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Physio-agronomic performance of kenaf as influenced by different carbon levels

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Abstract

Soil carbon levels can have a significant impact on growth, biomass production, chlorophyll content, photosynthesis rate, fibre yield and carbon stock in kenaf. To determine the impact of different carbon levels on the physio-agronomic performance of kenaf, three kenaf varieties were grown on sandy soil in a field at Terengganu, Malaysia, in two growing seasons. Organic carbon at levels of 0, 10 and 20 t C ha^{-1} was applied to the experimental plots. The experiment was arranged using four replicates in a randomized complete block design. Basal diameter, plant height, leaf number, leaf area, chlorophyll content and photosynthesis rate were measured as determinants of growth and biomass production. Plant roots, stems and leaves were separated and biomass content and fibre yield were determined at the time of harvest. The values for these parameters were highest at a carbon level of 20 t C ha^{-1}. Kenaf variety HC2 had the highest value for basal diameter, leaf number, leaf area, chlorophyll content, photosynthesis rate, fibre yield and carbon stock. We found a positive correlation between leaf area, photosynthesis rate and biomass production. Total biomass varied with carbon levels and among varieties, with the highest value at a carbon level of 20 t C $ha^{-1}$for the variety HC2. The highest fibre yield and carbon stock values were also found in variety HC2 at the same carbon level. The results of this study could be used as a basis for growing kenaf in sandy soils under effective organic carbon management.

Keywords: Carbon levels; chlorophyll content; growth; *Hibiscus cannabinus,* kenaf; photosynthesis; yield.
Abbreviations: TSP_Triple super phosphate; MoP_Muriate of Potash; POME_Palm oil mill effluent; DAP_Days after planting; DM_dry matter; DMRT_Duncan multiple range test; MOHE_Ministry of Higher Education.

Introduction

Kenaf (*Hibiscus cannabinus* L.) is an annual C3 plant native to East-central Africa and one of the world's most potential sources of fibre. It is frequently used in the cottage industry because of its high fibre yield (Mazumder et al., 2005; Bakhtiari et al., 2011). Regarding its height growth and fibre content, kenaf represents a multipurpose crop producing biomass for energy and natural fibre for industrial uses (Dauda et al., 2013). Recently, there has been an increased interest in growing kenaf worldwide for its high fibre content (Salih et al., 2014a). Kenaf fibres can be used in the production of a wide range of pulp, paper and paperboard products and may be a substitute for fibre glass and other synthetic fibres (Junejo et al., 2014). As a fibrous crop, kenaf appears to have enormous potential to become a valuable biomass crop in the future (Alexopoulou et al., 2000). It also has a high potential to be used as a raw material for boards with low density panels, suitable for both sound absorption and thermal resistance (Saad and Kamal, 2013). It has also been used as an alternative to wood in pulp production and the paper industries (Lips et al., 2009). Due to its fast-growing properties and high biomass yields, kenaf has a high carbon sequestration rate which makes it a suitable carbon dioxide sink and a substitute for non-renewable resources (Cosentino and Copani, 2003). The stalk of the kenaf plant is composed of two distinct fibre types: the bark contains the long fibre strands that are composed of many individual smaller bast fibres. The woody core material, the portion remaining after the bark has been removed, contains core fibres. Whole stalk kenaf bast and core fibres are promising fibre sources for the production of pulp and paper, ropes, twine, coarse burlap and fibreboard (Yu, and Yu, 2007; Jonoobi et al., 2011). The whole stalk material can also be used in non-pulping products such as building materials, i.e. particle boards, and within injection molded and extruded plastics (Juliana et al., 2012). The kenaf fibres can also serve as a virgin fibre to increase the quality and strength of recycled paper. Due to the high absorbency of the woody core material, researchers have investigated the use of kenaf as an absorbent, poultry litter, animal bedding and as a potting soil amendment (Kalaycioglu and Nemli, 2006). Plant growth and biomass production can be influenced by many physiological processes and environmental factors, but chlorophyll content and photosynthesis rate are the major determinants for these parameters. Photosynthetic activity is the basis for productivity and plants with an effective photosynthesis mechanism can produce high amounts of biomass. The basic index of plant photosynthetic activity is net photosynthesis (Aksyonov, 2007; Tahery et al., 2011).

Carbon is a key component of soil organic matter (Sundermeier et al., 2004; Kalisz et al., 2015) and plays a crucial role in a range of physical, chemical and biological soil processes. Hence, effective carbon management is critical to improve soil and biomass quality and to achieve optimal growth (Alexopoulou et al., 2007). Given the rapid increase of the use of kenaf fibre, mass production of this species has the potential to benefit the wood and fibreboard industries worldwide.

Only a few studies have investigated growth, chlorophyll content, photosynthesis rate, biomass production, fibre yield and carbon stock in kenaf and there is little information about the impact of different carbon levels on the chlorophyll content and photosynthesis rates in this plant species. In this study, we investigate the effect of soil carbon levels on the parameters mentioned above in three different kenaf varieties. We hypothesise that these parameters show different responses to soil carbon levels.

