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Dry matter and nutrient partitioning of kenaf (*Hibiscus cannabinus* L.) varieties grown on sandy bris soil

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Abstract

Dry matter and nutrient partitioning of different kenaf varieties grown on sandy Beach Ridges Interspersed with Swales (BRIS) soils were investigated. The experiment was conducted under a shade house condition. Five kenaf varieties, V36, G4, KK60, HC2 and HC95 were grown in pots, replicated four times in a randomized complete block design. Plants were partitioned into roots, stems, and leaves and the dry weights were recorded at harvesting time. The dry matter accumulation differed significantly among varieties. Total biomasses for the different varieties ranged from 56.19g to 63.33g. Stem accounted for the greatest proportion of dry matter (63.98%), followed by root (18.99%). The proportion of the dry matter accumulation in stem was highest (64.28%) in HC2, followed by V36 (64.04%). The average dry matters were 76.83% and 20.56%. in stems and leaves, respectively. The proportion of the macro- and micronutrients in kenaf parts differed significantly among varieties. Nitrogen content had the highest proportion (27.54 to 28.04%) in leaves and lowest (8.06 to 8.24%) in stem, which followed by K, Ca, P and Mg. Most of the kenaf varieties showed variation in nutrient use efficiency (NUE), respect to the measured nutrient elements. The NUE values of < 1.0 g dry matter mg^{-1} nutrient were observed for macronutrients, whereas higher NUE values obtained for micronutrients. Total nutrient accumulation in the plant components differed among the kenaf varieties. Partitioning of dry matter and nutrients in kenaf provides a means to select better varieties and makes it possible to grow kenaf on BRIS soil using better fertilizer program.

Keywords: Dry matter partitioning, BRIS soil, nutrient allocation, kenaf varieties.
Abbreviations: BRIS – beach ridges interspersed with swales; CEC – cation exchange capacity NUE – nutrient use efficiency; TNUE – total nutrient use efficiency.

Introduction

Kenaf (*Hibiscus cannabinus* L., family Malvaceae) is a woody-herbaceous annual plant cultivated for the fibre produced in its stem. In recent times, the interest in growing kenaf throughout the world for its high biomass yield and elevated fibre content has been increased. Kenaf is a fast growing crop and has high potential to be used as an industrial crop globally. As a herbaceous plant, kenaf has a high potential of the fibre materials or lignocellulosic material. The stems of kenaf have two principal components: bark with long fibres (2-6 mm), making up 35- 40 % of total stem weight; and core, with short fibres (0.6 mm), making up the remaining 60-65% (Manzanares et al., 1997). Kenaf fibres can be used for manufacturing of a wide range of pulp, paper and paperboard products and may be a substitute for fiberglass and other synthetic fibres. As fibrous crop, kenaf appears to have enormous potential to become a valuable biomass crop of the future (Alexopoulou et al., 2000). The plant whole-stalk 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). Nowadays, kenaf is being considered as an alternative and cheaper source of material for producing panel products, such as fibreboard and particleboard. According to Sellers et al. (1993), kenaf also has a high potential as a board raw material with low density panels suitable for sound absorption and thermal resistance. Due to the high absorbency of the woody core material, researchers have investigated the use of kenaf as an absorbent (Goforth, 1994), poultry litter, animal bedding (Tilmon et al., 1988), bulking agent for sewage sludge composting (Webber, 1994), and as a potting soil amendment (Laiche and Newman, 1994; Webber et al., 1999b). Kenaf can be potentially planted on sandy BRIS soil, which is poor in water holding capacity and nutrient availability due to high adaptability in all ranges of soils. The total area of BRIS soils spread along the east coast of the peninsular and the coastal area of Sabah is about 200, 000 ha in total with 155,400 ha in peninsular Malaysia and 40,400 ha in Sabah, respectively. The BRIS soils contain 82-99% sand particles, mainly quartz, and have a low cation exchange capacity (CEC) of 9.53 cmol (+) kg^{-1} with pH 4.3-4.4 (Chen, 1985). The information regarding dry matter and nutrient partitioning of kenaf planted on BRIS soils is scarce and almost not existed. The mass production of kenaf cultivars throughout the world is critical due to the increase of utilization of its high biomass, and strong and good fiber yield. Thus, the utilization of less fertile soils such as BRIS soil is important to increase the kenaf production throughout Malaysia. The information of kenaf adaptability on BRIS soil

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

Soil variables	Content	Soil variables	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

