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Effects of Different Fertilizer Application Level on Growth and Physiology of *Hibiscus cannabinus* L. (Kenaf) Planted on BRIS Soil

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Abstract

Hibiscus cannabinus L. or Kenaf is one of the most potential annual crop planted throughout the world. Being fast growing and multipurpose, it has been utilized as a substitute of jute and, more recently, as raw product for the production of pulp and paper. With strong and long fiber yield, mass production of Kenaf throughout Malaysia is critical. The utilization of less fertile soils such as BRIS soils is important to increase the Kenaf production throughout Malaysia. Thus, the objective of this study was to determine the effects of different level fertilizer application on growth and physiology of Kenaf planted on BRIS soils. V36 variety was used and planted in three different plots by treatments with fertilizers namely high (1960 kg/ plot), medium (1260 kg/ plot) and low (700 kg/ plot) respectively. Each plot comprises 106,000 trees where trees were planted on 20 lines. There were contrasting results on the effects of fertilizer on growth and physiology of Kenaf in the dry (41 days) and wet season (64 days). Significant effects were only observed for diameter, height, leaf number and area during the wet season. Similar results were also found for biomass. The increasing trends with increasing the rates of fertilizer were observed in the wet season for growth and biomass parameters. The correlation analyses between total aboveground biomass with diameter and height were more pronounced in the wet season. *AGR,* *RGR* and E_G calculated from the differences between the dry and wet season readings for aboveground biomass showed that the higher rate of fertilizer recorded the higher values of *AGR* and *RGR*. However, no trend was observed for E_G.

Keywords: Kenaf, BRIS soil, Growth, Physiology, Fertilizer

1. Introduction

Hibiscus cannabinus L. or normally known as Kenaf is one of the most potential annual crop planted throughout the world. It is a member of the hibiscus family (Malvaceae) and indigenous to Africa. Kenaf is an annual fibre crop of tropical origin. The plant has been utilized in the cordage and sacking manufacture as a substitute of jute and, more recently, as raw product for the production of paper pulp. The species is grown in the Asia-Pacific region, with India, China, Bangladesh, producing the largest part of the world supplies. Stems of Kenaf plants consist of an inner thick core of short woody fibres 0.5 to l mm long, and of an external bark with fibres of 3 to 4 mm long. The bast fibres are of better quality than the core fibres; both, however, can be utilized in various blends for the production of pulp (Petrini *et al*., 1994).

In Malaysia, It was first introduced in the early 70's and was highlighted in the late 90's 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. Being fast growing and multipurpose, Kenaf also is a good carbon sequester and can improve soil fertility. By the potential to be a valuable agronomic crop leading to the production of a number of commodities, effects of plant population, soil fertility, location and cultivar on Kenaf yields have to be studied (Bhangoo *et al*., 1986; Ching *et al*., 1992; Webber, 1993a, b). Kenaf variety needed suitable environmental conditions to predict accurately what and how much of a Kenaf commodity can be produced at a given site and geographic location (Ching *et al*., 1992; Webber, 1993b). With the highly adaptable with all ranges of soils; Kenaf can be potentially planted at Beach Ridges Interspersed with Swales (BRIS) soil which is poor in water holding capacity and nutrient availability.

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. BRIS soils contain 82-99% sand particles, mainly quartz, and have a low Cation Exchange Capacity (CEC) of 9.53 meq/100 g with pH 4.3 to 4.4 (Chen, 1985). BRIS soil structure contains mostly of sand particles with having low water-holding capacity (Jensen, 1989) and poor in nutrient. It is well known that water deficit affects every aspect of plant growth, modifying anatomy, morphology, physiology and biochemistry (Hsaio, 1973; Enu-Kwesi *et al*., 1986).

The information on growth and physiology of Kenaf planted on BRIS soils is almost non-existence and scarce. Thus, the limitation of growth on this type of soil should be studied thoughtfully based on information that Kenaf can adapt to all types of soils. Kenaf can reach at 4 m tall after one rotation (approximately 4 months) at the normal soil which rich in nutrient-water content.

With the increase of utilization, strong and long fiber yield, the mass production of Kenaf throughout Malaysia is critical. Thus, the utilization of less fertile soils such as BRIS soils is important to increase the Kenaf production throughout Malaysia. The information of Kenaf adaptability on BRIS soil is crucial. At the same time, silvicultural practices also need to be implemented on BRIS soil in order to increase growth and productivity of Kenaf. Therefore, the study on growth and physiology are important to determine the successfulness of different level fertilizer application of planting Kenaf on BRIS soil. Hence, the objective of this study was to determine the effects of different level fertilizer application on growth and physiology of Kenaf planted on BRIS soil.

2. Materials and methods

2.1 Study Site

The study was conducted in Setiu, Terengganu at the latitude of $5^{o}36'59.42''$N and longitude of $102^{o}44'18.04''$E. The location of the study area is about 200 m above sea level. Total cover areas in Setiu are 130,436.3 ha.