Results and Discussion

Plant growth

Plant height and leaf number of kenaf significantly responded to different soil C levels in terms of growth. Plant height and leaf number increased significantly and most rapidly at a level of 20 t C ha^{-1} (Figures 2 a, b). The control treatment showed the lowest plant height and leaf number. Compared to a C level of 20 t C ha^{-1}, plant height was reduced by 29% at a C level of 10 t C ha^{-1} and by 64% at a level of 0 t C ha^{-1} in the dry season. In the wet season, plant height was reduced by 27% at a level of 10 t C $ha^{-1}$and by 62% for a level of 0 t C ha^{-1}. Final leaf number was reduced by 25% at a C level of 10 t C ha^{-1} and by 75% at a level of 0 t C ha^{-1} in the dry season. For the wet season, the rates of reduction were 22% and 72%, respectively (Figures 3 a, b). Similarly, total leaf area was reduced by 35% at 10 t C $ha^{-1}$and by 89% at 0 t C ha^{-1}in the dry season and by 33% and 87% in the wet season, respectively (Figure 4). Basal diameter was also significantly reduced at C levels of 10 and 0 t C ha^{-1} (Figure 5) and it varied significantly among the three varieties (Figure 6 d). All varieties showed significant variation in growth. Variety HC2 had the highest basal diameter, plant height, leaf number and leaf area, whereas variety G4 had the lowest values of these parameters in both seasons (Figures 6 a, b, c, d). The present study indicates that kenaf shows poor growth at a carbon level of 0 t C ha^{-1}. The reduction in total leaf area at this level was mainly due to a reduction in both the expansion of younger leaves and the formation of new leaves. This leaf area reduction limits photosynthesis rates and further decreases biomass production. The positive correlation between total leaf area and biomass production (Figure 7) suggests that a decrease in leaf area limits productivity. These findings are in agreement with a similar study by Lokhande and Reddy (2015) who reported reduced plant productivity due to low leaf area index. Significant reduction of height and leaf numbers in kenaf at C levels of 0 t C $ha^{-1}$is partially due to decrease in apical growth (Sardans et al., 2005). Our results demonstrate that plant growth is higher in the wet season than in the dry season. Plants grown in the dry season showed a lower number of leaves which might be the result of water loss through transpiration and consequent water stress. This phenomenon adversely affects leaf area and photosynthesis rates. A higher yield in the wet season could be attributed to a higher atmospheric and soil moisture content; this is supported by a study by Johnson et al. (2002) who reported that soil moisture influences plant growth and ultimately fibre yield.

Dry matter production and its allocation

Total dry matter (DM) and its components in kenaf were significantly affected by C levels. Compared to a C level of 20 t C ha^{-1}, total dry weight was reduced by 42% at a level of 10 t C ha^{-1} and by 92% at a level of 0 t C ha^{-1}in the dry season and in the wet season by 40% and 91%, respectively (Tables 1 and 2).The highest amount of dry matter at a level of 20 t C ha^{-1} was mainly manifested as a greater production of leaf and stem biomass. In previous studies, the application of organic manure increased soil organic carbon which improved soil properties, water holding capacity and nutrient availability. These improvements have the capacity to enhance biomass and crop yield (Berzsenyi et al., 2000; Onemli, 2004). Root, stem and leaf dry weight responded similarly to different C levels. The root:shoot ratio at 10 t C $ha^{-1}$was slightly higher than the one at20 t C ha^{-1}.At a level of 0 t C ha^{-1} the root:shoot ratio was higher than at the other levels in both the dry and the wet season. This could be explained by a reduction of the total dry matter and a biomass allocation to the roots under reduced carbon levels. Such a reduction in biomass might be due to an insufficient nutrient supply related to a reduction of leaf area (Fernaandez et al., 1996) and CO_2 assimilation rates (Ciompi et al., 1996; Reddy et al., 1997a). Increased root:shoot ratios under stress conditions have been observed in other woody species (Gonzalez-Rodriguez et al., 2005). All kenaf varieties showed significant variation in total dry matter production and its components. The highest dry matter production, in both seasons, was observed in variety HC2 and the lowest in variety G4. The high amount of total dry matter in variety HC2 could be attributed to plant height. In a similar study, an increase in dry matter production was observed due to an increase in plant height (Webber and Bledsoe, 2002). The high amount of dry matter in variety HC2 might also be due to its higher chlorophyll synthesis and photosynthetic capacity compared to the other varieties (Salih et al., 2014b). The highest amount of dry matter was found in the stems of all the varieties in both seasons; this is in agreement with a similar study by Andres et al. (2010). Higher amounts of dry matter result in higher stalk yields which are crucial for kenaf fibre production (Webber and Bledsoe, 2002).

Chlorophyll content and photosynthesis

C levels had noticeable effects on chlorophyll content and photosynthesis rates (Tables 3 and 4). In both seasons, the values of these traits were highest at a level of 20 t C ha^{-1} and lowest at a level of 0 t C ha^{-1}. The differences in chlorophyll content and photosynthesis rates may be related to the variability in moisture supply during the dry and the wet season and to different nutrient availabilities at varied C treatments (Scordia et al., 2013). Previous studies suggest that nutrient deficiency affects leaf development and photosynthesis rates (Field and Mooney, 1986; Reddy et al., 1997b). Other studies show that low nutrient levels can cause slower leaf expansion and consequently lower photosynthesis rates (Gerik et al., 1998; Muchow, 1990). The reduction in chlorophyll content reduces photosynthesis rates and decreases biomass production; this is consistent with the positive correlation between photosynthesis and total dry matter production (Figure 8). Similar studies show decreased biomass production as a result of a reduction in chlorophyll content and photosynthesis rates (Li et al., 2009; Zhang et al., 2014; Lokhande and Reddy, 2015). The kenaf varieties in our study had significantly different values of chlorophyll content and photosynthesis rate. The highest values of these traits were found for variety HC2 and the lowest for variety G4. This variation might be due to intrinsic differences in chlorophyll synthesis and photosynthetic capacity among the three varieties (Salih et al., 2014b).

Table 1. Dry matter production and root: stem ratio of kenaf at different C levels and varieties in the dry season.