Table 2. Dry matter partitioning into plant parts of different kenaf varieties

Variety	Root dry weight (g $plant^{-1}$)	Stem dry weight (g $plant^{-1}$)	Leaf dry weight(g $plant^{-1}$)
KK60	10.97c	36.33d	9.78 d
HC2	11.85a	40.71a	10.77a
V36	11.53a	39.35b	10.56b
G4	11.31b	38.15c	10.13c
HC95	10.85 c	35.67e	9.67d

Means with the same letter are not significantly different at $P \leq 0.05$

is crucial. The study on dry matter and nutrient partitioning are important to determine the success of kenaf growing in BRIS soil. Hence, the objective of this study was to determine the dry matter and nutrient partitioning of different kenaf varieties planted on BRIS soil.

Materials and methods

Study site and plant materials

The experiment was conducted at the Experimental Farm No. 2, Universiti Putra Malaysia, Serdang, Selangor, Malaysia ($2^o59^{\prime}$ 20.56″N, $101^o42^{\prime}$ 44.42″E) under a shade house for a period of four months from April to July 2010. Five kenaf varieties, such as V36, G4, KK60, HC2 and HC95 were used 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 each pot (height, 40 cm; diameter, 25 cm). Five kenaf varieties, namely V36, G4, KK60, HC2, and HC95 were used in this experiment as treatments. Since, these varieties were new to Malaysia, there was a need to study dry matter and nutrient partitioning to understand their potentiality to be grown on sandy BRIS soil. 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 vigour. 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 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 arranged in randomized complete block design (RCBD) with four replications. The insecticide Chlorpyrifos at the rate of 2 L ha^{-1} was applied one month after planting to control insects. The plants were watered with sprinkler system during the crop growing season to maintain the soil moisture at field capacity, measuring with tensiometer.

Soil sampling and analysis

Soil samples were collected randomly from four points in each pot (0-20 cm depth) before planting using a stainless steel auger. The soil mixed thoroughly in a plastic container to give a composite sample, then packed in the labeled plastic bags and transported back to the laboratory for sample preparation. In the laboratory, the soil samples were air-dried and sieved through a≤ 2.0 mm sieve. 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), Iron (Fe), Manganese (Mn), zinc (Z), and copper (Cu) were determined by atomic absorption spectrophotometer (Perkin-Elmer 5100 PC). The initial physical and chemical characteristics of the soil are presented in Table 1.

Biomass measurements

At harvest roots, stems and leaves were separated and dried at 65^oC in an electric oven for 48 hours to constant weight to estimate plant components dry weights. From these measurements, partitioning to above and below ground parts was calculated.

Nutrient concentration measurements

After drying, all the plant components were ground and sub-sampled. Between 100 and 500g of oven-dried roots, stems and leaves were digested using sulphuric acid and hydrogen peroxide (Benton, 2001) in a block digester at 350^oC. Digested solutions were filtered though no. 44 Whatman filter paper and made up with distilled water to 100 ml. The concentrations of N, P and K were determined using an auto-

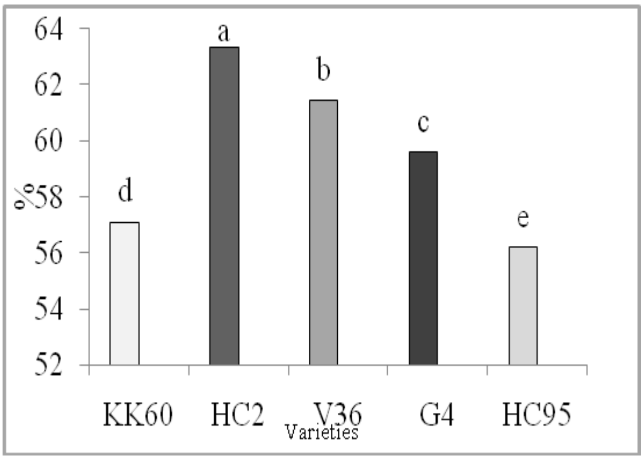

Fig 1. Total dry weight of different kenaf varieties.

