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Full Length Research Paper

Effects of carbon levels on shoot growth and root characteristics of different kenaf (*Hibiscus cannabinus* L.) varieties grown on sandy bris soil

M. D. Hossain[1]*, M. M. Hanafi[2], H. Jol[2] and A. H. Hazandy[3]

[1]Laboratory of Plantation Crops, Institute of Tropical Agriculture, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia.
[2]Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia.
[3]Laboratory of Sustainable Bioresource Management, Institute of Tropical Forestry and Forest Products, Putra Infoport, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia.

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The effects of carbon levels on shoot growth and root characteristics of five kenaf varieties were assessed in a shade house experiment. The kenaf plants were grown in pots containing sandy beach ridges interspersed with swales (BRIS) soil. Organic carbons at levels of 0, 10, 20 and 30 t ha^{-1} were applied to pots using organic fertilizer. The plants at carbon levels 20 t ha^{-1} had the highest plant height, leaf area, shoot and root dry matter, total root length, root surface area, total root volume, and number of root tips. Increasing carbon levels had negatively affected shoot growth and root morphology of all varieties under study. There was an obvious difference in response to carbon levels among the five varieties with HC2 showing the highest performance in terms of shoot growth and root characteristics. These results provide significant insights into limitations and opportunities for growing of kenaf in BRIS soil with better organic carbon management.

Key words: Kenaf varieties, carbon levels, root traits, root and shoot growth, sandy BRIS soil.

INTRODUCTION

Kenaf (*Hibiscus cannabinus* L.) is an annual plant that can be used as a source of low cost natural fiber. It is a fast-growing plant, and can be used in the industry for a wide range of products (building materials, adsorbents, textiles, livestock feed, etc.) especially for its fiber content and can also be useful for paper production industry (Webber and Bledsoe, 1993). It has become a jute fiber substitute. Kenaf also has a high potential as a board raw material with low density panels suitable for sound absorption and thermal resistance (Sellers et al., 1993). Kenaf plant has high assimilation capacity and produces high biomass (Cosentino and Copani 2003). Kenaf stem is the commercial product of the plant. Most of the biomass is accumulated in the stem. Higher stem biomass contributes to the production of higher stalk yield. The stalk yields are important for kenaf fiber production because the stalks are the source of bast and core fibers (Webber and Bledsoe, 2002). Therefore, biomass production is the main selection criteria of growing kenaf and for breeding programme. The varieties with high biomass yield have larger root growth (Jiang et al., 1988), higher nutrient absorbing ability (Osaki, et. al., 1991).

These findings highlight the contribution of root morphological improvements to biomass production. Plants with better root growth have more active absorption of water and nutrients and have higher rates of growth (Caldwell and Richards, 1986; Kummerow, 1989; Wilcox et al., 2004). Root absorption capacity is related to total root length, root surface area and root dry weight (Fitter, 1991). Plants with highly competitive root systems can

*Corresponding author. E-mail: delwar200@yahoo.com. Tel: +60102837368. Fax: +60389468968.

Table 1. The initial characteristics of sandy BRIS soil used in the experiment.

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

explore the soil intensively (Caldwell and Richards, 1986). To the farming point of view this crop is currently being seen as a useful alternative to tobacco in the coastal zone of Peninsular Malaysia where the sandy BRIS soil is dominating.

The establishment of the kenaf crop in this soil area will depend if kenaf production can be competitive with other crops especially tobacco grown in the area. Hence, the knowledge of kenaf root traits is important to select better varieties and to produce kenaf with high biomass and fiber yield. Therefore, the objectives of this study were to investigate the effects of carbon levels on root traits of kenaf; and to compare the performance of different varieties in terms of root characteristics as well as root and shoot growth.

MATERIALS AND METHODS

Description of site and plant materials

The experiment was conducted in the shade house of Universiti Putra Malaysia, Serdang, Selangor, Malaysia (2°59´ 20.56˝N, 101°42´ 44.42˝E, about 45 m above sea level) at the Experimental Farm No. 2 for a period of forty days during October to November 2010. Five kenaf varieties, such as V36, G4, KK60, HC2 and HC95 were used in the experiment as plant materials.