Treatments	Dry weights				R:S ratio
	Root	Stem	Leaf	Total	
	g plant^{-1}				
Clevels t ha^{-1}					
0	1.70±0.05 c	2.52±0.06 c	1.87±0.05c	6.09±0.15 c	0.72±0.03 a
10	8.92±0.53 b	30.43±0.64b	7.45±0.55b	46.80±0.32b	0.29±0.02b
20	14.20±0.47a	50.22±0.75a	12.98±0.58a	77.41±.44a	0.28±0.01 b
Variety					
HC2	8.61±0.03a	28.85±0.53a	7.64±0.15 a	45.10±0.45a	0.29±0.02 a
V36	8.42±0.53 a	27.88±0.35b	7.59±0.34 a	43.89±0.53b	0.30±0.02 a
G4	7.79±0.12 b	26.45±0.32c	7.08±0.26 b	41.32±0.54cc	0.29±0.01 a

Means within the column that have the same letter are not significantly different by DMRT at P ≤ 0.05. Values are means ± SD.

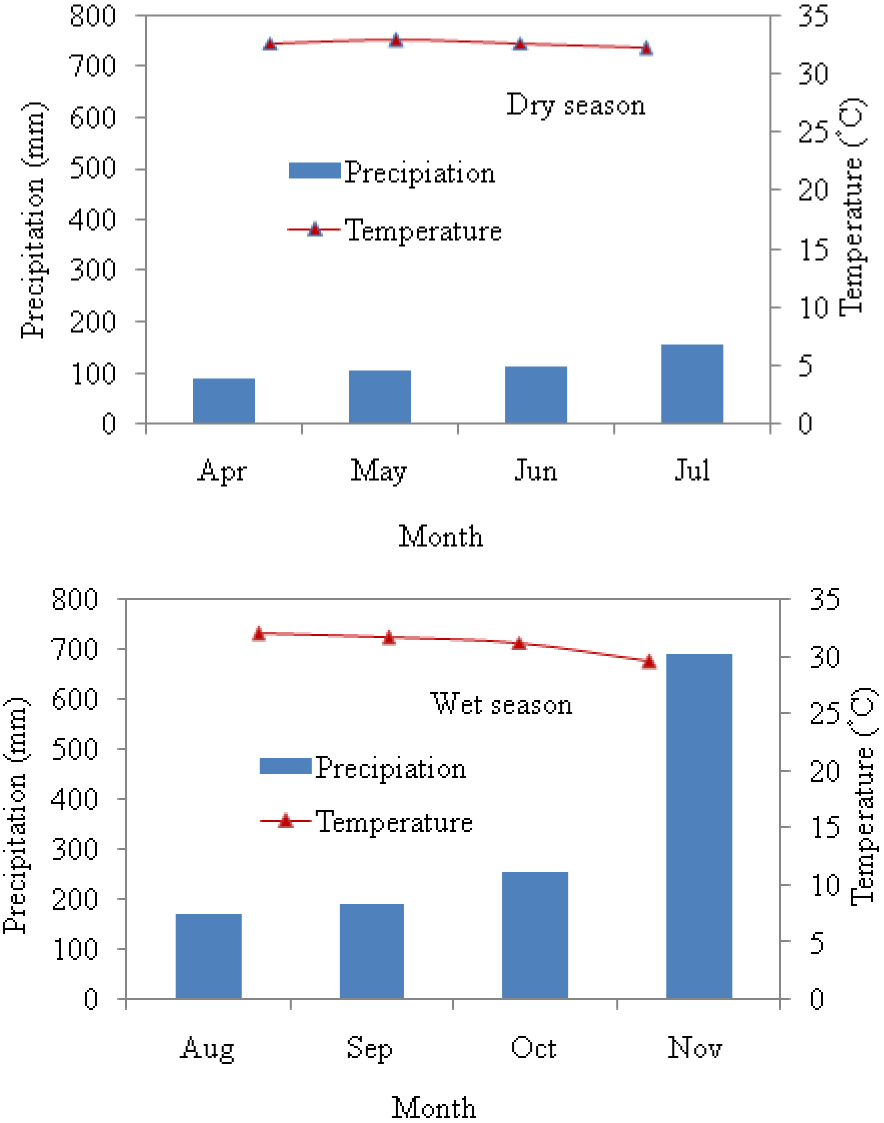

Fig 1. Monthly total precipitation (mm) and monthly mean temperature (°C) for the experimental site during the two growing seasons (dry and wet).

Table 2. Dry matter production and root: stem ratio of kenaf at different C levels and varieties in the wet season.

Treatments	Dry weights				R:S ratio
	Root	Stem	Leaf	Total	
	g plant^{-1}				
C levels t ha^{-1}					
0	1.93±0.04 c	2.97±0.11 c	2.34±0.06 c	7.24±0.21c	0.67±0.06 a
10	9.30 ±0.34b	31.49±0.35b	8.33±0.43 b	49.12±0.45b	0.30±0.02 b
20	15.02±0.43a	52.28±0.54a	14.14±0.54a	81.44±0.65a	0.28±0.01 b
Variety					
HC2	9.17±0.45 a	30.08±0.67a	8.58±0.21 a	47.83±0.53a	0.30±0.02 a
V36	8.91±0.32 a	29.09±0.56b	8.41±0.17 b	46.42±0.34b	0.31±0.02 a
G4	8.17±0.36b	27.57±0.53c	7.82±0.32 c	43.57±0.37c	0.30±0.01a

Means within the column that have the same letter are not significantly different by DMRT at $P \leq 0.05$. Values are means ± SD.