The mean relative humidity of the study site is about 70% to 90% (Malaysia Meteorological Department, 2008). The ranges of mean minimum and maximum temperature are 22°C to 37°C respectively. The annual rainfalls in Setiu fluctuated from the lowest 2990 mm to the highest of 4003 mm per year.

2.2 Plant Materials

V36 was used in this experiment and planted on BRIS soils in Setiu, Terengganu. This variety was selected by Lembaga Tembakau Negara (National Tobacco Board) and was planted on 14^{th} February 2008 in three different plots assigned by treatments (levels of fertilizer). Each plot comprises 106,000 plants and were planted in 20 lines.

2.3 Experimental design

The plant samples were randomly selected using quadrate sampling within the plots and generated using random table. In each experiment, 15 samples per treatments were used in both the dry and the wet seasons. NPK with the ratio of 12:12:36 + 2MgO + TE and the micronutrient compositions were Boron, Cuprum, Iron, Manganese, Molybdenum and Zink were used. The treatments were divided into three different fertilizer levels namely high (1960 kg/ plot), medium (1260 kg/ plot) and low (700 kg/ plot) respectively. Fertilizer was sprayed for 16 second per liter for every plot per day.

2.4 Growth parameters

2.4.1 Sampling procedure of growth parameters

Ten samples per treatment were selected randomly for measurement. Plant height (*Ht*), diameter (*D*), number of leaves (*LN*), leaf area (A_L) and biomass were taken. For plant biomass, plants were divided into components namely leaf mass (M_{Leaf}), stem mass (M_{Stem}), root mass (M_{Root}) and flower mass (M_{Flower}). Total aboveground biomass (M_{AG}) was calculated by summing the values of M_{Leaf} and M_{Stem}. Root to shoot ratio (*Rt:St*) was also calculated by dividing the values of M_{Root} and M_{AG}. In addition, absolute growth rate (*AGR*), relative growth rate (*RGR*) and growth efficiency (E_G) were also measured (Muchow, 1979). Plant *Ht* was measured using a steel ruler and height stick while *D* (10 cm above the ground) was measured using digital caliper. The *Ht* was measured from cotyledon level up to the base at the terminal bud. Measurement of collar *D* was made using a digital caliper and starting point of the measurement was marked using permanent marker pen. Two readings were made at the right angles to each other. The A_L was measured using Model Li-3100 Area Meter, LICOR, inc. Lincoln, Nebraska USA.

For biomass experiment, leaves, stems and roots were dried in oven at 60-70°C for 48 hour until the constant weight was obtained. Total aboveground biomass was calculated by summing the values of stems and leaves dry weight.

The absolute growth rate (*AGR*), relative growth rate (*RGR*) and growth efficiency (E_G) were determined after aboveground biomass at first reading (dry season) and second reading (wet season) were obtained using equation as stated below:

$$AGR = \frac{W_2 - W_1}{\Delta T}$$

Where:

AGR : Absolute Growth Rate

W_1 : Biomass at first reading

W_2 : Biomass at second reading

ΔT : Different in time

$$RGR = \frac{Ln\ (W_2) - Ln\ (W_1)}{\Delta T}$$

Where,

RGR : Relative Growth Rate

Ln : Longitude

W_1 : Biomass first reading

W_2 : Biomass second reading

ΔT : Different in time

$$E_G = \Delta W / \Delta T \times (1 / A_L)$$
$$= (W2 - W1/T2\text{-}T1) \times (1 / A_L)$$

Where,

E_G = growth efficiency

A_L = total leaf area

W_2 = weight at second reading

W_1 = weight at first reading

T_2 = time at second reading

T_1 = time at first reading

2.4.2 Sampling procedure for gas exchange

Prior to the destructive sampling, the same samples used in the growth measurement were selected in this experiment. For every sample, three measurements were taken using gas exchange analyzer (Model LI-6400, LICOR, inc. Lincoln, Nebraska USA). This measurement was done to determine the net photosynthesis rate (A_{net}), stomatal conductance (*Gs*) and transpiration rate (E_L). All the measurements were taken at 0800 to 1100 h to avoid the midday depression in photosynthesis as being recommended by Hiromi *et al*. (1999).

In addition, water use efficiency (*WUE*) is expressed as the quotient of the diffusive fluxes of CO_2 into the leaf and water vapour out of the leaf during photosynthesis (Farquhar and Richards, 1984). *WUE* is a fundamental aspect of the physiology of terrestrial plants. The parameter determine the efficiency of plant bring in carbon dioxide for photosynthesis without losing much water out of its stomata. It is the ratio of carbon dioxide intake to water lost through transpiration. All the gas exchange measurements were carried out on the fully expanded and non-senescing leaves at the fifth node from the apex.

2.5 Statistical analysis

Data of growth and physiological of Kenaf were analyzed using analysis of variance (ANOVA) (SPSS version 16.0) to estimate the treatment variations while Duncan's Multiple Range Test (DMRT)were used to detect the significant grouping among the treatments. In addition, *AGR*, *RGR* and E_G were analyzed using mean separation test. Correlation for height, diameter and aboveground biomass were analyzed using SigmaPlot version 10.0.