Growing of plants, treatments and experimental design

Sandy BRIS soil was used as the potting medium. The initial characteristics of the soil are presented in Table 1. The soil was air-dried and un-decomposed plant materials were removed by sieving. Twenty-five kilograms of soil was packed in pots (height, 40 cm; diameter, 25 cm). Organic carbons at levels of 0, 10, 20 and 30 t ha^{-1}, from palm oil mill effluent (POME) were applied. 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_20, 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 and incorporated to the soil surface before planting. Nitrogen was applied in single dose at thinning stage. The experiment was conducted in a 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 (F_c) 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).

Measurements of growth and biomass

The plant height and leaf area were recorded on five plants in each replication. Plant height was measured using a steel ruler. The height was measured from cotyledon level up to the base of the terminal bud. Leaf area was measured using the Li-3100 leaf area meter (LiCOR, Inc., Lincoln, Nebraska, USA) from all treatments. At sampling, the plants were divided into below and above ground parts, and washed with distilled water. Fresh samples were put into the oven at 65°C for 48 h to get constant weight, and the dry weights of root and shoot were recorded.

Determination of root characteristics

The plants were carefully excavated at the end of the experiment, 40 days after sowing. The roots were then washed carefully with distilled water to ensure clean root system. Total root length, root surface area, total root volume, and number of root tips were determined with a root scanner (MIN MAC, STD 1600), equipped with a commercial software package 4.1 Win RHIZO (Regent Instruments, 2000, USA) (Arsenault et al., 1995).

Statistical analysis

Data on plant height, leaf area, dry matter of root and shoot, total root length, root surface area, root volume and number of root tips were analyzed by factorial analysis of variance (ANOVA) using SAS statistical package (SAS, 2007). Mean comparisons were performed by Tukey's HSD (Honestly Significant Difference) test at P≤0.05. Relationships between variables were determined by Pearson's correlations coefficient test at P≤0.05 level.

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

Treatment	Plant height (cm)	Leaf area (cm^2 $plant^{-1}$)
Carbon levels (t ha^{-1})		
0	20.61^d	147.11^d
10	29.63c	236.78^c
20	60.25^a	355.56^a
30	58.51^b	326.95^b
Variety		
KK60	39.93^d	263.13^d
HC2	44.72^a	273.64^a
V36	42.90^b	269.92^b
G4	41.62^c	266.18^c
HC95	38.71^e	260.12^e

Means within the column that have same letter are not significantly different (DMRT, P≤0.05).

Table 3. Root and shoot dry matter weights of kenaf as influenced by carbon levels and varieties.

Treatment	Root dry weight (g $plant^{-1}$)	Shoot dry weight (g $plant^{-1}$)
Carbon levels (t ha^{-1})		
0	0.11^d	0.35^d
10	0.49^c	1.69^c
20	0.68^a	2.70^a
30	0.59^b	2.29^b
Variety		
KK60	0.44^c	1.70^c
HC2	0.55^a	1.92^a
V36	0.50^b	1.83^b
G4	0.45^c	1.72^c
HC95	0.39^d	1.62^d

Means within the column that have same letter are not significantly different (DMRT, P≤0.05).

RESULTS

Shoot growth response to carbon levels

Plant height was significantly affected by carbon levels (Table 2). Carbon levels significantly increased plant height at 20 t ha^{-1} carbon levels when compared with the control. At lower levels the effects were adverse and the adverse effects were more pronounced at 0 carbon level. Plant height decreased with further increase in carbon level. The analysis of variance conducted on the plant height of the five kenaf varieties showed that there were significant differences in plant height. Variety HC2 attained the highest plant height and was significantly different from those of others, while HC95 attained the least. Leaf area was significantly affected by carbon levels and reached highest with advancing carbon levels up to 20 t ha^{-1}(Table 2). After that the value of leaf area declined. Different responses were noted among studied kenaf varieties. The variety HC2 had the highest leaf area, while the variety HC95 had the lowest.