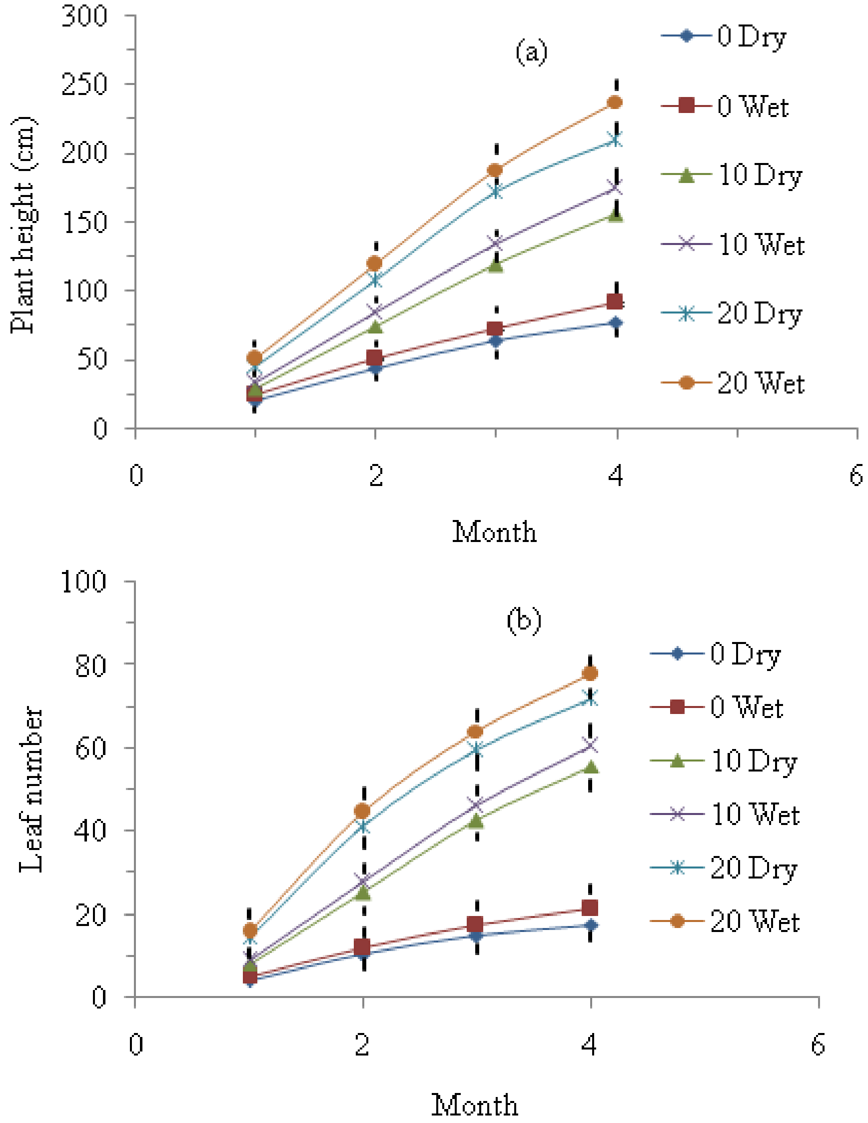

Fig 2. (a)Plant height and (b) leaf number of kenaf over a four month period in the dry and wet seasons as affected by carbon levels. Bars represent standard error of means.

Table 3. Chlorophyll content and photosynthesis rate of kenaf at different C levels in the dry season.

Treatments	Chlorophyll content	Photosynthesis rate
	spad value	µmol $m^{-2}s^{-1}$
Carbon levels t ha^{-1}		
0	28.23±0.98c	3.01±0.45c
10	43.38±0.87b	11.58±0.48b
20	49.23±0.76 a	14.98±0.57a
Variety		
HC2	41.65±0.72a	10.11±0.43a
V36	39.97±0.65 b	9.89±0.32 b
G4	39.30±0.54c	9.56±0.36c

Means within the column that have the same letter are not significantly different by DMRT at P ≤ 0.05. Values are means ± SD.