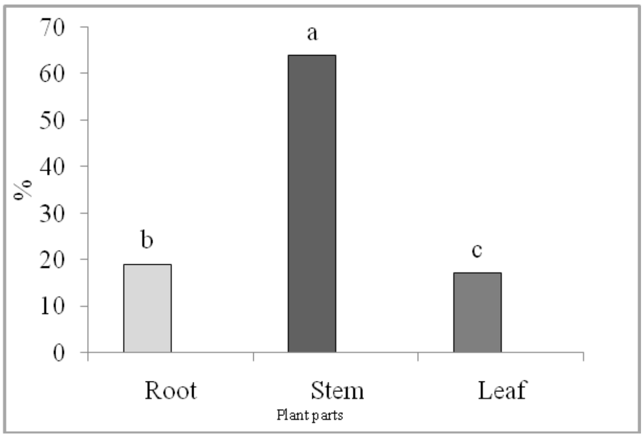

Fig 2. Average dry matter of different plant parts in kenaf varieties.

analyzer (QuikChem, Series 8000, Lachat Instruments Inc., USA) and the concentrations of Ca, Mg, Fe, Mn, Zn and Cu were determined using atomic absorption spectrophotometer (Perkin-Elmer 5100 PC).

Statistical analysis

Data on dry matter and nutrient partitioning in different plant parts of kenaf were analyzed using the SAS statistical procedure (SAS, 2007). Duncan's Multiple Range Test was used to detect the significant grouping among the treatments.

Results and discussion

Partitioning of kenaf dry matter

The dry matter accumulation at harvest differed significantly among kenaf varieties (Table 2). Multiple mean comparisons of the five varieties indicated that all the varieties allocated more dry matter to shoots than roots. The highest dry matter of stem (40.71g) was produced in variety HC2 which was followed by the stem dry matter (39.35g) of variety V36 and HC95 had the lowest (35.67g) stem dry matter (Table 2). These findings are in agreement with the results of Hasanuzzaman et al. (2008) who reported the highest stem dry matter allocation in *Aloe vera*. In the case of root dry matter the variety HC2 had the highest root (11.85 g) dry matter which was similar to V36. The variety HC95 had the lowest root (10.85 g) dry matter. Higher stem dry matter contributes to the production of higher stalk yield. The stalk yields are important for kenaf fibre production because the stalks are the source of the bark (bast) and core fibres (Webber, 1993b; Charles et al., 2002). The leaf dry matter differed considerably among the five varieties (Table 2). The variety HC2 had the highest leaf dry matter (10.77g) and HC95 had the lowest leaf dry matter (9.67g). In above ground plant material, the variety V36 produced the highest composition (21.15%) and KK60 had the lowest value (19.77%) for leaf dry matter composition (Table 3). The average composition of the leaf dry matter of above ground plant material of all kenaf varieties showed the dry matter accumulation of 20.56 % in leaves. This was close to the findings of Charles et al. (2002) who reported average of 26% of leaf dry matter from five kenaf cultivars. Leaf dry matter is important ctiteria for selection of cultivars for forage production, because the leaves are the primary source of protein (Webber, 1993a; 1993b). For example, Webber reported that 'Guatemala 51' had the greatest leaf dry matter yield among 5 cultivars (1993a) and 'Guatemala 45' had the greatest leaf dry matter among 6 cultivars (1993b). The total dry matter content varied significantly among the kenaf varieties. The variety HC2 had the highest value of total dry matter (63.33 g) and HC95 had the lowest (56.19 g) total dry matter (Fig. 1). The highest total dry matter obtained by HC2 could be attributed to the highest plant height (204.74 cm) of this variety (data not shown). The plant dry matter production increase when the plant height extended. Charles et al. (2002) observed in an experiment that the stalk dry matter yield of kenaf increased with the increase in plant height. This result is consistent with Ching et al. (1993) who reported the same trend with full season kenaf for fibre production. Ejieji and Adeniran (2010) also observed that stem dry matter of grain Amaranth (*Amaranthus cruentus*) increased with the increase in plant height. Based on the average of plant parts across the different kenaf varieties, the highest amount of the dry matter accumulation occurred in stems (63.98%) followed by the dry matter accumulation in root (18.99%) (Fig 2). With regard to the percentage of stem dry matter to the total plant dry matter, there was a clear distinction between kenaf varieties with the highest value (64.28%) obtained by HC2 and the lowest value (63.64%) obtained by KK60 (Table 3). The kenaf stem dry matter percentages are important factors in selecting cultivars to be used for kenaf fibre production. The majority of the breeding programs in the US have developed cultivars that are more suitable for producing greater stalk dry matter percentages (Webber, 1993b). The total above ground plant matter differed significantly among varieties (Table 3). In terms of yield per unit area the percentage of the total above ground plant matter is important to evaluate different kenaf varieties (Charles et al., 2002). In the present study, the HC2 had the highest above ground plant matter (81.28%) which was statistically similar to above ground plant matter produced by the V36 (81.23%) and the variety HC95 that had the lowest above ground plant matter (80.69%). The variety HC2 had the highest composition (79.07%) of the stem dry matter to above ground plant matter and the variety HC95 had the lowest stem dry matter composition (72.95%) of the above ground plant material. The average stem dry matter composition across the different kenaf varieties in the present study was 76.83%. A similar trend was reported by Charles et al. (2002) where the average stem dry matter of 74% was estimated from five kenaf varieties.