Dry weight of shoot and root

Shoot and root dry weights were significantly affected by carbon levels (Table 3). Shoot and root dry weight increased with increasing levels of carbon. The maximum

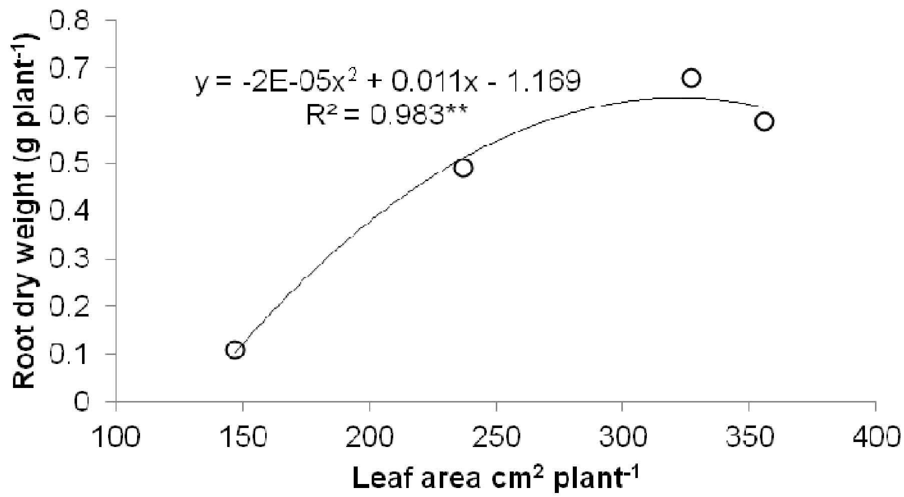

Figure 1. Relationship between leaf area and root dry weight of kenaf.

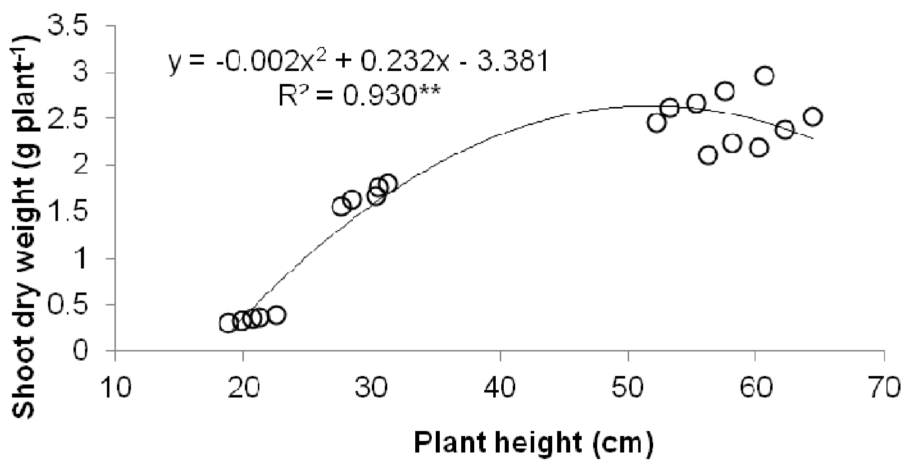

Figure 2. Relationship between plant height and shoot dry weight of kenaf.

values of root and shoot dry weights were obtained at 20 t ha^{-1} carbon level and the minimum values were obtained from 0 carbon level. Among the varieties the difference in root and shoot dry weights were significant. Variety HC2 showed the highest root and shoot dry weights, while the variety HC95 had the lowest. In this study, root growth was reduced with the reduction of leaf area (Figure 1). The result indicates that shoot growth was positively related with plant height (Figure 2).

Total root length and number of root tips

Carbon levels significantly influenced total root length and number of root tips (Table 4). Similarly, significant difference was also observed for these parameters among the five varieties under study. Total root length and root tips increased significantly with increasing carbon levels when compared with control treatment. The highest values for these parameters were observed at 20 t ha^{-1} carbon level. The variety HC2 ranked first in terms of highest number of root tips and total root length when compared with other varieties.

Root surface area and root volume

Root surface area and root volume were markedly varied due to the effects of carbon levels (Table 5). The values for these parameters were significantly higher in plants grown at carbon levels 20 t ha^{-1} than in plants grown at other carbon levels. The root surface area and root volume were evidently different for all the five varieties at different levels of carbon. Variety HC2 produced the highest root surface area and root volume when compared with the all other varieties.