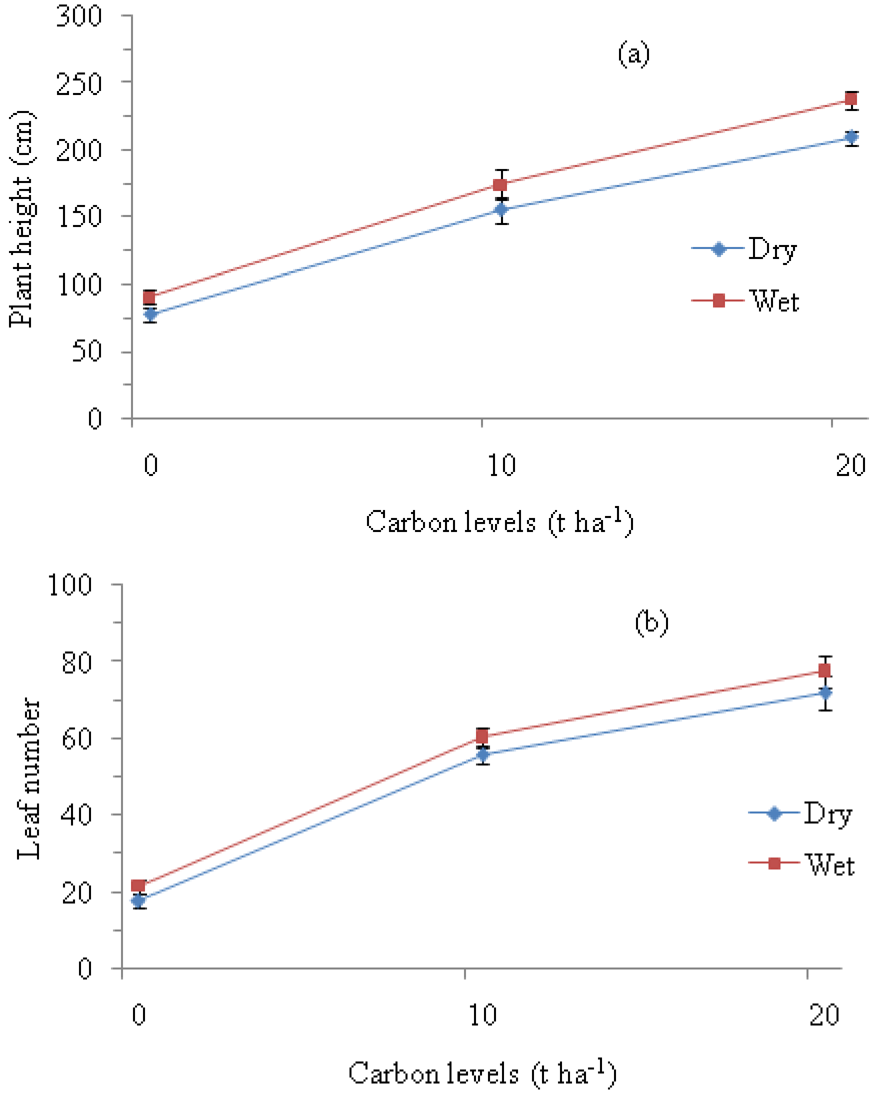

Fig 3. Response of (a) plant height and (b) leaf number of kenaf to various C levels in the dry and wet seasons. Bars represent standard error of means.

Fibre yield of kenaf

Bast and core fibre yield of kenaf were significantly affected by C levels. Both bast and core fibre yields showed maximum rates at a C level of 20 t C ha^{-1}. This can be explained by the beneficial effect of organic carbon on soil and the consequent changes in physical soil properties (McCauley et al., 2005), nutrient availability and water holding capacity which result in longer and stronger fibres and higher fibre yields (Bryan, 2000; Jahan, et al., 2009). Johnson et al. (2002) also observed that organic matter significantly influences fibre quality and yield. A similar study shows a strong positive relationship between soil carbon and plant fibre (Khalil, et al., 2015). Campbell et al. (2010) reported an increased fibre yield (52% to 56%) when the plants were treated with twice the amount of carbon in open field plots and growth chambers. In our study, the plants at a level of 0 t C ha^{-1} had the lowest bast and core fibre yields in both seasons (Tables 5 and 6). Under a level of 0 t C ha^{-1} the plants were shorter, had fewer leaves, a smaller leaf area, a lower chlorophyll content, lower photosynthesis rates and lower amounts of total biomass which contributed to produce less bast and core fibre yields as compared to a C level of 20 t C ha^{-1}. Compared to 20 t C ha^{-1}levels, bast fibre yields were reduced by 39% for a C level of 10 t C $ha^{-1}$and by 96% for a level of 0 t C ha^{-1}in the dry season. In the wet season, bast fibre yields were reduced by 37% and 94%, respectively. Core fibre yields were reduced by 48% for a C level of 10 t C $ha^{-1}$and by 97% at 0 t C ha^{-1} in the dry season. In the wet season, core fibre yields were reduced by 46% and 95%, respectively. In the wet season, both the bast and core fibre yields were higher compared to the dry season which could be attributed to higher soil moisture values and increased nutrient availability. In a similar study, the authors observed that soil moisture influences soil quality and fertility which in return might affect plant growth and thus fibre quality and yield (Bauer and Busscher 1996; Banwart, 2011).

The three kenaf varieties showed variation in bast and core fibre yields. Variety HC2 had the highest bast and core fibre yields and variety G4 produced the lowest yields in both seasons (Tables 5 and 6). Among the three varieties, HC2 had the highest stem diameter, plant height, leaf number, leaf area, chlorophyll content, photosynthesis rate and total biomass; it therefore showed a maximum fibre yield. Our results are in agreement with the findings of Nasreen et al. (2014) who reported the highest bast and core fibre yields in this variety. Higher fibre yield is a major consideration for the selection of a particular variety.

Carbon stocks in kenaf

We found a significant difference in C stocks in kenaf under different C levels. Maximum C stocks were observed at 20 t C ha^{-1} in both seasons. A similar study found that kenaf has a high carbon sequestration potential (Riggi et al., 2004). In our study, carbon stocks were lowest at control levels compared to C levels of 20 t C ha^{-1} (Figure 9). Among the three varieties, HC2 showed the highest C sequestration rates; lowest C stock values were observed in variety G4 in both seasons (Figure 10). The difference in C stock among the varieties can be attributed to differences in chlorophyll content, photosynthesis rates and dry matter production (Lokhande and Reddy, 2015; Salih et al., 2014b). Net change in soil organic C was significantly influenced by C levels. The highest net change of soil organic C was observed at a C level of 20 t C ha^{-1}, and this value was significantly higher than the one at a level of 10 t C ha^{-1} (Figure 11). Our results agree with the findings of Hao et al. (2002), Liu et al. (2005) and Triberti et al. (2008) who reported increased soil organic C values as a result of organic manure application.

Materials and Methods

Experimental site and plant materials

The study was conducted in 2011at the Experimental Farm of the National Kenaf and Tobacco Board, Terengganu, Malaysia (5°36′ N, 102°44′ E), 42 m above sea level, during two growing seasons (dry and wet season) (Figure 1). Three kenaf varieties, V36, G4 and HC2, were grown in a field on sandy soil. Variety HC2 was procured from the Jute Research Institute, Bangladesh. The other two varieties were provided by the Institute of Tropical Forestry and Forest Products, Universiti Putra, Malaysia. The three varieties were chosen because of their high yield and high potential to be grown worldwide.

