Asian Journal of Plant Sciences

ISSN 1682-3974

science alert

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Asian Journal of Plant Sciences 7 (4): 352-359, 2008
ISSN 1682-3974

Influence of Adventitious Root Removing and Timing of Fertilizer Application in Flooded Soil on Growth, Yield and N, P, K Uptake of Kenaf (*Hibiscus cannabinus* L.) Under Greenhouse and Field Conditions

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Abstract: A greenhouse experiment was conducted in Department of Plant Science and Agricultural Resources, Faculty of Agriculture, Khon Kaen University in 2005. The objective of this study were to investigate the effects of adventitious root removing and timing of fertilizer application on growth, yield and nutrient uptake of kenaf (*Hibiscus cannabinus* L.). The results showed that removing adventitious roots from the plant significantly reduce in growth, yield and nutrient uptake of kenaf in comparison with no adventitious root removing. Splitting chemical fertilizer application as basal at planting, combined with top dressing at 60 days after planting during adventitious root forming in flooded soil did not show any significant difference in fiber yield in comparison with once application as basal at planting. A field experiment was conducted in Ban Muong village, Muang district in Khon Kaen province in 2005-2006. The objective of this study was to investigate the effects of timing of fertilizer application on growth, yield and nutrient uptake of kenaf (*Hibiscus cannabinus* L.). The results showed that splitting chemical fertilizer application as basal at planting, combined with top dressing at 60 days after planting significant increase in fiber yield as compared to once basal application at planting or once top dressing at 60 days after planting. The new finding indicate that the response of adaptive adventitious roots (water roots) of economic kenaf crops to flooding stress mainly affects nutrient uptake, similar to the aquatic roots of wetland plants.

Key words: Adventitious root, fertilizer application, flooding, kenaf

INTRODUCTION

Kenaf (*Hibiscus cannabinus* L.) is a warm-season annual that, when mature, can produce fiber using for rope, carpet backing and paper. In Thailand, kenaf fiber used mainly for carpet backing. Kenaf is highly effective for wastewater treatment in comparison with other crops (Abe and Ozaki, 1999, 2007). Kenaf is considered to be waterlogging tolerant due to its development of several adventitious roots in water above the soil surface as an adaptive mechanism. It is well documented that growth and yield of kenaf is slightly reduced when subjected to flooding (Pratcharoenwanich, 2002). Adventitious root formations probably have an important function in water and nutrient uptake for the adapting kenaf flood-tolerant plant (Pratcharoenwanich, 2002). These roots formed numerous finely branched lateral similar to aquatic roots of wetland graminoids species which function mainly in nutrient uptake (Lukina and Smirnova, 1988). The anatomical adaptation of the roots is well developed aerenchyma and barrier to radial oxygen loss from aerenchymatous root (Armstrong and Armstrong, 1988). To evaluate this hypothesis, adventitious roots will be artificial removed from the plant in order to comparison with the adventitious roots remaining in the plant for normal growth under greenhouse conditions. The existing cropping pattern of kenaf as a pre-rice crop has been practiced by the farmers of Northeast Thailand for a long time (Polthanee, 2004). In general, plants are subjected to flooding around 60 to 90 days after planting until harvest, depending on rainfall patterns, which vary year by year. The farmers usually apply chemical fertilizer once at planting as basal, to improve crop yield when kenaf is grown before rice in low fertility soil. Maximum nutrient use efficiency, in general, should be achieved with the latest possible application, particular N this would avoid N loss through leaching, denitrification, volatilization and runoff since on active root system ensures uptake of the N fertilizer applied. Adventitious roots normally continue to develop in water above the soil surface (water roots) when the paddy fields start flooding until harvest. There is no information on fertilizer application to flooded soil

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during the various stages of adventitious root development. Splitting applications as basal at planting and top dressing application during adventitious root formation to reduce nutrient loss might be a more appropriate fertilizer management strategy for farmers. Therefore, the objectives of this study were to investigate the effects of adventitious root removing, forming and timing of fertilizer applications in flooded soil on growth, yield and nutrient uptake of kenaf (*Hibiscus cannabinus* L.) under the greenhouse and field conditions.