Table 4. Total root length and root tips of kenaf varieties as affected by carbon levels.

Treatment	Total root length (cm plant^{-1})	Root tips (no. plant^{-1})
Carbon levels (t ha^{-1})		
0	156.56^{d}	275.90^{d}
10	216.08^{c}	561.40^{c}
20	389.53^{a}	1061.15^{a}
30	379.47^{b}	931.00^{b}
Variety		
KK60	274.52^{d}	663.94^{d}
HC2	308.13^{a}	807.25^{a}
V36	295.26^{b}	749.31^{b}
G4	284. 62^{c}	698.56^{c}
HC95	264.52^{e}	617.75^{e}

Means within the column that have same letter are not significantly different (DMRT, P≤0.05).

Table 5. Root surface area and root volume of kenaf varieties as affected by carbon levels.

Treatment	Root surface area (cm^{2} plant^{-1})	Root volume (cm^{3} plant^{-1})
Carbon levels (t ha^{-1})		
0	14.36^{d}	0.16^{d}
10	30.04^{c}	0.30^{c}
20	70.78^{a}	0.71^{a}
30	58.46^{b}	0.62^{b}
Variety		
KK60	41.44^{d}	0.42^{d}
HC2	47.42^{a}	0.51^{a}
V36	45.28^{b}	0.48^{b}
G4	43.42^{c}	0.45^{c}
HC95	39.47^{e}	0.39^{e}

Means within the column that have same letter are not significantly different (DMRT, P≤0.05).

DISCUSSION

Shoot growth response to carbon levels

The shoot growth responded well at carbon level 20 t ha^{-1} producing highest plant height and leaf area. The shoot growth was markedly reduced at control. The significant shoot growth reduction was due to restricted development of plant height, and leaf area. Shoot growth was markedly affected by the root characteristics. Root morphological changes under varied environmental conditions bring direct influences to the plant structure and above ground parts (Zhang et al., 2002; Liu et al., 2006). In this study, the marked difference in the shoot growth of the different varieties was due to differential root traits.

Dry weight of shoot and root

In this study, carbon level treatments increased dry weight of shoot and root of kenaf varieties up to 20 t ha^{-1}. The dry weight was markedly reduced at control. The significant dry matter reduction was due to restricted plant growth, and leaf area. The reduction in leaf area limits photosynthesis and further decreases biomass production. Root growth depends on the supply of carbohydrate from aboveground parts (Ogbonnaya et al., 1997), thus the reduction of leaf area would be expected to reduce root growth. This was observed from the positive relationship between leaf area and root dry weight (Figure 1). The five varieties used in this experiment responded differently in terms of shoot and root biomass accumulation. In this study, higher plant height and leaf area of variety HC2 caused a significant increase in dry weight of shoot of this variety compared to others. This was reflected in the positive relationship between plant height and shoot dry weight (Figure 2).

Total root length and root tips

Total root length and root tips increased significantly with increasing carbon levels up to 20 t ha^{-1} when compared with the control treatment. In response to carbon levels, root responded through changes in total root length and number of root tips. The control treatment resulted in reduced biomass of shoots and roots and adverse impact on total root length and root tips. Significant difference in number of root tips and total root length was found among the varieties. Variety HC2 ranked first in terms of highest number of root tips and total root length when compared with others. The result indicated that roots of variety HC2 have great potential to give better shoot growth.

Root surface area and root volume

The carbon levels treatment showed significant effect on root surface area and root volume. In response to carbon levels, root responded through changes in terms of root surface area and root volume. A decrease in root surface area and root volume under control treatment may be due to decreased availability of photosynthates from shoots which resulted in lower shoot dry weight. A decrease in root surface area and root volume under stress condition was reported earlier by Gohar et al. (2003). Five kenaf varieties in this experiment responded differently to carbon levels in terms of root surface area and root volume which resulted in variable shoot growth.