Experimental design

Prior to sowing, the field was ploughed and harrowed and the plots were tilled by hand hoe. A basal dressing containing 66 kg P ha^{-1} as triple super phosphate (TSP) and 125 kg K ha^{-1} as muriate of potash (MoP) was applied and incorporated into the soil. Nitrogen in the form of urea was applied at the rate of 300 kg N ha^{-1} in three splits at 20-day intervals. Three levels of carbon (C), 0, 10 and 20 t C ha^{-1}, and three varieties of kenaf, V36, G4 and HC2, were used as experimental treatments. Organic C from palm oil mill effluent (POME) was applied to the plots seven days prior to planting. Seeds of the kenaf varieties were sown at a spacing of 30 × 12 cm, totalling 240, 000 plants ha^{-1}. The size of each plot was 4 × 2.5 m. The experiment was conducted using a randomized complete block design with four replicates. Alachlor (Lasso), a pre-planting herbicide, was applied at the rate of 3.0 L ha^{-1} and Deltamethrin (Decis), an insecticide, was applied at the rate of 2.0 L ha^{-1} one month after planting. In the dry season, the crop was harvested four months after planting from a 1 m^2 area of each plot and the fibre was extracted by retting to determine the core and bast fibre yields. The seeds of the three kenaf varieties were sown for growth in the wet season following the same spacing and fertiliser application. The plants were irrigated with a sprinkler system in the dry season and supplemental irrigation was applied in the wet season when needed. After four months, the plants were harvested from a 1 m^2 area of each plot and the core and bast fibre yields were determined.

Biometric measurements

Plant height and leaf number were recorded monthly for five plants in each replicate. Plant height from soil level to the base of the terminal bud was measured using a steel ruler. Leaf number was counted when the main veins were first visible. At maturity, ten randomly selected plants were harvested by uprooting and the basal diameter was measured using digital calipers. Leaf area from all treatments was measured at the time of harvest using a Li-3100 leaf area meter (LiCOR, Inc., Lincoln, Nebraska, USA). Total leaf area was measured for five plants in each replicate. For biomass measurements, leaves, stems and roots were separated and oven-dried at 65°C for 48 hours or until constant weight was reached. Dry matter and total dry matter yields of the different plant components were then determined.

Table 4. Chlorophyll content and photosynthesis rate of kenaf at different C levels in the wet season.

Treatments	Chlorophyll content	Photosynthesis rate
	Spad value	µmol $m^{-2}s^{-1}$
C levels t ha^{-1}		
0	29.52±0.72 c	3.38±0.41c
10	44.78±0.76 b	12.66±0.44 b
20	51.11±0.91a	16.35±0.51a
Variety		
HC2	43.05±0.48a	11.15±0.38a
V36	41.39±0.45 b	10.84±0.62 b
G4	40.97±0.42 b	10.41±0.43 c

Means within the column that have the same letter are not significantly different by DMRT at $P \leq 0.05$. Values are means ± SD.

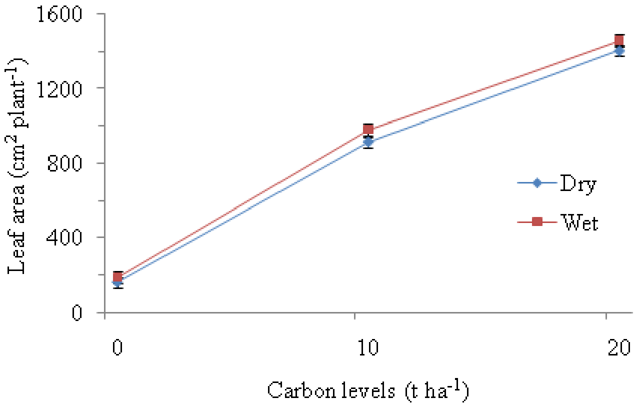

Fig 4. Response of leaf area of kenaf under different C levels in the dry and wet seasons. Bars represent standard error of means.

Table 5. Bast and core fibre yield of kenaf at different C levels in the dry season.

Treatments	Bastfibre yield	Core fibre yield
	kg ha^{-1}	
C levels t ha^{-1}		
0	158.40±26.57c	309.40±28.76 c
10	1949.47±73.25 b	4899.60±114.24 b
20	2932.80±128.76 a	9199.00±154.37a
Variety		
HC2	1727.67±71.56 a	4942.20±112.54a
V36	1699.53±75.64 a	4831.20±116.45 b
G4	1613.47±69.87 b	4634.60±121.35 c

Means within the column that have the same letter are not significantly different by DMRT at $P \leq 0.05$. Values are means ± SD.

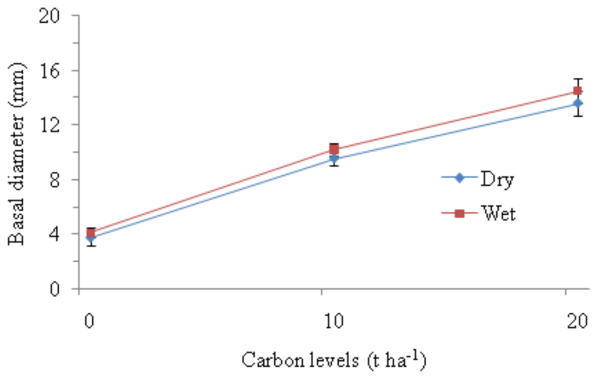

Fig 5. Basal diameter of kenaf under different C levels in the dry and wet seasons. Bars represent standard error of means.

Table 6. Bast and core fibre yield of kenaf at different C levels in the wet season.

Treatments	Bastfibre yield	Core fibre yield
	kg ha^{-1}	
C levels t ha^{-1}		
0	216.80±27.65 c	416.80±25.65 c
10	2086.44±75.65 b	5211.29±112.54 b
20	3220.91±124.45 a	9689.88±125.34 a
Variety		
HC2	1893.64±64.67 a	5282.70±116.54a
V36	1853.65±66.67 a	5128.92±123.43 b
G4	1776.86±58.76 b	4903.34±132.47 c

Means within the column that have the same letter are not significantly different by DMRT at P ≤ 0.05. Values are means ± SD.