MATERIALS AND METHODS

A pot experiment was carried out using plastic pots (37.5 cm diameter and 38 cm depth) holding 30 kg of air-dried soil taken from the field experiment site in Ban Muong village, Muang district in Khon Kaen Province in 2006 . The physical and chemical characteristics of the soil used in the pot experiment were as follows: texture, loamy sand (2.5% clay, 12.5% silt and 85% sand); pH 4.65 (1:2.5 w/v water); organic matter content 0.57% (Walkley and Black); total N 0.37% (Kjeldahl method); extractable P 13 ppm (Bray II extraction) and extractable K 34 ppm (1 N ammoniumacetate extraction). Max. and min. temperature values during the growing period were 30.5-37.5°C and 23.9 and 28.4°C, respectively. Similarly, light intensity was recorded between 6.3-19.5 (MJ/m^2/day) during the growing season in the experiment. Temperature and light intensity were recorded at the metrological station, department of Plant Science and Agricultural Resources, Khon Kaen University. The experimental design was a two factor completely randomized design with four replications. Factor (A) is the root management (No Adventitious Root Removing (NARR) and adventitious root (root formed in water) removing (ARR)). Factor (B) is timing of fertilizer applications (156 kg ha^{-1} banded below seeds at planting (BBP), 78 kg ha^{-1} banded BBP combined with 78 kg ha^{-1} Top Dressing (TD) at 60 Days After Planting (DAP), 78 kg ha^{-1} BBP seeds at planting, combined with 78 kg ha^{-1} TD at 90 days DAP). Five seeds were sewn on 24 June 2005 in each pot and thinned to three after emergence. The Khon Kaen 60 cultivar was used in this study. The water content of the soil was maintained at 75% of field capacity gravimetrical, by adding water daily. After 45 days of growth, the plants were subjected to flooding (maintaining water at 5 cm above soil surface) until harvest. Therefore, the adventitious roots were developed in water above the soil surface (Fig. 1), beginning at 45 days after seeding. For root removing treatment, the adventitious roots located in water above the soil surface were cut daily using scissors. After 150 days of growth in the greenhouse, the shoots were harvested and the leaves, stem and adventitious roots above the soil surface were separated and dried at 80°C for three days. After determining dry weight (expressed as g plant^{-1}), the leaves were ground and digest for N analysis (Kjeldahl method), P analysis (Bray No.2 extraction) and K analysis (1 N ammonium acetate extraction). Nutrient uptake was calculated by multiplying dry weight with concentration. The stems were soaked in water for 15 days in a plastic pots and separate fiber from the stem by hand. The fibers were dried at 80°C for 3 days and measure fiber yield. Soil roots were removed from a plastic pots washing with water and dried at 80°C for three days and measure soil root dry weight. Using the same kenaf cultivar Khon Kaen 60 as those used in the pot experiment, a field experiment was conducted in the 2005-2006 cropping season under rainfed conditions at the farmer's field (paddy fields in Khon Kaen province, Thailand). The soil was loamy sand with pH 4.65, organic matter 0.57%, total N 0.37%, extractable P 13 ppm and exchangeable K 34 ppm. The experimental design was a randomized complete block design with four replications. Timing of fertilizer application comprised: (1) Fertilizer grade 15-15-15 (N, P_2O_5, K_2O) at rate of 156 kg ha^{-1} applied banding below seeds at planting (BBP); (2) Fertilizer grade 15-15-15 at rate of 156 kg ha^{-1} applied top dressing at 60 days after planting (TD at 60 DAP); (3) Fertilizer grade 15-15-15 at rate of 78 kg ha^{-1} applied as banding below seeds at planting (BBP), combined with fertilizer grade 15-15-15 at rate of 78 kg ha^{-1} applied top dressing at 60 days after planting (BBP + TD at 60 DAP). The kenaf seeds were sewn on 22 June 2005 with plant spacing of 30 cm by 10 cm and thinned to one after emergence. The plants were harvested 150 days after planting. Weeds were controlled by hand hoeing at 25 days after planting. No pesticides were used during the entire growing season. The total precipitation during the growing period was approximately 885 mm. In this experiment, water table depth at the planting date was about 76 cm below soil surface and increased to 29 cm above the soil surface at harvest. The fields were flooded around 75 days at 5 to 29 cm above soil surface after seeding (data not shown). Ten plants from each plot were randomly selected from outside the harvesting area to measure leaf and stem dry weight and to determine the concentration of N, P and K in the leaf tissues at 90, 120 and 150 DAP. Plant height and girth (15 cm above soil surface) were recorded from ten plants randomly selected from each plot, 150 DAP. At harvest (150 DAP) ten plants from each plot were randomly selected and root samples located in both the soil and in the water above the soil surface (adventitious roots) were taken, to measure root dry weight. Leaf and stem were separated and leaves were ground and digest for N, P and K analyses the same as greenhouse experiment. Soil roots were taken two samples from the area where the main root mass was located using a soil core at 0-45 cm soil depths. Water roots were taken four samples from the area between kenaf rows in each plot using a soil core. Fiber yields (similar as greenhouse) were determined from areas 3×2 m in the harvesting area of each plot. Nutrient uptake (total amount) was calculated by multiplying dry weights with concentrations. The data was subjected to analysis of variance (ANOVA). Least Significant Difference (LSD) was used to compare mean differences (Gomez and Gomez, 1984).