3. Results

3.1 Growth Parameters

3.1.1 Diameter and Height

There were contrasting results found for diameter and height of *Hibiscus cannabinus* L. grown in two different seasons between treatments. A highly significant difference between treatments was found in the wet season for both parameters (Table 1). However, the result showed clearly that both parameters were not significantly different in the dry season (early stage of planting).

The mean values of diameter ranged from as low as 8.54 mm (High) to 10.12 mm (Low) in the dry season and from 12.62 mm (Low) to 17.46 mm (High) in the wet season. Meanwhile, the mean values of height ranged from 79.4 cm (High) to 89.6 cm (Medium) and 178.3 cm (Low) to 240.4 cm (High) in the dry and the wet season respectively. In the wet season, the values of both parameters increased with increasing the level of fertilizer but no increasing patterns were found in the dry season (Table 2).

3.1.2 Leaf Number and Leaf Area

Significant differences were only found in the wet season for leaf number (*LN*) and leaf area (A_L). Significant difference at $p \leq 0.01$ was found for *LN* and at $p \leq 0.05$ for A_L (Table 3).

The mean values of *LN* and A_L for both seasons were shown in Table 4. In the dry season, there were no increasing trends with increasing the level of fertilizer found for *LN* but the increasing trend was only found in the wet season. Similar results were also found for A_L. However, DMRT grouping shown that medium and high application of fertilizer did not differ to each other with only small fraction of differences between them for both *LN* and A_L. The differences were about 1% and 4% for *LN* and A_L respectively.

3.1.3 Biomass

Table 5 shows the analysis of variance (ANOVA) for the plant biomass for two seasons. The plant biomass was divided into leaf mass (M_{Leaf}), stem mass (M_{Stem}), root mass (M_{Root}) and flower mass (M_{Flower}). Total aboveground biomass (M_{AG}) was calculated by summing the values of M_{Leaf} and M_{Stem}. Root to shoot ratio (*Rt:St*) was also calculated by dividing the values of M_{Root} and M_{AG}. Significant differences between treatments were found at $p \leq 0.05$ for M_{Leaf} and M_{root} in the wet season only. However, significant differences were found for the rest of the parameters in both seasons.

Mean values for biomass components were shown in Table 6 for two seasons. Biomass for stem, flower and aboveground biomass increased with the increasing of fertilizer level. Meanwhile, the DMRT grouping for biomass components for both seasons shows inconsistent results except biomass for root, flower and aboveground stem.

Based on the correlation analyses conducted using SigmaPlot 10.0 (Systat Software Inc.), there were no strong correlations between diameter and height with total aboveground biomass for every treatment except for height in the high level of fertilizer in the dry season (Figure 1). However, the results of correlation analyses between growth parameters and aboveground biomass were more profound in the wet season (Figure 2). Both height and diameter showed high correlation except for correlation between aboveground biomass and height at high level of fertilizer showed low correlation ($R^2 = 0.47$).

In addition, the true growth performance of *H. cannabinus* can be determined based on absolute growth rate (*AGR*), relative growth rate (*RGR*) and growth efficiency (E_G) of biomass. The values for *AGR*, *RGR* and E_G were only able to be calculated based on the mean values of biomass in both time of measurements (dry and wet) due to the samples were destructed. The increasing trends with increasing the level of fertilizer were found for *AGR* and *RGR* but no specific trend was observed for E_G (Figure 3). The substantial increased of *AGR* was observed from the low to the medium level of fertilizer application and the degree of increment was starting to reduce from the medium to the high level of fertilizer application. Growth efficiency from the medium level of fertilizer application is low because it has higher reading in leaf area. The values of increment relative to the final biomass or relative growth rate were found to increase constantly from the low to the medium and to the high rate of fertilizer application. The value was found higher in the low level of fertilizer application followed by the high and medium level of fertilizer application for E_G.

3.2 Gas exchange

The analysis of variance (ANOVA) revealed that photosynthesis rate (A_{net}) and water use efficiency (*WUE*) were significantly different at $P \leq 0.05$ in the dry season while contrasting results were found in the wet season where only A_{net} was not significant (Table 7).

In the dry season, the mean value of net photosynthesis (A_{net}) was found higher in the high level of fertilizer application followed by the medium and the low level of fertilizer application. Similar results were also observed for water use efficiency (*WUE*), where the mean values increased with increasing the level of fertilizer i.e. 3.96 (low), 4.22 (medium) and 4.43 (high) in respectively. In the wet season, the mean value of stomatal conductance (*Gs*) was found higher in the high level of fertilizer application followed by the medium and the low level of fertilizer application. Similar results were also found in transpiration rate (*E*). However, the mean value of water use efficiency (*WUE*) was only found significantly higher in the medium level of fertilizer (Table 8).

