Effect of Waterlogging at Different Growth Stages on Growth and Yield in *Hibiscus cannabinus* (Kenaf), *H. sabdariffa* (Roselle) and *Corchorus olitorius* (Jute)

Thepwadee Changdee[1], Anan Polthanee[1*], Chutipong Akkasaeng[1] and Shigenori Morita[2]

ABSTRACT: The objective of this study was to investigate the effects of waterlogging on growth and yield of fiber crops. A greenhouse experiment was conducted at the Agronomy Farm at Khon Kaen University in 2005. The experiment was a 3 x 5 factorial in a completely randomized design with four replications. The two factors were waterlogging treatments (30 DAS, 60 DAS, 90 DAS and 120 DAS for 30 days, and well-drained as the control) and fiber crop species (*H. cannabinus*, *H. sabdariffa* and *C. olitorius*). The results showed that the waterlogging at different growth stages significantly affects the plant height, stem diameter, leaf area, biomass production and root growth. In addition to waterlogging at 30, 60 and 90 days after sowing decreased fiber yield by 48.8, 31.7 and 13.4% compared to the control, respectively. However, waterlogging at 120 days after sowing did not show any significant difference on fiber yield compared to the control. Fiber crop species significantly affected on plant growth and fiber yield. *H. cannabinus* generally gave the higher plant growth and fiber yield than with *H. sabdariffa* and *C. olitorius*.
Keywords: *Corchorus olitorius*, growth, *Hibiscus cannabinus*, *H. sabdariffa*, waterlogging

Introduction

Hibiscus sabdariffa (roselle), *H. cannabinus* (kenaf), and *Corchorus olitorius* (jute) are important fiber crops widely grown in Asian countries. These crops provide raw materials for pulp and paper production and are important sources of textile fibers for the manufacture of twine, rope, burlap bags, and carpet backing using traditional retting ponds in Africa, Asia, and Latin America (Wilson et al., 1965; Boulanger, 1990; Ogbonnaya et al., 1998). These fiber crops are fast-growing and give high yields of fibers. Kenaf gives the highest fiber yield among these crops and the range of the yields is 5.48 - 5.70 t ha^{-1} (Baldwin et al., 2006). In Thailand, average roselle fiber yields over five locations were in the range of 2.9-3.2 t ha^{-1} depending on plant densities (Sermsri et al., 1987). Jute fiber yield in Thailand was about 1.5 t ha^{-1} while that in Viet Nam was as high as 3.2 t ha^{-1} (FAO, 2009). These crops displayed flooding tolerance to some extent (Changdee et al., 2008) and may be suitable for flooding-prone environments.

Areas under agricultural crops are currently on the decline, while the population is continuously increasing. Therefore, crop intensification on the paddy fields seems to be a significant strategy to increase the land use efficiency. In Northeast Thailand, the paddy areas are suitable for growing field crops before rice transplanting. However, during the periods of crop growth, waterlogging and flooding in the paddy areas frequently occurred (Polthanee, 1989). The extent and duration of waterlogged or flooded condition

[1] Department of Plant Science and Agricultural Resources, Faculty of Agriculture, Khon Kaen University, 40002, Thailand

[2] Field Production Science Center, Graduate School of Agricultural and Life Sciences, The University of Tokyo, Midori-cho, 111 Nishitokyo, Tokyo 188-0002, Japan

* Corresponding author: panan@kku.ac.th

was unpredictable and may be detrimental to most field crops that are not able to adapt to such environment (Yetisir et al., 2006). Growth and development of many crops are susceptible to this stressful environment leading to a reduction in crop growth and yields. The magnitude of yield reduction is determined to some extent by crop growth stages at which the stress occurs and by the intensity and duration of the waterlogging or flooding environment (Orchard and Jessop, 1984; Zhou and Lin, 1995; Umaharan et al., 1997; Davies et al, 2000; Zaidi et al., 2004). Growing crops that exhibit adaptive responses to this stressful condition may be successful in the paddy filed prior to rice transplanting. The objective of this study was to investigate the effects of waterlogging at different growth stages on growth and yield in the three fiber crops.