Conclusion

Carbon levels increased shoot growth, shoot dry matter of plant up to 20 t ha^{-1} and lower levels of carbon reduced shoot growth and dry weight. The root growth, total root length, number of root tips, root surface area and root volume showed marked differences in their responses to carbon levels. The varieties, maintaining the higher shoot growth were associated with the higher values of root traits studied in this experiment. The results of the present study indicated that better kenaf growth could be achieved using better carbon management at field on BRIS soil with enhanced root growth of kenaf.

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REFERENCES

Arsenault JL, Pouleur S, Messier C, Guay R (1995). WinRhizo, a root measuring system with a unique overlap correction method. Hort. Sci. 30(4): p. 906.

Bray RH, Kurtz LT (1945). Determination of total, organic and available forms of phosphorus in soils. Soil Sci. 59: 39-45.

Bremner JM (1960). Determination of nitrogen in soil by the Kjeldahl method. J. Agric. Sci. 55: 11-31.

Caldwell MM, Richards JH (1986). Competing root systems: morphology and models of absorption. In: Givnish TJ (Ed.). On the economy of plant form and function. Cambridge: Cambridge University Press, 251-273.

Cosentino SL, Copani V (2003). Leaf photosynthesis in kenaf (*Hibiscus cannabinus* L.) in response to water stress. Agroindustria, 2: 137-145.

Day PR (1965). Particle size fractionation and particle size analysis. In: Black CA (Ed.): Methods of soil analysis, part 1, Madison, WI, pp. 545-567.

Fitter AH (1991). Characteristics and functions of root systems. In: Waisel Y, Eshel and Kafkafi U (Ed.): Plant roots. The hidden half, New York: Marcel Dekker, Inc., pp. 3-25.

Gohar ZN, Ahmad R, Gul H (2003). Growth and development of cotton roots at various soil textures under soil conditions. Pak. J. Bot. 35(5): 949- 959.

Jiang C, Hirasawa T, Ishihara K (1988). Physiological and ecological characteristics of high yielding varieties in rice plants. II. Leaf photosynthetic rates. Japanese J. Crop Sci. 57: 139-145.

Kummerow J (1989). Structural aspects of shrubs in Mediterranean-type plant communities. In: Options Mediterraneennes, vol 3. Zaragoza: Instituto Agronomico Mediterraneo-CIHEAM, pp. 5-11.

Liu DH, Wang M, Zou JH, Jiang WS (2006). Uptake and accumulation of cadmium and some nutrient ions by roots and shoots of maize. Pak. J. Bot. 38: 701-709.

Mehlich A (1953). Determination of P, Ca, Mg, K, Na, and NH_4. Soil Test Division (Mimeo). Raleigh, North Carolina, USA.

Ogbonnaya CI, Macauley HR, Nwalozie MC, Annerose DJM (1997). Physical and histochemical properties of Kenaf (*Hibiscus cannabinus* L.) grown under water deficit on a sandy soil. Ind. Crops Prod. 7: 9-18.

Osaki M, Morikawa K, Shinano T, Urayama M, Tadano T (1991). Productivity of high-yielding crops. II. Comparison of N, P, K, Ca, and Mg accumulation and distribution among high-yielding crops. Soil Sci. Plant Nutr. 37: 445-454.

SAS (2007). SAS/STAT User's Guide, Version 9.2. SAS Institute Inc., Cary, NC, USA.

Webber III CL, Bledsoe RE (1993). Kenaf: production, harvesting, processing and products, In: Janick J, Simon JE (Ed.): New Crops, Wiley, New York, USA, pp. 416-421.

Webber III CL, Bledsoe VK (2002). Kenaf yield components and plant composition. In: Janick J, Whipkey A (Ed.). Trends in New Crops and New Uses. ASHS Press, Alexandia, VA. pp. 348-357.

Wilcox CS, Ferguson JW, Fernaddez GCJ, Nowak RS (2004). Fine root growth dynamics of four Mojave Desert shrubs as related to soil moisture and microsite. J. Arid Environ. 56: 129-148.

Zhang L, Li JM, Wang HX (2002). Physiological and ecological responses of wheat (*Triticum aestivum* L.) root to cadmium stress. Chin. J. Soil Sci. 33: 61-65.