4. Discussion

4.1 Growth parameter

Diameter and height during the dry season showed that there were no significant differences found between treatments with regards to the level of fertilizer concentrations. This is due to the poor growth performance of plants when the water level in soil was inadequate. Plants need sufficient amount of water to survive and keep their cells in good conditions at the early stage of development in order to produce new tissues and cells. In addition, the readings were taken after 41 days of planting, thus the differences in terms of performance is too soon to be detected. According to Muchow and Wood (1980), Kenaf plants under continuous irrigation vigorously increased plant height from the beginning of the experiment to its termination at the 10^{th} week. Height increased slowly with the plants under stress, and severe stress had the most detrimental effect on height increment. In terms of biomass component, roots biomass showed outstanding performance compared to aboveground biomass. This is due to the need of more water to absorb at the dry season. The second measurement was taken during the wet season. The readings for both parameters showed significantly different between the level of fertilizer. The high and medium levels of fertilizer were obviously different with the low level where the different in terms of concentration between medium and low was 560 kg/plot. Thus, the medium level of fertilizer should be considered as most economic silvicultural practices to produce the best level of growth performance so far.

Leaf number and leaf area were not significantly different among treatments in the dry season and the mean values were also low. The plants might reduce the numbers of leaf to deter loss of water during the dry season through the process of transpiration. According to Charles-Edwards *et al*. (1983), daily increment in aboveground growth, depends on the proportion of incident light intercepted by the crop and the crop potential daily photosynthetic integral is obviously a function of the daily radiation integral. This might due to the early stage of planting where the differences in terms of growth were relatively not varied and the effect of fertilizer also still at the early stage. According to Tanner and Sinclair (1983), at the early stage of trees development, the differences were not significant. This phenomenon was also reported by Gartlan (1986). In contrast, leaf number and leaf area were significantly different for every level of fertilizer rate in the wet season. The high and medium levels of fertilizer were significantly affecting the number of leaves and leaf area. This will enhance plant to absorb light and produce food for the plants during the process of photosynthesis. Thus, this will also influence the level of plant water usage.

Biomass component during the dry season showed no differences between the parameters. However, during the wet season, leaf mass and root mass revealed the significant differences between the levels of fertilizer. Referring to the leaf mass at high and medium level of fertilizer, the results were better than low rate of fertilizer. This is due to the atmospheric and soil water content at the wet season is higher than the dry season. This phenomenon will influence plants to increase their leaf mass to enhance the respiration, transpiration and photosynthesis process. The high potassium (K) is needed for the process of respiration. This will encourage the plant stomata opening and energy production for photosynthesis process. This condition will influence the plant nutrient requirement at the maximum level.

For instance, in natrophilic (salt tolerant) plants, the K requirements can be lower. Plant requirement for K varies with the stage of growth, with the highest uptake rates often attained during the vegetative stage (Marschner, 1986). Negative correlation between increasing leaf K concentration and the concentrations of Calcium (Ca) and Magnesium (Mg) in *Hibiscus rosasinensis*, is also consistent with the reports that high K concentrations in the soil cause a decline in the uptake of Mg and Ca in cereals (Mengel and Kirkby, 1987). However, K is known to have a positive effect on the growth and dry matter accumulation of plants (Mengel and Kirkby, 1987). However, it is a similar that the chemical analysis in the soil and also in the plant could not be carried out due to the time constraint and equipment limitation.

4.2 Gas exchange

Net photosynthesis was not significantly different during wet season. This could be due to the requirement for light at the early stage of growth is more profound compared to the matured plants. High level of fertilizer applied was highly affected net photosynthesis, transpiration rate and water use efficiency. A common response to water stress is stomatal closure, which reduces both flux of CO_2 and water vapour. Alternatively, stomates may remain open while turgor is maintained through osmotic adjustment. Stomatal conductance and transpiration rate in Kenaf progressively declined with age in the adequately watered control. All the levels of stress brought stomatal conductance and transpiration to zero. Kenaf was also observed to roll its leaves during drought. These two mechanisms could be described as drought tolerance by dehydration postponement (Kramer, 1983), equivalent to drought avoidance by Levitt (1980). In wet season, stomatal conductance, transpiration rate and water use efficiency was significant but not for net photosynthesis rate. Wet moisture in the air might be affect stomatal conductance that reduce water through vapour to balance physiological plants.

4.3 Relationship between growth parameters and physiological attributes

Stem development and elongation are the critical components of the growth process (Schulze and Chapin, 1987). Physiological efficiency of any particular fibre species is manifested in the increment of plant height and increase in basal diameter. These parameters which result from the respective activities of apical growth and intercalary growth are generally considered dependable yield components of a bast fibre crop. Water deficit during dry season was observed to have significantly reduced height and diameters in growth parameter independent to the levels of fertilizer. In addition, when water supply is limited, turgor pressure approaches the yield threshold, and growth depends on the rate of water supply. This phenomenon was proven during the wet season where results of diameter and height were highly significant. Levels of fertilizer also contribute to the growth performance where high level of fertilizer gave better growth performance and otherwise. In addition, water use efficiency showed that the optimum level of fertilizer is medium compared with high and low. The alteration of these growth parameters under water deficits (in dry season) is due in part to the role of water in turgidity maintenance necessary for cell enlargement (Kramer, 1983). Cell division also decreases with increased water deficits, because cells apparently must attain a certain size before they can divide. As there is no direct method for assessing the fibre yield from a standing crop, plant height and basal diameter are considered as the general guiding criteria for efficient production of fibres in a particular species (Maiti and Chakravarty, 1977). It can therefore be concluded that drought affects the efficient production of fibres in Kenaf.