Table 3. Composition of dry matter (%) in plant parts of different kenaf varieties

Variety	Composition of root dry matter of the total dry matter (%)	Composition of stem dry matter of the total dry matter (%)	Composition of leaf dry matter of the total dry matter (%)	Composition of above ground plant matter of the total dry matter (%)	Composition of stem dry matter of above ground plant matter (%)	Composition of leaf dry matter of above ground plant matter (%)
KK60	19.21a	63.64b	17.13a	80.78c	74.30c	19.77c
HC2	18.71b	64.28a	17.00b	81.28a	79.07a	20.92b
V36	18.76b	64.04a	17.18a	81.23a	78.84b	21.15a
G4	18.97b	64.02a	16.99b	81.02b	79.01a	20.98b
HC95	19.30a	63.90b	17. 20a	80.69c	72.95d	20.00c

Means with the same letter are not significantly different at $P \leq 0.05$

Table 4. Proportion of nutrient (%) in the plant components of different kenaf varieties

Plant parts	Variety	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn
	KK60	10.27	1.70	7.03	3.98	0.95	0.04	0.01	0.01	0.01
	HC2	10.70	2.01	6.13	3.49	0.91	0.03	0.01	0.01	0.01
Root	V36	10.69	2.04	6.21	3.51	0.93	0.03	0.01	0.01	0.01
	G4	11.17	1.67	6.49	3.67	0.97	0.04	0.01	0.02	0.01
	HC95	10.71	1.77	7.06	4.15	0.99	0.06	0.01	0.02	0.01
	KK60	8.24	1.98	8.14	5.33	1.31	0.08	0.01	0.02	0.01
	HC2	8.24	2.40	7.93	5.58	1.20	0.07	0.01	0.02	0.01
Stem	V36	8.18	2.42	7.86	5.60	1.21	0.07	0.01	0.02	0.01
	G4	8.54	2.30	8.22	5.62	1.22	0.07	0.01	0.02	0.01
	HC95	8.06	2.07	8.49	5.56	1.31	0.08	0.01	0.02	0.01
	KK60	28.02	3.84	9.78	7.08	1.97	0.09	0.01	0.01	0.01
	HC2	28.04	4.21	10.50	6.40	1.94	0.08	0.01	0.01	0.01
Leaf	V36	27.92	4.20	10.44	6.48	1.96	0.08	0.01	0.02	0.02
	G4	27.54	3.68	10.21	6.54	1.81	0.09	0.01	0.03	0.02
	HC95	27.66	3.47	9.15	7.12	2.05	0.10	0.01	0.02	0.01

Table 5. Nutrient use efficiency (g dry matter mg^{-1} nutrient) for different kenaf varieties

Varieties	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn	Total
KK60	0.06	0.33	0.09	0.14	0.56	14.06	292.44	45.20	66.95	0.025
HC2	0.05	0.25	0.08	0.12	0.51	13.59	284.13	43.11	62.94	0.022
V36	0.05	0.24	0.08	0.11	0.50	13.50	285.54	44.02	63.40	0.023
G4	0.06	0.28	0.07	0.13	0.55	13.78	288.94	44.75	64.41	0.023
HC95	0.07	0.35	0.09	0.14	0.57	14.14	293.34	45.66	67.84	0.027

Table 6. Nutrient content (g plant^{-1}) of different kenaf varieties

Varieties	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn	Total
KK60	15.97	2.98	10.83	7.11	1.80	0.071	0.003	0.022	0.014	38.83
HC2	18.78	4.05	12.30	8.16	1.96	0.073	0.004	0.023	0.016	45.40
V36	18.31	4.00	11.99	8.05	1.93	0.073	0.003	0.022	0.015	44.43
G4	17.73	3.47	11.78	7.76	1.82	0.072	0.004	0.022	0.014	42.70
HC95	15.19	2.86	11.53	7.05	1.74	0.070	0.003	0.021	0.015	37.51