Materials and methods

A pot experiment was done in greenhouse conditions at the Agronomy Farm at Khon Kaen University located in Khon Kaen Province, Thailand (latitude 16^{0}28$^{/}$N and longitude 102^{0}48$^{/}$E). The soil was sandy loam texture, 5.24 pH (1:2.5 w/v water), 0.58 percent organic matter content (Walkley and Black, 1934), 257 mg kg^{-1} total N (Kjeldahl method, Bremner, 1960), 16 mg kg^{-1} available P (Bray II extraction, Bray and Kurtz, 1945), and 38 mg kg^{-1} exchangeable K (1 N ammoniumacetate pH 7 extraction, Schollerger and Simmon, 1945).

Plastic pots having a diameter of 37.5 cm and a height of 38 cm were filled with 30 kg of air-dried paddy soil. Seeds were sown in February to July 2005. The treatments were combinations of 3 x 5 factorial treatments arranged in completely randomized design with four replications. Factor A was 5 waterlogging treatments imposed for 30 days on 30 days after sowing (DAS), 60 DAS, 90 DAS and 120 DAS for 30 days, and no waterlogging as the control. The level of water was maintained at 10 cm above the soil surface whereas in the non-flooding, soil moisture was maintained at field capacity. Factor B was three tropical fiber crops, *H. cannabinus* (kenaf, cv. KhonKaen 60), *H. sabdariffa* (roselle, Thai kenaf, cv. NonSoong 2) and *C. olitorius* (jute, cv. KhonKaen 1).

Five seeds were sown at the depth of 3 cm in plastic pots and fertilizer (15-15-15 of N-P_2O_5-K_2O) was applied at the rate of 156 kg ha^{-1}. Seedlings were thinned to one plant per pot at the two-leaf stage to obtain uniform seedlings. Weeds were removed from the pots on 30 days after sowing (DAS). No pesticides were used in this study.

They were harvest on day 150 after sowing. Plant height, stem diameter, leaf area and dry weight of leaves, bark, wood, shoot, root and fiber yield were recorded. Plant height was measured from the soil level to the terminal bud of the main stem. Stem diameter was measured at 10 cm from soil level using a Vernier caliper. Leaf area was measured using a leaf area meter (LI-COR 3100, LI-COR, Lincoln, NE). A plant was separated into leaves, bark, and wood. In addition, adventitious roots in the flooded water and roots in the soil were taken for dry weight determination. The bark was soaked in water for 15 days in a plastic container and clean fiber was obtained. Individual components were oven dried at 80^{o}C until constant weights and dry matter of each component was determined.

Parameters such as plant growth and yield in three fiber crops were examined with respect to time of waterlogging. The results for all the parameters were analyzed according to the experimental design using Statistic 8 software (Analytical software, 2003). The treatment means were compared using least significant difference at 0.05 probability level.

Results

Waterlogging effect on plant height

The fiber crop species and time of waterlogging had significant effect on plant height, and the interaction between the two factors was observed. *H. cannabinus* gave the highest plant height, followed by *H. sabdariffa* and *C. olitorius*. Height of fiber crops was progressively reduced with delayed water flooding as compared with the control. The crops subjected to waterlogging at 30, 60, 90 and 120 DAS had a reduction in plant height by 29.6, 25.9, 7.2 and 3.1%, respectively. However, the crops subjected to waterlogging at 120 DAS (late growth stage) did not show any significant reduction in plant height as compared to the control (**Table 1**). The interaction between fiber crop species and time of waterlogging was shown in **Figure 1A**. *H. cannabinus* subjected to waterlogging treatment at 30, 60, 90 and 120 DAS had reduced plant heights by 22.4, 18.6, 4.2 and 2.1%, relative to the control, respectively. The reductions were 26.2, 23.3, 7.7 and 1.2% in *H. sabdariffa*, and 40.7, 36.3, 9.7 and 6.0% in *C. olitorius*. The lowest plant height was observed in *C. olitorius* at 30 DAS (early growth stage). *H. cannabinus* had a higher plant height than *H. sabdariffa* or *C. olitorius* at 120 DAS (late growth stage).