Leaf growth is the most sensitive of plant processes to water deficits and is frequently inhibited in field crops (Hsaio, 1973; Schulze and Chapin, 1987). For a given location and growth duration, the amount of light intercepted is primarily dependent on leaf area development, and these have been shown to be directly linked to leaf turgor. There were variable results between wet and dry seasons. During the dry season, water deficit condition adversely affected number of leaves, leaf mass and leaf area due to poor leaf expansion and defoliation. Plants usually grow straight and unbranched in dense stands in allocation energy for transform food to growing stem mass. At the same time during dry season, net photosynthesis rate and water use efficiency have significant different.

In the wet season, only net photosynthesis rate was not significant between other physiological parameters. This might due to plant need to reduce net photosynthesis because the leaf number and area were low. However, at this period, growth efficiency gave the highest performance at the low level of fertilizer. In addition, wet moisture in the air might be affect stomatal conductance that reduce water through vapour to balance physiological plants and at the same time photosynthesis rate was reduced. During the wet season, medium level of fertilizer showed outstanding performance compared to low and high level of fertilizer. Based on the growth performance and physiology characteristics, medium level of fertilizer is the best rate to produce good stands of Kenaf at BRIS soils compared to low and high level of fertilizer.

5. Conclusion

Based on the growth attributes for 41 (dry season) and 64 days (wet season) of planting, the effect of fertilizer on the growth traits were varied and more profound at the age of 64 days of planting. The results couldn't be treated at a general statement of V36 performance on BRIS soils due to the number of site replication where the research conducted was at one particular place (Setiu, Terengganu) instead of all BRIS soil sites in Malaysia. In terms of gas exchange characteristics, the changes of stomatal conductance, transpiration rate and water use efficiency were greater after 64 days of planting. However, the photosynthesis rate is otherwise. The study should be repeated to verify the findings. In addition, the knowledge on gas exchange can support for better understanding of physiology of Kenaf on its water requirements and its ability in light conversion in carbonaceous molecules influencing the biomass production and, indirectly, the carbon sequestration activity in different rate of fertilizer application. In addition, knowledge on Kenaf's carbon balance, as a response of assimilation and respiration rate to environmental conditions, is fundamental for understanding and assessing crop growth and productivity.

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References

Bhangoo, M.S., H.S. Tehrani, and J. Henderson. (1986). Effect of planting date, nitrogen levels, row spacing, and plant population on kenaf performance in the San Joaquin Valley, California. *Agronomic Journal* 78: 600–604.

Charles-Edwards, D.A., R.C. Muchow, and I.M. Wood. (1983). Effect of sowing date on the growth and yield of Kenaf (*Hibiscus cannabinus*) grown under irrigation in tropical Autralia. III. Physiological analysis. *Field Crop Research* 7: 103-113.

Chen, C.P. (1985). The research and development of pastures in Peninsular Malaysia. In *Pastures in The Tropics and Subtropics*, ed. J.P. Andriesse, p. 18: 33-51. Japan: Tsukuba.

Ching, A., C.L. III Webber and S.W. Neill. (1992). Effect of location and cultivar on kenaf yield components. *Industrial Crop Products* 1: 191–196.

Enu-Kwesi, L.; M.C. Nwalozie and D.I. Anyanwu. (1986). Effects of pre-sowing hydration-dehydration on germination, vegetative growth and fruit yield of *Abelmoschus esculentus* grown under two moisture regimes. *Tropical Agriculture* 63: 181– 184.

Farquhar, G.D. and R.A.Richards. (1984). Isotopic composition of plant carbon correlates with water-use efficiency of wheat genotypes. *Autralian Journal Plant Physiology* 11: 539-552.

Gartlan, J.S. (1986). The Biological Importance of the Korup Forest. In *Proceedings of the Workshop On Korup National Park*, eds. J.S. Gartlan and H. Macleod, p. 123-145. Republic of Cameroon: Mundemba.

Hiromi, H., I. Ninomiya, T. Koike, and K. Ogino. (1999). Stomatal regulation of canopy trees in a tropical rain forest. *Japan Journal of Ecology* 49: 68-76.

Hsaio, T.C. (1973). Plant responses to water stress. *Annual Review Plant Physiology* 24: 519–570.

Jensen, C.R. (1989). Plant water relations approaches and measurements. In *Vattninsbehov och Narings-tillforse,* eds. R. Persson and A. Wredin, p. 45-63. United Kingdom: Cambrige

Kramer, P.J. (1983). Water relations of plants. In *Glossary of Meteorology*, ed. R.E. Huschke, p. 161–168. New York: Academic Press.

