphological data of all kenaf varieties proved that there were differences in their length, width, lumen width and cell wall thickness. These distinctive characteristics of kenaf fibers can be utilized as a tool to indentify and select better kenaf varieties for quality paper production as well as in breeding program. The differences in plant growth, yield and fiber morphological dimensions suggested that the variety HC2 can be considered as the most appropriate to be grown on BRIS soil under better management of organic carbon.

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