Table 1 Plant height, stem diameter and leaf area as influenced by waterlogging at different growth stages and fiber crops at harvest.

Treatment	Height (cm)	Diameter (cm)	Leaf area (cm^2)
Fiber crop (F)			
H. cannabinus (kenaf)	268.3 a	2.04 a	7735.4 a
H. sabdariffa (roselle)	257.3 a	1.94 a	7149.4 a
C. olitorius (jute)	230.1 b	1.78 b	5184.8 b
Time of waterlogging (T)			
control	290.0 a	2.26 a	9335.3 a
waterlogged 30-60 DAS	204.2 c	1.44 c	3385.0 c
waterlogged 60-90 DAS	215.0 c	1.67 b	4818.3 c
waterlogged 90-120 DAS	269.2 b	2.10 a	7111.7 ab
waterlogged 120-150 DAS	281.1 a	2.13 a	8599.0 a
F-test			
Fiber crop (F)	**	**	**
Time of waterlogging (T)	**	**	**
F x T	**	**	**
CV(%)	7.66	8.14	20.07

1/In a column, means followed by the same letter at the same column were not significantly different according to least significant difference (LSD), **; Significant at $P < 0.01$.

2/DAS; days after sowing.

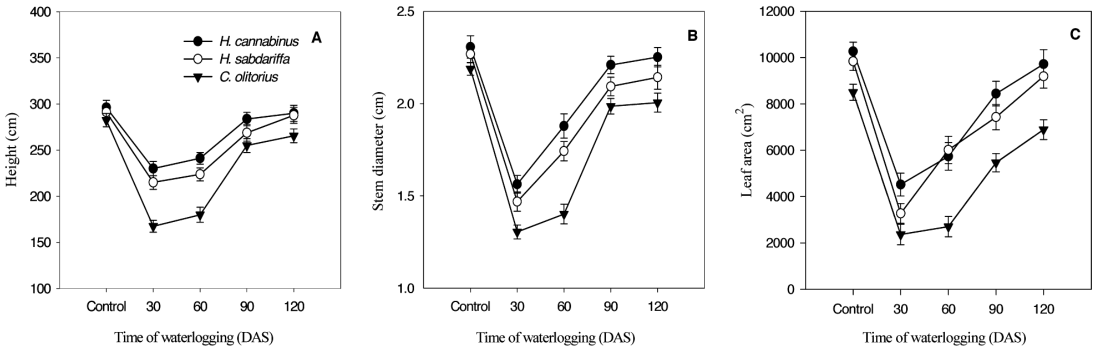

Figure 1 Effect of waterlogging at different growth stages on plant height (A), stem diameter (B) and leaf area (C) of three fiber crops at harvest (*H. cannabinus*, *H. sabdariffa* and *C. olitorius*). Vertical bars on symbols indicate ± standard errors. DAS; days after sowing.

Waterlogging effect on stem diameter

There were significant differences in stem diameter among fiber crop species and waterlogging treatments. There was also interaction between fiber crop species and time of waterlogging. *H. cannabinus* had the highest stem diameter, followed by *H. sabdariffa* and *C. olitorius*. Stem diameter of plants decreased, depending on growth period when the waterlogging is applied. The crops subjected to waterlogging treatment at 30, 60, 90 and 120 DAS had reductions in stem diameter of 33.5, 23.4, 3.7 and 2.3%, respectively, relative to the control treatment. However, the crops subjected to waterlogging at 90 and 120 DAS (late growth stage) did not have any significant difference in stem diameter (**Table 1**). Interaction effect between fiber crop species and time of waterlogging was shown in Figure 1B. *H. cannabinus* subjected to waterlogging treatment at 30, 60, 90 and 120 DAS decreased stem diameter by 30.1, 16.0, 1.2 and 0.6%, respectively, as compared to the control. The reductions in stem diameter were 32.9, 20.4, 4.4 and 2.2% in *H. sabdariffa*, and 38.5, 33.9, 6.3 and 5.4% in *C. olitorius* when waterlogging was imposed at 30, 60, 90 and 120 DAS. Stem diameter was bigger in *H. cannabinus* than in *H. sabdariffa* or *C. olitorius* at 120 DAS.