Levitt, J. (1980). Responses of plants to environmental stress. New York: Academic Press.

Maiti, R.K. and K. Chakravarty. 1977. A comparative study of yield common Indian bast fibres. *Economic Botany* 31: 55-60.

Marschner, H. (1986). Mineral nutrition of higher plants. In *A Comprehensive Account of Mineral Nutrition in Plants*, ed. P. Galet, p. 199-267. London: Academic Press.

Mengel, K. and E.A. Kirkby. (1987). Principles of Plant Nutrition, Fourth edition, p. 427-453. *International Potash Institute,* Bern, Switzerland.

Muchow, R.C. and I.M. Wood. (1980). Yield and growth responses of Kenaf (*Hibiscus cannabinus* L.) in a semi-arid tropical environment to irrigation regimes based on leaf water potential. *Irrigation Science* 1: 209-222.

Petrini, C., R. Bazzocchi and P. Montalti. (1994). Yield potential and adaptation of Kenaf (*Hibiscus cannabinus*) in north-central Italy. *Industrial Crops and Products* 3: 11-15.

Schulze, E.D. and F.S. Chapin III. (1987). Plant specialization to environments of different resource availability. In *Plant Resource Allocation*, eds. F.A. Bazzaz and J. Grace, p. 93-107. New York: Academic Press.

Sellers, T., G.D. Miller and M.J. Fuller. (1993). Kenaf core as a board raw material. *Forestry Products Journal* 43: 69-71.

Tanner, C.B. and T.R. Sinclair. (1983). Water use efficiency in plant physiology. In *Limitations to Efficient Water Use in Crop Production*, eds. H.M. Taylor, WR. Jordan and TR. Sinclair, p: 1-27. New York: Academic Press.

Webber, C.L. III. (1993a). Yield components of five Kenaf cultivars. *Agronomic Journal* 85: 533–535.

Webber, C.L. III. (1993b). Crude protein and yield components of six kenaf cultivars as affected by crop maturity. *Industrial Crop Products* 2: 27–31.

Table 1. The summary ANOVA of diameter and height parameters of *Hibiscus cannabinus* L. with regard to the level of fertilizer

Season			Diameter (*D*)		Height (*Ht*)	
		df	Mean Square	F Value	Mean Square	F Value
DRY	Fertilizer	2	3.66	0.95[ns]	146.07	1.23 [ns]
WET	Fertilizer	2	60.52	5.92**	9873.43	9.74***

*Significantly different at P≤ 0.01 and P≤ 0.001

Table 2. The mean values of diameter and height of *Hibiscus cannabinus* L. with regard to the level of fertilizer in the dry and the wet seasons

Parameter	Level of fertilizer		
	Low	Medium	High
		DRY	
D (mm)	10.12 ± 1.02 [a]	9.91 ± 0.96 [a]	8.54 ± 0.59 [a]
Ht (cm)	81.4 ± 5.81 [a]	89.6 ± 5.79 [a]	79.4 ± 2.04 [a]
		WET	
D (mm)	12.62 ± 1.06 [b]	15.77 ± 1.05 [a]	17.46 ± 0.92 [a]
Ht (cm)	178.3 ± 10.57 [b]	217.7 ± 10.43 [a]	240.4 ± 9.14 [a]

Mean values followed by the same letter in the same row do not differ statistically as per Duncan's Multiple Range Test at P≤ 0.05.

Table 3. The summary of ANOVA for leaf number and leaf area parameters of *Hibiscus cannabinus* L. with regard to the rate of fertilizer

Season			Diameter (*D*)		Height (*Ht*)	
		df	Mean Square	F Value	Mean Square	F Value
DRY	Fertilizer	2	966.47	2.16 [ns]	34944.5	0.63 [ns]
WET	Fertilizer	2	4969.3	6.50**	2037083	3.64*

*Significantly different at P≤ 0.05 and P≤ 0.01

Table 4. The mean values of leaf number and leaf area of *Hibiscus cannabinus* L. between the rate of fertilizer in the dry and the wet seasons

Parameter	Level of fertilizer		
	Low	Medium	High
		DRY	
LN	62.6 ± 14.9 [a]	44.0 ± 6.4 [a]	35.4 ± 2.4 [a]
A_L	620 ± 147 [a]	524 ± 88.3 [a]	453 ± 65 [a]
		WET	
LN	47.4 ± 6.5 [b]	84.7 ± 8.0 [a]	87.2 ± 11.1 [a]
A_L	705 ± 124 [b]	1410 ± 253 [a]	1546 ± 298 [a]

Mean values followed by the same letter in the same row do not differ statistically as per Duncan's Multiple Range Test at P≤ 0.05.