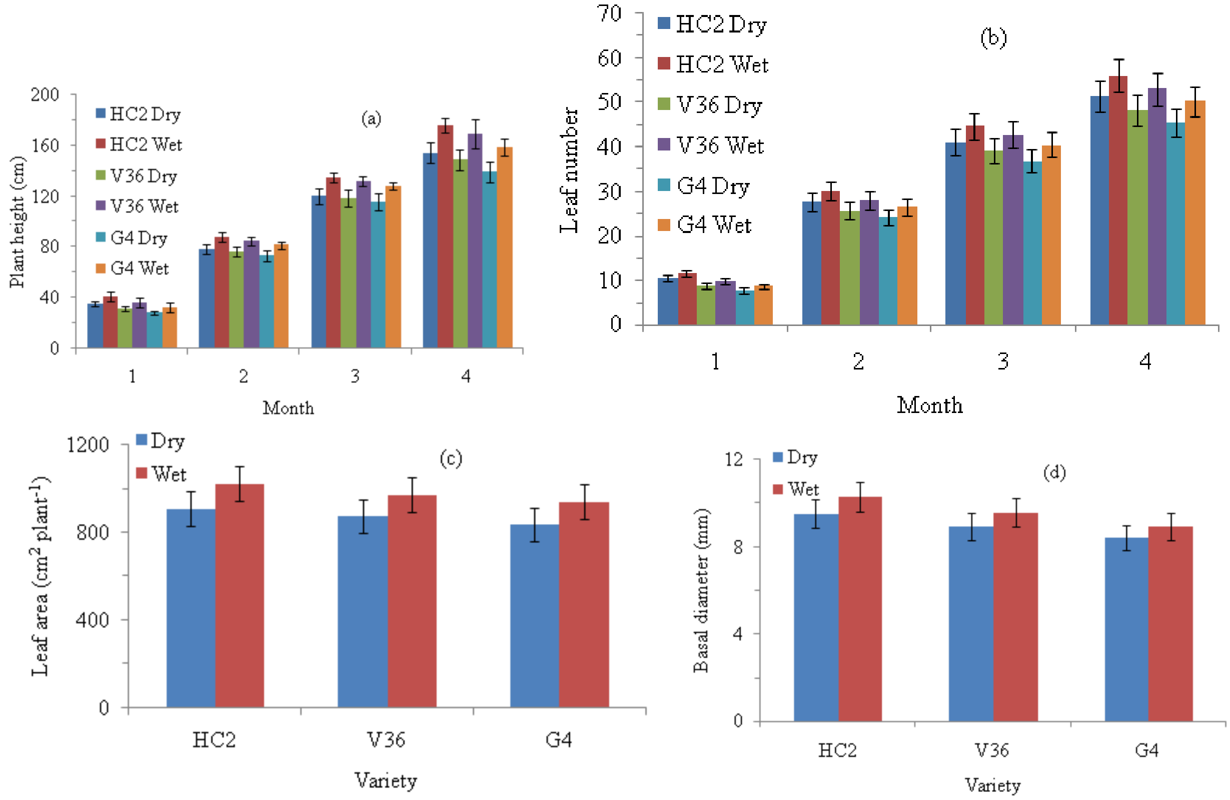

Fig 6. (a) Plant height, (b) leaf number, (c) leaf area and (d) basal diameter of three kenaf varieties in the dry and wet seasons. Bars represent standard error of means.

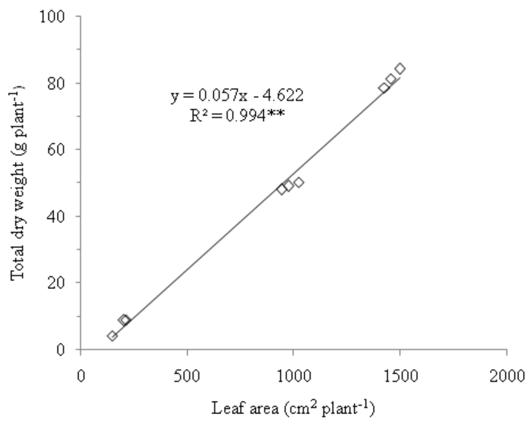

Fig 7. Relationship between leaf area and total dry weight of kenaf.

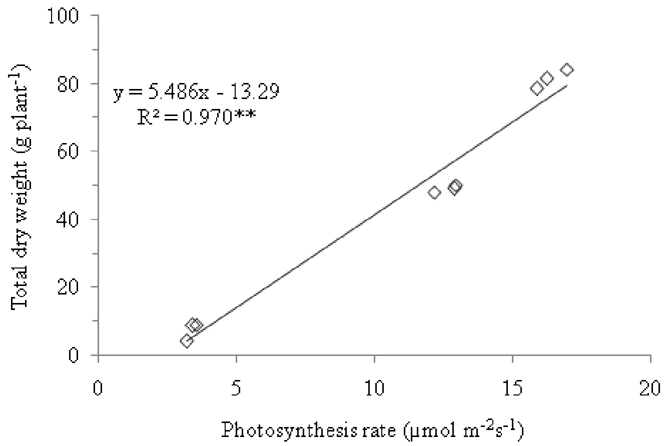

Fig 8. Relationship between photosynthesis rate and total dry weight of kenaf.

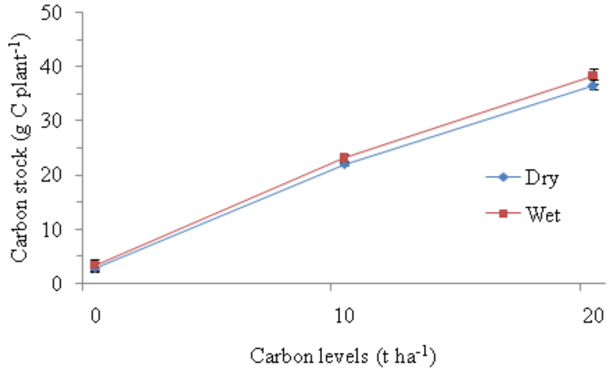

Fig 9. Effects of C levels on C stock by kenaf plant in the dry and wet seasons. Bars represent standard error of means.