Waterlogging effect on leaf area

Fiber crop species and time of waterlogging had significantly effect on leaf area, and the interaction between the two factors was observed. *H. cannabinus* had largest leaf area, followed by *H. sabdariffa* and *C. olitorius* (**Table 1**). Leaf area of crops subjected to waterlogging at 30, 60, 90 and 120 DAS decreased by 63.7, 48.4, 23.8 and 7.9 %, respectively, as compared to the control (**Table 1**). Interaction between fiber crop species and waterlogging durations was shown in Figure 1C. *H. cannabinus* subjected to waterlogging treatments at 30, 60, 90 and 120 DAS had a reduction in leaf area by 56.0, 44.1, 17.8 and 3.6%, respectively, as compared to the control. Similarly, the reductions in leaf area were 65.7, 37.0, 22.1 and 5.4% in *H. sabdariffa*, and 71.2, 67.0, 33.4 and 16.0% in *C. olitorius*.

Waterlogging effect on aboveground biomass

There was a significant effect of time of waterlogging on production of above ground biomass of fiber crop species the interaction between the two factors was observed (**Table 2**). *H. cannabinus* produced the highest value aboveground biomass, followed by *H. sabdariffa* and *C. olitorius*. The effect of waterlogging on above ground biomass was dependent on growth stage. The crops subjected to waterlogging at 30, 60, 90 and 120 DAS had a reduction in wood dry weight by 70.6, 52.5, 28.3 and 5.0%, respectively as compared to the control. Similarly, there were reductions in bark dry weight by 67.7, 54.5, 32.9 and 5.2%, respectively. In addition, the crops subjected to time of waterlogging at 30, 60, 90 and 120 DAS reduced leaf dry weight by 65.4, 50.7, 5.7 and 8.5%, respectively as compared to the control. However, the crops subjected to waterlogging at 120 DAS (late growth stage) did not show any significant reduction in aboveground biomass (**Table 2**). An interaction effect between fiber crop species and time of waterlogging was shown in Table 3. Wood, bark, and stalk dry weight of *H. cannabinus* were higher than those of *H. sabdariffa* and *C. olitorius* under waterlogging. In addition, the leaf dry matter of *H. sabdariffa* reduced less than those of *H. cannabinus* and *C. olitorius* compared to the control (**Table 3**). The patterns of growth in bark, wood, stalk, and overall plant production were similar. Waterlogging treatments at 30 and 60 DAS (early and mid growth stages) showed most significant decreases in bark wood and shoot dry weight compared to the control; however, at 120 DAS (late growth stage), those undergoing waterlog treatments were similar to the control.

Table 2 Dry mater of leaf, wood core, bark and shoot dry weight as influenced by waterlogging at different growth stages and fiber crops at harvest.

Treatment	Leaf dry wt. (g)	Wood dry wt. (g)	Bark dry wt. (g)	Shoot dry wt. (g)
Fiber crop (F)				
H. cannabinus (kenaf)	14.00 a	92.11 a	31.39 a	121.10 a
H. sabdariffa (roselle)	13.26 a	84.99 b	26.21 b	111.00 b
C. olitorius (jute)	10.51 b	66.76 c	20.37 c	87.13 c
Time of waterlogging (T)				
control	17.30 a	117.23 a	38.25 a	155.48 a
waterlogged 30-60 DAS	5.98 c	34.49 d	12.35 d	45.18 d
waterlogged 60-90 DAS	8.53 b	59.33 c	17.42 c	77.75 c
waterlogged 90-120 DAS	15.31 a	84.05 b	25.65 b	107.37 b
waterlogged 120-150 DAS	15.83 a	111.32 a	36.28 a	147.60 a
F-test				
Fiber crop(F)	*	**	**	**
Time of waterlogging (T)	**	**	**	**
F x T	**	**	**	**
CV(%)	19.92	10.24	10.91	13.87

1/ In a column, means followed by the same letter at the same column were not significantly different according to least significant difference (LSD), * ; Significant at $P < 0.05$, **; Significant at $P < 0.01$.