RESULTS

Leaf and stem dry weight under the greenhouse conditions: Leaf and stem dry weight values were significantly affected by adventitious root removing and timing of fertilizer application. Maximum leaf and stem dry weight was obtained in the non-adventitious root removing pot. Fertilizer application in a BBP gave the highest stem dry weight. TD at 60 days after planting produced the maximum leaf dry weight (Table 1). There was a significant interaction effect between root management and the timing of fertilizer application on leaf dry weight. Root-removed pots were less responsive to the timing of fertilizer application compared to rooted pots, on leaf dry weight. On stem dry weight there is no significant interaction effects between root management and the timing of fertilizer application. Under the field conditions: Timing of fertilizer application had no significant effect on leaf dry weight of kenaf at 90 and 120 DAP, but leaf dry weight was significantly affected by timing of fertilizer application at 150 DAP (Table 2). The highest leaf dry weight was obtained when fertilizer applied as banding below kenaf seed, combined with top dressing at 60 DAP. Stem dry weight of kenaf showed significant results from the timing of fertilizer application at 90 DAP, but did not affect the stem dry weight at 120 and 150 DAP (Table 2). The maximum stem dry weight was obtained when fertilizer applied as banding below kenaf seed, combined with top dressing at 60 DAP.

Plant height and girth under the greenhouse conditions: Plant height and girth values were significantly affected by adventitious root removing and timing of fertilizer application. Maximum plant height and girth was obtained in the non-adventitious root removing pot (Table 1). Fertilizer application in a BBP gave the highest plant height and girth. There was a significant interaction effect between root management and the timing of fertilizer

Table 1: Growth and yield components of kenaf as affected by timing of fertilizer application at harvest in the greenhouse