Proportion of nutrient in kenaf plant components

Besides biomass, the plants also allocate resources, like nutrients into various plant parts in a balanced system (Poorter and Villar, 1997). Plant nutrients are derived from soil solution and absorbed by roots through electrogenic pumps (Mengel and Kirkby, 1982). In this study, several ions such as N, P, K, Ca, Mg, Cu, Fe, Mn and Zn were analyzed. The concentrations of these nutrients varied significantly among plant parts and kenaf varieties (data not shown). For example, the highest concentrations of nitrogen in leaves (42.15g kg^{-1}), and potassium in stem (11.24g kg^{-1}) were obtained in the variety HC2. Because of the differences in concentrations of nutrients in various kenaf plant parts, nutrients were partitioned according to the plant parts (in percentage) relative to the total amount of nutrients analyzed in the whole plant (Table 4). In a balanced system, a change in the composition of one nutrient might increase or decrease other nutrients. In sunflower plant the same principle was used to determine the effects of increasing Mg application on various cation species (Scharrer and Jung, 1955). This also suggested by Mengel and Kirkby (1982), while Poorter and Villar (1997) argued that the total composition of plant compounds should be add up to 100%, based on their eight categories. The proportion of nutrients among kenaf plant parts and varieties differed significantly (Table 4). This variation could possibly be due to the environmental conditions and/or inherent differences between varieties. In spite of special care taken to the management of growing crop plant, the various interacting effect of environment on crop growth may affect dry matter and nutrients partitioning (Bazzaz, 1997). Among all of the nutrient elements analyzed in the present study, N showed the highest proportion (27.54 to 28.04%) in leaves and lowest (8.06 to 8.24%) in stem parts, which followed by K, Ca, P and Mg (Table 4). This supports this concept that N is the most important nutrient element in terms of plant growth, physiology and carbohydrate content (Terbe, 2004; Almodeares et al., 2008). The differences in kenaf varieties were clearly evident based on N proportion in leaves, whereas variety HC2 showed the most (28.04%) and variety G4 (27.54%) the least for kenaf plants on BRIS soil. Potassium showed the second highest proportion in leaves (9.15 to 10.50 %) and (6.13 to 7.06%) in roots. Potassium plays an important role in several physiological and biochemical processes (Igras and Danyte, 2007). Along with nitrogen, it is the mineral which is absorbed in the greatest quantity (Marschner, 1965). This finding supports our study where potassium was found as the second highest proportion of nutrient. The proportion of micronutrients varied significantly in different plant components and varieties except Cu (Table 4). The highest proportion of Fe, Zn and Mn was found in leaves. Similar variation of micronutrients in roots, shoots and leaves were reported in common bean (*Phaseolus vulgaris*) (Patrick et al., 2011).

Nutrient use efficiency in different kenaf varieties

Most of kenaf varieties showed variation in NUE with respect to the nutrient elements measured (Table 5). In the case of macronutrients NUE were < 1.0 g dry matter mg^{-1} nutrient. However, higher NUE values of dry matter mg^{-1} nutrient were obtained in the case that micronutrients had higher values for Cu, followed by Mn, Zn and Fe.

Quantity of nutrients in kenaf varieties

The total nutrients in kenaf plants differed substantially between varieties (Table 6). The variety HC2 gave the highest total nutrient content (45.40g plant^{-1}) and HC95 had the lowest total nutrient content (37.51g plant^{-1}). However, this order was reversed to the TNUE, whereas the smallest value obtained by the variety HC2 (0.022) and the greatest by HC95 (0.027) (Table 5). This indicates that absorption of nutrients by kenaf varieties varied because of the differences in each variety's ability to uptake or utilize each nutrient according to the function of each plant part. Based on the total nutrients measured in the dry matter of kenaf parts, we suggest that the variety HC2 performed better on BRIS soil as compared to others in terms of utilization of nutrients.

Conclusion

The dry matter accumulation and partitioning of five kenaf varieties into roots, stem and leaves varied substantially. Based on the total dry weight of kenaf plant parts, the variety HC2 produced the highest dry matter followed by V36. Most of the dry matter accumulation occurred in stems (63.98%) followed by the dry matter accumulation in root (18.99%). Of the above ground plant materials across the five varieties, the average dry matter in stem was 76.83% and in leaves was 20.56%. The proportion of macro- and micro-nutrients differed markedly with kenaf plant components and varieties. However, based on the total nutrients accumulated in the plant components, the kenaf variety HC2 showed better performance among the varieties grown on BRIS soil.

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