2/ DAS; days after sowing.

Table 3 Interaction effects of fiber crop species x time of waterlogging on leaf, wood bark and stalk dry weight.

Fiber crop x Time of waterlogging

Fiber crop	Time of waterlogging	Leaf dry wt. (g)		Wood dry wt. (g)		Bark dry wt. (g)		Stalk dry wt. (g)	
H. cannabinus	control (well-drained)	19.83	a	121.80	a	40.55	a	162.35	a
	waterlogged 30 DAS	7.98	ef	47.05	d	18.30	d	60.35	f
	waterlogged 60 DAS	10.13	de	82.72	c	27.53	c	110.25	cd
	waterlogged 90 DAS	15.36	bc	91.58	bc	31.48	b	116.06	c
	waterlogged 120 DAS	17.15	ab	117.42	ab	39.08	ab	156.50	a
H. sabdariffa	control (well-drained)	17.43	ab	115.88	ab	38.58	ab	154.46	a
	waterlogged 30 DAS	5.78	f	39.25	de	13.03	d	52.28	f
	waterlogged 60 DAS	9.68	de	73.30	c	17.40	d	89.70	e
	waterlogged 90 DAS	17.18	ab	84.68	c	24.85	c	109.53	cd
	waterlogged 120 DAS	16.23	b	111.82	ab	37.20	ab	149.02	ab
C. olitorius	control (well-drained)	14.65	bc	114.00	ab	35.63	b	149.63	ab
	waterlogged 30 DAS	4.18	f	17.18	f	5.73	e	22.91	g
	waterlogged 60 DAS	5.78	f	21.98	ef	7.33	e	33.31	g
	waterlogged 90 DAS	13.85	bc	75.90	c	20.63	c	96.53	de
	waterlogged 120 DAS	14.10	bc	104.73	b	32.55	b	137.28	b

[1/]Means followed by the same letter at the same column were not significantly different according to least significant difference (LSD).

[2/]DAS; days after sowing.

Waterlogging effect on root growth

There were significant effects of crop species and time of waterlogging on root growth and the interaction between the two factors was observed (**Table 4**). Root dry weights of the crops subjected to waterlogging at 30, 60, 90 and 120 DAS decreased by 36.8, 25.7, 12.6 and 10.6%, respectively, as compared to the control. Root dry weights of plants at 30, 60 and 90 DAS waterlogging treatments were significantly lower than those of the control; however, at 120 DAS waterlogging there was no significant difference in root dry weight of the crops subjected to waterlogging at 120 DAS and the non-waterlogging plants. Dry weight of adventitious roots under waterlogging at 30 DAS was not different from that at 60 DAS. However, dry weights of adventitious roots under waterlogging at 30 and 60 DAS were significantly lower than those at 90 and 120 DAS. The interaction between fiber crop species and time of waterlogging on root growth was shown in Figure 2. *H. cannabinus* had the higher root in soil and adventitious root dry matter than *H. sabdariffa* and *C. olitorius* under waterlogged condition. There was no adventitious root development in the non-waterlogged control.