Treatments	Plant height (cm)	Leaf dry# weight ($g\ plant^{-1}$)	Stem dry# weight ($g\ plant^{-1}$)	Girth (cm)	Soil root# dry weight ($g\ plant^{-1}$)	Total root# dry weight ($g\ plant^{-1}$)	Fiber# yield ($g\ plant^{-1}$)
Root management (R)							
NARR (R_1)	204.7	8.9a	22.8a	1.2	4.8	18.9a	8.9a
ARR (R_2)	156.5	5.5b	11.5b	0.9	4.6	4.6b	5.4b
Fertilizer application (F)							
BBP (F_1)	191.7	7.4a	20.5a	1.2	6.0a	15.1a	8.5a
TD at 60 DAP (F_2)	187.3	8.0a	14.0c	1.1	3.4c	8.8c	5.8b
BBP + TD at 60 DAP (F_3)	162.9	6.3b	16.9b	0.9	4.5b	11.6b	7.2a
R×F							
$R_1 \times F_1$	215.1a	8.8b	26.3a	1.4a	5.7	23.9a	10.7a
$R_1 \times F_2$	211.8a	10.4a	19.8b	1.2b	3.2	14.0c	7.1b
$R_1 \times F_3$	187.3b	7.7a	22.2b	1.1c	4.6	18.7b	9.0a
$R_2 \times F_1$	168.3bc	5.9d	14.8c	0.9d	6.3	6.3d	6.3c
$R_2 \times F_2$	162.8c	5.7d	8.3e	0.9d	3.0	3.0e	4.6d
$R_2 \times F_3$	138.5d	5.0d	11.6d	0.9d	4.5	4.5de	5.4cd
Root management (R)	**	**	**	**	NS	**	**
Fertilizer application (F)	**	**	**	**	**	**	**
R×F	*	*	NS	*	NS	**	*

*Significant at $p<0.05$, **: Significant at $p<0.01$, NS: Non significant, #: Mean followed by the same letter at the same column was not statistically significant

Table 2: Leaf and stem dry weight of kenaf grown under field conditions as affected by timing of fertilizer application at 90, 120 and 150 days after planting

Treatments	Leaf dry weight# ($g\ plant^{-1}$)			Stem dry weight# ($g\ plant^{-1}$)		
	90 DAP	120 DAP	150 DAP	90 DAP	120 DAP	150 DAP
BBP	62.9	80.3	34.9b	221.2a	276.2	319.1
TD at 60 DAP	57.1	81.4	46.6a	206.8b	277.1	314.4
BBP + TD at 60 DAP	71.4	93.9	51.4a	222.4a	286.8	321.5
F-test	NS[2/]	NS[2/]	*[1/]	*[1/]	NS[2/]	NS[2/]
CV (%)	13.6	11.3	10.8	3.7	3.1	6.1

*[1/]: Significant at $p<0.05$, NS[2/]: Non significant, #: Mean followed by the same letter at the same column was not statistically significant

Table 3: Plant height, girth, root dry weight and fiber yield of kenaf grown under field conditions as affected by timing of fertilizer application at 150 days after planting

			Root dry weight[#](g plant^{-1})		
Treatments	Plant height (cm)	Girth (cm)	Soil root	Water root	Fiber yield (kg ha^{-1})
BBP	315.0	1.9	21.9	26.4b	874.0b
TD at 60 DAP	316.2	1.9	22.8	34.9a	897.5b
BBP + TD at 60 DAP	319.5	2.0	20.4	29.5ab	998.8a
F-test	NS[2/]	NS[2/]	NS[2/]	*[1/]	*[1/]
CV (%)	2.1	9.8	18.5	10.7	13.1

*[1/]: Significant at p<0.05, NS[2/]: Non significant, [#]: Mean followed by the same letter at the same column was not statistically significant

application on plant height and girth. Root-removed pots were less responsive to the timing of fertilizer application compared to rooted pots, on plant height and girth. Under field condition: Timing of fertilizer application had no significant effects on plant height or girth of kenaf at 150 DAP (Table 3). Fertilizer applied as banding below seeds, combined with top dressing at 60 DAP tended to give the greatest plant height and girth in kenaf.