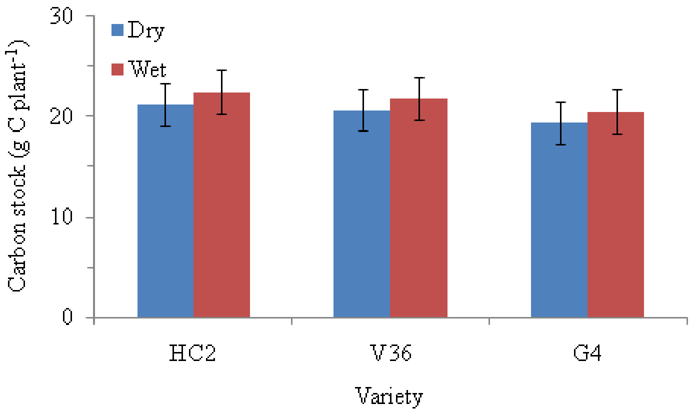

Fig 10. Carbon stock by different varieties of kenaf in the dry and wet seasons. Bars represent standard error of means.

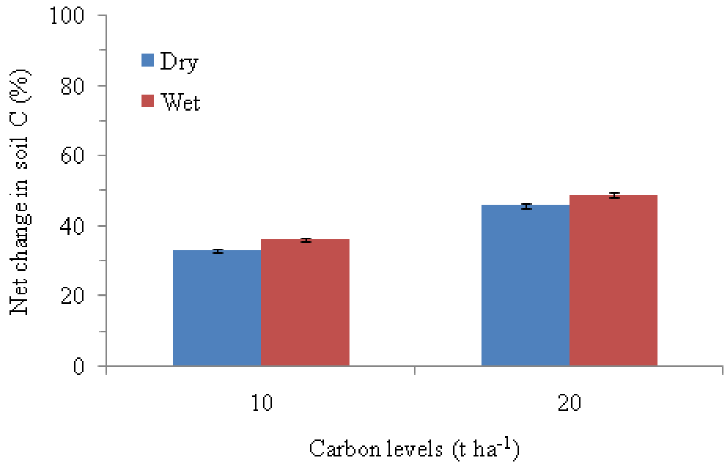

Fig 11. Effects of C levels on net change in soil organic C in the dry and wet seasons. Bars represent standard error of means.

The root: shoot ratio was calculated for each plant by dividing the dry root weight by the dry shoot weight.

Physiological measurements

The chlorophyll content of the third fully expanded leaf from the top was measured using a portable chlorophyll meter (Minolta SPAD-502, Japan) from 8:00 to 11:00 am following the method described by Jones (2003). Measurements were performed at the middle part of each leaf and the average of five readings was taken as an SPAD value. Sixty days after planting, net photosynthesis rates of the uppermost expanded main stem leaves, the third from the main axis terminal, were measured for five plants in each treatment between 8.00 and 11.00 am using an open gas exchange system, the LI-6400XT portable photosynthesis system (LiCOR Inc., Lincoln, Nebraska, USA).

Determination of C stocks in kenaf

Carbon stocks in kenaf were determined using the formula below (Carre et al., 2010):

$C_{STOCK} = C_{BIOMASS} = (B_{AGB} + B_{BGB})*CF$,

where $C_{BIOMASS}$ is the total C stock in the biomass (t C ha^{-1}), B_{AGB} is the carbon stock in the above-ground biomass (t C ha^{-1}), B_{BGB} is the carbon stock in the below-ground biomass (t C ha^{-1}) and CF is the carbon fraction of the dry matter (DM) (t C/t DM). The default IPCC 2006 value is 0.47 t C/t DM.

Computation of C change in soil

Prior to planting and after harvesting, the organic C of the soil samples was determined using a LECO C Analyser (model CR-412; LECO Corp., St. Joseph, Mich.). The net change in soil C (%) was determined using the formula from Singh et al. (2009):

$$\text{Net change in soil C (\%)} = \frac{(\text{Ctreatment} - \text{Ccontrol})x\ 100}{\text{Ccontrol}},$$

where $C_{treatment}$is soil organic C in the treatment and $C_{control}$ is soil organic C in the control.

Statistical analysis

All variables from the measurements were analysed using two-way analysis of variance (ANOVA). Duncan's multiple range test (DMRT) was used to determine significant differences at the 0.05 level. Relationships between variables were determined using Pearson's correlation coefficient test at 0.05 probability level. Simple regression lines were generated to test for significant correlations between variables. Two-way ANOVA was also performed on the leaf number and plant height data taken every four months. All statistical analyses were performed using the SAS software package (SAS Institute, 2009).

Conclusion

In the present study, the parameters growth, dry matter production, chlorophyll content, photosynthesis rate, fibre yield and carbon stock in kenaf showed a positive response to the application of organic carbon to the soil. Our results show that amendment of the soil with up to 20 t C ha^{-1} in the form of organic carbon results in an increase in stem diameter, plant height, leaf number, leaf area, chlorophyll content, photosynthesis rate, C stock and ultimately in a higher fibre yield. This demonstrates the importance of a sufficient carbon supply to ensure vigorous growth. To achieve optimum growth, we suggest an application of organic C at a level of 20 t C ha^{-1}. Based on the parameters dry matter production and allocation, photosynthesis rate, carbon stock and bast and core fibre yield varieties HC2 and V36 are both suitable for being grown commercially in sandy soils under effective carbon management.

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