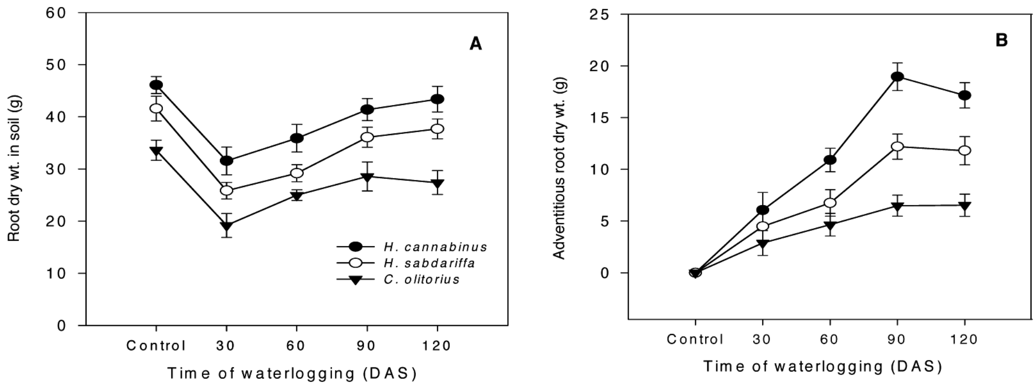

Figure 2 Effect of waterlogging at different growth stages on root in soil and adventitious roots dry weight of three fiber crops (*H. cannabinus*, *H. sabdariffa* and *C. olitorius*) at harvest. Vertical bars on symbols indicate ± standard errors. DAS; days after sowing.

Table 4 Root dry mater, fiber yield and bark thickness as influenced by waterlogging at different growth stages and fiber crops at harvest.

Treatment	Belowground root dry wt. (g)	Adventiotious root dry wt. (g)	Bark thickness (cm)	Fiber yield (g)
Fiber crop (F)				
H. cannabinus (kenaf)	39.65 a	10.61 a	0.30 a	17.41 a
H. sabdariffa (roselle)	34.07 b	7.05 b	0.29 a	15.43 b
C. olitorius (jute)	26.73 c	4.11 c	0.25 b	12.45 c
Time of waterlogging (T)				
control	40.41 a	0.00 d	0.33 a	18.70 a
waterlogged 30-60 DAS	25.52 d	4.47 c	0.25 c	9.56 d
waterlogged 60-90 DAS	30.01 c	7.43 b	0.25 c	12.80 c
waterlogged 90-120 DAS	35.33 b	12.54 a	0.29 b	16.28 b
waterlogged 120-150 DAS	36.14 b	11.83 a	0.30 ab	18.16 a
F-test				
Fiber crop(F)	**	**	**	**
Time of waterlogging (T)	**	**	**	**
F x T	**	**	**	*
CV(%)	20.42	24.64	7.79	8.06

[1/]In a column, means followed by the same letter at the same column were not significantly different according to least significant difference (LSD), * ; Significant at $P < 0.05$, **; Significant at $P < 0.01$.

[2/]DAS; days after sowing.

Table 5 Interaction effects of fiber crop species x time of waterlogging on bark thickness and fiber yield.

Time of waterlogging	Bark Thickness (cm)			
	H. cannabinus (kenaf)	*H. sabdariffa* (roselle)	*C. olitorius* (jute)	Mean
control (well-drained)	0.35 a	0.34 ab	0.29 cd	0.33
waterlogged 30 DAS	0.26 ef	0.28 de	0.20 g	0.25
waterlogged 60 DAS	0.28 d	0.26 ef	0.21 g	0.25
waterlogged 90 DAS	0.30 cd	0.29 cd	0.27 de	0.29
waterlogged 120 DAS	0.32 bc	0.30 cd	0.28 d	0.30
Mean	0.30	0.29	0.25	

Time of waterlogging	Fiber yield (g)			
	H. cannabinus (kenaf)	*H. sabdariffa* (roselle)	*C. olitorius* (jute)	Mean
control (well-drained)	20.27 a	18.40 b	17.42 b	18.70
waterlogged 30 DAS	11.65 e	10.83 e	6.20 g	9.56
waterlogged 60 DAS	15.50 c	13.80 d	9.09 f	12.80
waterlogged 90 DAS	19.62 a	16.30 c	12.93 d	16.28
waterlogged 120 DAS	20.03 a	17.82 b	16.63 c	18.16
Mean	17.41	15.43	12.45	

1/ Means followed by the common letter in the row and column were not significantly different according to least significant difference (LSD).
2/ DAS = days after sowing.

Waterlogging effect on bark thickness

Both fiber crop species and times of waterlogging significantly affected bark thickness and the interaction between the two factors was observed. *H. cannabinus* had the greatest bark thickness, followed by *H. sabdariffa* and *C. olitorius*, respectively (**Table 4**). When crops subjected to waterlogging at 30, 60, 90 and 120 DAS, bark thickness decreased by 24.2, 24.2, 12.1 and 9.1 %, respectively, as compared to the control (**Table 4**). Interaction effect between fiber crop species and times of waterlogging was shown in **Table 5**. Waterlogging at 120 DAS, *H. cannabinus* had a greater bark thickness than the other two species.