Soil root and total root dry weight under the greenhouse: Adventitious root removing (roots formed in water) failed to show any significant effect on the dry weight of soil roots (roots living in soil), compared to pots with roots intact (Table 1). Soil root dry weight was significantly affected by the timing of fertilizer application. Maximum soil root dry weight was obtained when fertilizer application was applied as banding below seeds at planting. There was no interaction effect between root management and timing of fertilizer application on soil root dry weight. There was a highly significant difference in the total root dry weight (soil roots + water roots) between adventitious root removed and non-adventitious root removed pots (Table 1). The maximum total root dry weight was obtained in the non-adventitious root removed pot. In this experiment, adventitious root formation in water was about 14.1 g plant^{-1}. Timing of fertilizer application had a highly significant effect on total root dry weight (Table 1). Fertilizer application as banding below seeds gave the highest total root dry weight. There was a highly significant interaction effect between root management and timing of fertilizer application on total root dry weights, indicating that the timing of fertilizer application shows different responses to root management. The root-removed pot showed a greater response to fertilizer application on total root dry weight in comparison with the root-intact pot. Under the field conditions: Soil roots were not significantly affected by the timing of fertilizer application, but timing of fertilizer application had significant effect on water root in kenaf (Table 3). The highest water root dry weight was obtained when fertilizer was applied as top dressings at 60 DAP.

Fiber yield under the greenhouse conditions: Adventitious root removing had highly significant effects in reducing fiber yield in comparison with non-adventitious root removing (Table 1). The maximum fiber yield was obtained from the non-adventitious root removed pot. There were also highly significant differences in the findings from timing of fertilizer application. Fertilizer applied in a band below kenaf seed gave the highest fiber yield, but failed to show significant difference with fertilizer applied as banding below seeds, combined with topdressing at 60 days after planting (Table 1). We saw significantly affected interactions between root management and timing of fertilizer application on fiber yield, indicating that timing of fertilizer application shows different responses to root management on fiber yield. Adventitious root removal displayed a greater response to timing of fertilizer application on fiber yield than non-root removed cases. Under the field conditions: Timing of fertilizer application had significant effects on fiber yield (Table 3). Fertilizer applied as banding below seed and combined with top dressing at 60 DAP gave the highest fiber yield, by increasing 14% over banding below seed at planting (control).

N, P, K uptake by the leaves under the greenhouse conditions: Adventitious root cutting was highly significant in reducing N concentration and total N uptake in leaves as compared with non-adventitious root removal (Table 4). Maximum N concentration was obtained with non-adventitious root removing. Timing of N application was highly significant in affecting N concentration levels and total N uptake in leaves (Table 4). N applied as a band below kenaf seed gave maximum concentration and total uptake levels of N in leaves. There was no interaction effect between root management and timing of N application on concentration of N in leaves. There was significant interaction effect between root management and timing of N application on total uptake levels of N in leaves. The root removed pot showed a greater response to timing of fertilizer application in comparison with non-root-removed pots. P concentration and total P uptake

Table 4: Nutrient concentration and uptake of leaves of kenaf as affected by timing of fertilizer application at 120 days after planting in the greenhouse

	Nutrient concentration# (mg kg^{-1} dry weight)			Nutrient uptake# (g plant^{-1})		
Treatments	N	P	K	N	P	K
Root management (R)						
NARR (R_1)	14.5a	1.16a	19.4a	13.0a	1.04a	17.4a
ARR (R_2)	8.9b	0.57b	7.1b	4.9b	0.31b	3.9b
Fertilizer application (F)						
BBP (F_1)	14.4a	1.13a	14.8a	10.6a	0.83a	10.9a
TD at 60 DAP (F_2)	9.3c	0.65c	11.3c	7.4b	0.52b	9.1b
BBP + TD at 60 DAP (F_3)	11.5b	0.08b	13.7b	7.3b	0.52b	8.6b
R×F						
$R_1 \times F_1$	16.9	1.38a	19.7	14.9a	1.22a	17.5a
$R_1 \times F_2$	12.3	0.99bc	18.3	12.7b	1.03ab	18.9a
$R_1 \times F_3$	14.3	1.12b	20.1	10.0b	0.86b	15.5ab
$R^2 \times F_1$	11.8	0.88c	9.9	6.9c	0.52c	5.9c
$R^2 \times F_2$	6.3	0.31e	4.3	3.5d	0.18d	2.5d
$R_2 \times F_3$	8.7	0.52d	7.1	4.3d	0.26d	3.6cd
Root management (R)	**	**	**	**	**	**
Fertilizer application (F)	**	**	**	**	**	**
R×F	NS	**	NS	*	**	*