Table 5. ANOVA of biomass parameters of *Hibiscus cannabinus* L. between the level of fertilizer in the dry and the wet seasons

Parameter		*DRY*		*WET*	
	df	Mean Square	F Value	Mean Square	F Value
M_{Leaf}	2	2.81	0.65 ns	357.71	5.07*
M_{Stem}	2	10.12	1.23 ns	2946.81	1.31 ns
M_{Root}	2	0.52	0.16 ns	307.47	3.41*
M_{Flower}	2	-	-	195.15	3.18 ns
M_{AG}	2	18.89	0.84 ns	10174.9	2.54 ns
Rt:St	2	0.02	1.92 ns	0.03	1.41 ns

*Significantly different at P≤ 0.05

Table 6. The mean values of biomass parameters of *Hibiscus cannabinus* L. between the level of fertilizer in the dry and the wet seasons

Parameter	Level of fertilizer		
	Low	Medium	High
		DRY	
M_{Leaf}	4.74 ± 1.33 a	3.80 ± 0.77 a	3.26 ± 0.48 a
M_{Stem}	7.09 ± 1.27 a	7.92 ± 1.71 a	5.15 ± 0.64 a
M_{Root}	2.39 ± 0.57 a	2.46 ± 0.48 a	2.98 ± 1.17 a
M_{Flower}	-	-	-
M_{AG}	11.83 ± 2.50 a	11.72 ± 2.47 a	8.41 ± 1.12 a
Rt:St	0.20 ± 0.01 a	0.21 ± 0.03 a	0.32 ± 0.08 a
		WET	
M_{Leaf}	6.37 ± 1.16 b	17.88 ± 3.40 a	14.95 ± 2.87 a
M_{Stem}	50.05 ± 18.47 a	76.62 ± 12.85 a	82.16 ± 13.02 a
M_{Root}	8.74 ± 2.42 b	18.69 ± 3.63 a	17.95 ± 2.83 a
M_{Flower}	2.12 ± 1.46 b	4.26 ± 2.21 a b	10.61 ± 3.38 a
M_{AG}	61.70 ± 22.19 b	107.05 ± 20.83 a b	123.23 ± 16.58 a
Rt:St	0.17 ± 0.01 a	0.20 ± 0.02 a	0.16 ± 0.0.01 a

Mean values followed by the same letter in the same row do not differ statistically as per Duncan's Multiple Range Test at P≤ 0.05.

Table 7. Analysis of variance of gas exchange of *Hibiscus cannabinus* L. between the level of fertilizer in the dry and the wet seasons

Parameter	*DRY*		*WET*	
	Mean Square	F Value	Mean Square	F Value
Anet	273.97	16.92*	9.65	0.39^{ns}
G_S	0.03	0.94^{ns}	0.09	5.57*
E	3.96	2.40^{ns}	9.21	9.22*
WUE	1.68	3.90*	4579.66	7.50*

*Significantly different at P≤ 0.05

Table 8. The mean values of gas exchange of *Hibiscus cannabinus* L. between level of fertilizer in the dry and the wet season s

Parameter	*DRY*			*WET*		
	Low	Medium	High	Low	Medium	High
Anet	11.34^{b}	12.07^{b}	17.07^{a}	13.39^{a}	12.48^{a}	12.35^{a}
G_S	0.27^{a}	0.24^{a}	0.21^{a}	0.27^{b}	0.34^{a}	0.38^{a}
E	2.79^{a}	2.55^{a}	2.03^{a}	2.53^{b}	3.29^{a}	3.60^{a}
WUE	3.93^{b}	4.22^{ab}	4.43^{a}	33.46^{b}	45.49^{a}	33.46^{b}

Mean values followed by the same letter in the same row do not differ statistically as per Duncan's Multiple Range Test at P< 0.05.

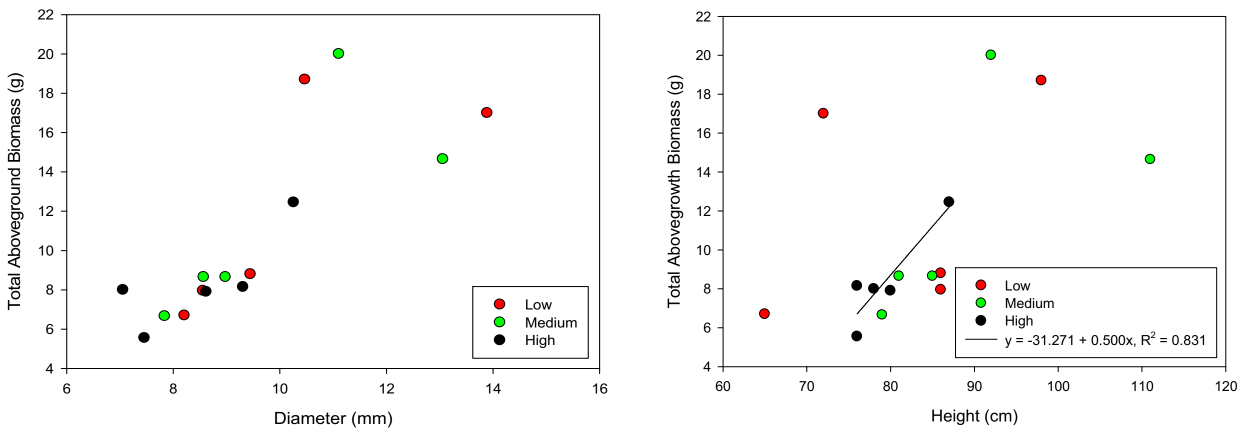

Figure 1. Correlation between total aboveground biomass with diameter and height in the dry season