*Significant at p<0.05, **Significant at p= 0.01, NS: Non significant, #Mean followed by the same letter at the same column was non statistically significant

Table 5: Nutrient concentration and total uptake in leaves of kenaf grown under field conditions as affected by timing of fertilizer application at 120 days after planting

	Nutrient concentration# (mg kg^{-1} dry weight)			Nutrient uptake# (g plant^{-1})		
Treatments	N	P	K	N	P	K
BBP	16.9b	3.1	12.1	13.6b	2.5	9.7
TD at 60 DAP	17.9b	2.9	12.5	14.6b	2.4	9.8
BBP + TD at 60 DAP	20.8a	3.2	12.9	19.6a	3.0	11.8
F-test	*1/	NS2/	NS2/	*1/	NS2/	NS2/
CV (%)	6.6	7.1	12.1	11.5	10.3	13.6

*1/Significant at p<0.05, NS2/: Non significant, #Mean followed by the same letter at the same column was not statistically significant

levels in leaves were significantly affected by root management (Table 4). Adventitious root removal gave the lowest P concentration and total P uptake in leaves. Timing of P application was highly significant in affecting P concentration and total P uptake in leaves (Table 4). P applied as a band below kenaf seed gave the maximum P concentration and total uptake. There was highly significant interaction effects seen in root management and timing of P application on P concentration and total P uptake in leaves. The root-removed pot showed a greater response to timing of fertilizer application in comparison with non-root-removed pots. Removal of adventitious roots was highly significant in reducing K concentration and total K uptake in leaves (Table 4). The maximum K concentration and total K uptake in leaves was obtained with non-adventitious root removing treatment. Timing of K application was also highly significant for K concentration and total K uptake levels in leaves (Table 4). There was no interaction effect between root management and timing of K application on K concentration, but had affected on and total K uptake in leaves. The adventitious root removed pot showed a greater response to timing of fertilizer application in comparison with non-root-removed pots. Under the field conditions: N concentration and total N uptake in leaves at 120 DAP was considerably influenced by the timing of N application (Table 5). The maximum concentration and total uptake levels of N were obtained when it was applied as banding below seeds at planting, combined with top dressing at 60 DAP. Timing of P and K application had no significant effect on the P and K concentration and total P and K uptake in leaves of kenaf at 120 DAP. The P and K applied as banding below seeds, combined with top dressing at 60 DAP, invariably gave the highest P and K concentration and total uptake levels.

DISCUSSION

In the greenhouse experiment, growth and yield of kenaf was significant reduced when water-located adventitious roots were removed from the plant. This was due to low nutrient uptake (Table 4) and water uptake (data not shown). The kenaf crop grown under flooded soil by removing adventitious roots showed wilting at 125 DAP, while kenaf grown under flooded soil with intact adventitious roots did not shown any wilting symptoms (Fig. 1). This indicates that adventitious root formation in surface water is a significant mechanism in flooding adaptation and functions mainly for nutrient and water uptake. The efficiency of adventitious root removal of N

Fig. 1: Leaves of kenaf at 125 days old flooded with adventitious roots (left) and without adventitious roots (right) shown wilting symptoms

Fig. 2: Adventitious roots of kenaf at 90 days old flooded (left) and 125 days old flooded (right)

and P under flooding kenaf was about 82-92% have been reported by Abe and Ozaki (2007). Kenaf grown under flooding stress gave slightly decreased fiber yield compared to non-flooded control, due to the development of adventitious root in surface water (Pratcharoenwanich, 2002) and form large gas spaces with adventitious roots around the stem base when in water and this is a typical feature of these roots (Koncalova and Pazourek, 1987; Mano and Omori, 2007). Adventitious root formation at the soil surface is one of the most important adaptations to flooding conditions. Many plant species have bean reported e.g., soybean (Bacanamwo and Purcell, 1999), tomato (McNamara and Mitchell, 1990), sugarcane (Uraiwan, 2002), barley (Stanca *et al.*, 2003) and maize (Mano and Omori, 2007). This characteristic allows the root system to obtain oxygen directly from the air because the adventitious roots develop in shallow layer of the soil and even at the water surface. Aerenchyma development in adventitious root is and another important adaptive response of crops to flooding condition. There is a close relationship between enhanced ethylene production and aerenchyma formation in some species (Justin and Armstrong, 1991). The increase in ethylene production promoted by low levels of O_2 is due to increased levels of 1-aminocyclopropane-1-carboxylic acid (ACC), a precursor of ethylene (Bradford and Yang, 1980), resulting form enhanced ACC synthase activity (Wang and Arteca, 1992). Aerenchyma provides a low resistance in the internal pathway for gas exchange between the plant parts above and below the water surface and improves the internal supply of oxygen for submerged tissues (Konings, 1982; Justin and Armstrong, 1987; He *et al.*, 1996). This is similar to several reports on wetland graminoids e.g., Phragmites Australis and Typha Angustifolia. The aquatic roots function mainly in nutrient uptake (Lukina and Smirnova, 1988; Koncalova, 1990). In the present experiments, water root dry weights were 14.1 and 30.3 g plant^{-1} for kenaf grown under greenhouse and field conditions, respectively, while soil root dry weight was 4.8 and 19.7 g plant^{-1} for kenaf grown under greenhouse and field conditions, respectively. The results indicate that water roots have numerous finely branched laterals (Fig. 2), while soil roots are usually thick and poorly branched (data not shown). Splitting and single fertilizer application at planting (control) had no significant effect on fiber yield under greenhouse but did under field conditions. However, fertilizer applied as once banding below kenaf seed at planting at rate of 156 kg ha^{-1} tend to gave higher fiber yield than that of splitting application as banding below seed at planting at rate of 78 kg ha^{-1}, combined with top dressing at 60 DAS at rate of 78 kg ha^{-1} in the greenhouse and vice versa under field conditions. This is probably due to very minor amounts of nutrient loss in the greenhouse, as opposed to heavy nutrient loss under field conditions, especially nitrogen (Table 5). N loss usually occurs from leaching or runoff (Craswell and Godwin, 1984; Lopez-Bellido *et al*., 2006), or volatilization of N loss due to alternate soil wetting and drying where occurred under field conditions. In the field experiment, flooding occurred around 75 DAP. Therefore, the nutrient uptake by top dressing application practiced here is mainly due to adventitious root (water roots) formation. The study indicates that splitting application to improve fiber yield results obtained under field conditions cannot be used for controlled greenhouse cases.

CONCLUSION

Adventitious root formation in water above the soil surface is a significant adaptive mechanism of kenaf to flooding stress. Adventitious roots function mainly in nutrient and water uptake when the plant is subjected to flooding, in order to maintain normal growth and give satisfactory yield. In this study, adventitious root removal from the plant caused a significant reduction in nutrient uptake, growth and fiber yield. Splitting chemical fertilizer application to improve fiber yield results obtained under field conditions cannot be used in a controlled greenhouse environment. This is due to how splitting application minimizes nutrient loss, mainly from leaching. Fertilizer applied once at 60 DAP, as a short time before adventitious root formation, also gives similar fiber yield to that of split application, indicating that the roots adapt to flooding stress and this makes an important contribution to nutrient and water uptake, like the aquatic roots of wetland plants. The results of the experiments suggested that splitting chemical fertilizer application as banding below seeds combined with topdressing at 60 days after planting is recommended to improve fiber yield of kenaf grown as a pre-rice crop.

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