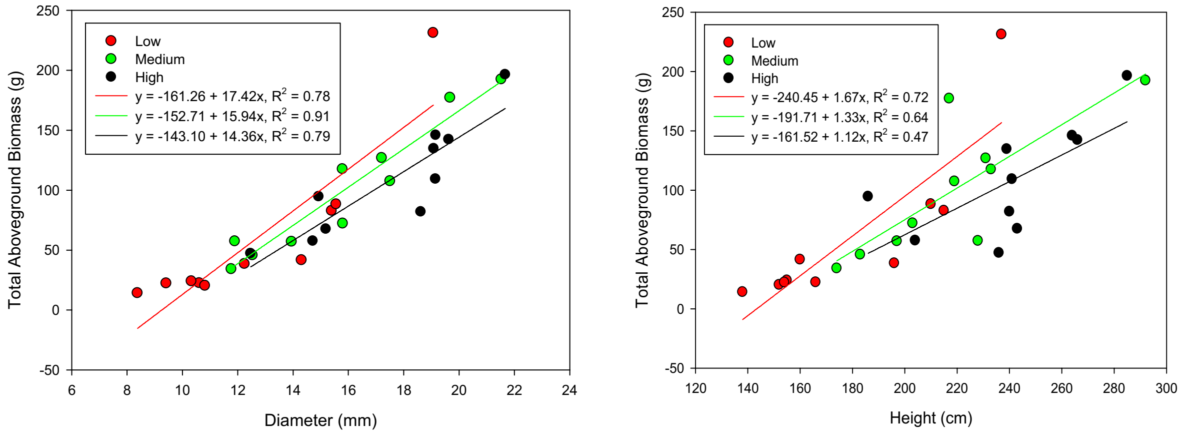

Figure 2. Correlation between total aboveground biomass with diameter and height in the wet season.

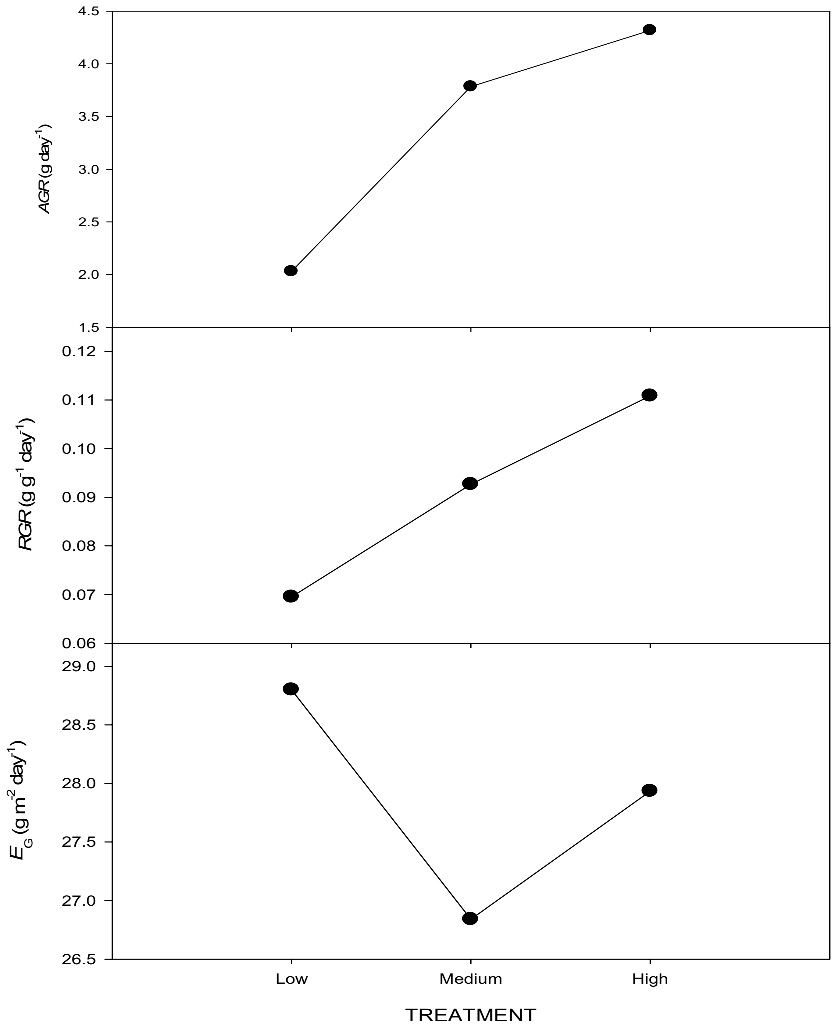

Figure 3. The summary of *AGR*, *RGR* and E_G parameters of *Hibiscus cannabinus* L. at the different levels of fertilizer in the dry and the wet seasons