Waterlogging effect on fiber yield

Fiber crop species and times of waterlogging significantly affected on fiber yield, and the interaction between the two factors was observed (**Table 4**). *H. cannabinus* gave the highest fiber yield, followed by *H. sabdariffa* and *C. olitorius*. The crops subjected to waterlogging at 30, 60, 90 and 120 DAS had a reduction in fiber yield by 48.8, 31.7, 13.4 and 2.0%, respectively, as compared to the control. The effect of waterlogging on fiber yield reduction at 120 DAS (late growth stage) was minimal. There were no significant differences in fiber yields among times of waterlogging and non-waterlogging. However, the three fiber crops subjected to waterlogging at 30 DAS (early growth stage) produced significantly lower fiber yield than the control. The interaction between fiber crop species and waterlogging durations was shown in Table 5. *H. cannabinus* produced higher (20.03g) fiber yield than the other fiber crops when waterlogged at 120 DAS. There was a lower reduction in fiber yield of *H. cannabinus* than those of *H. sabdariffa* and *C. olitorius* under waterlogging condition. In this experiment, fiber yield of *H. cannabinus* under waterlogging in the early and mid growth stages were significantly decreased to 42.4% and 23.6%, respectively, as compared to the control.

Discussion

Waterlogging can cause considerable damage to the growth and yield of field crops (Malik et al., 2002; Lee et al., 2003). In Northeast Thailand, farmers have been growing fiber crop before rice season. Drainage in most rainfed paddy field is poor, however, partly because of terrain condition, intermittent shallow flooding will often damage severely growth and yield of such pre-rice crops. The data from this study indicated that crops subjected to waterlogging at 30 DAS (early growth stage) and 60 DAS (mid growth stage) had reduced plant height, stem diameter and leaf area. The primary stress factor induced by waterlogging is reduction in soil oxygen availability. Oxygen deficiency periods can trigger functional and developmental responses that promote acclimation to hypoxic or anoxic conditions. Low oxygen concentrations lead to long-term morphological adaptations (Geigenberger, 200 3). Growth and development of the vast majority of vascular plants are impeded by waterlogging, which might result in death (Jackson and Colmer, 2005). In other crops, plant height was reduced in response to flooding by 25-37% in soybean (Githiri et al., 2006). Similar reduction in plant height due to flooding has been reported for wheat (Collaku and Harrison, 2002). Plant height and basal diameter of stem are important traits for fiber species. There was a good linear relationship between plant height and fiber yield (Figure 3A). In addition, stem diameter at harvest was positively correlated with the fiber yield (Figure 3B). The growth stage at which waterlogging occurred was very critical in determining growth and yield of crops. Soybeans were susceptible to flooding stress at early vegetative and early reproductive stages (Linkemer et al., 1998). In this study stem diameter, plant height, stem dry weight and leaf area decreased under waterlogging at early and mid growth stages. However, *H. cannabinus* under waterlogging at late growth stage did not display significantly reduction in growth and yield as compared to the control.

Waterlogging just before harvest did not affect yield in sweet potatoes, but the yield was reduced by waterlogging at midseason (Robert and Russo, 1991). The yield under waterlogging was reduced by 3.9-88.6% in wheat (Olgun et al., 2008). Under waterlogging at early growth stage, *C. olitorius* had a smaller reduction in fiber yield than *H. cannabinus* and *H. sabdariffa*. This was due to a small decrease in plant height, stem diameter, leaf area, above-ground biomass and bark thickness. Results from this study indicated that the three fiber crops can survive under waterlogged conditions at different times or growth stages. *H. cannabinus* had a greater ability to survive under waterlogged conditions than the other two species. Such differences in tolerance for waterlogging were also shown in wheat (Burgos et al., 2001) and fiber yield from flooding in the early season was significantly decreased to 13% of the non-flooded in kenaf (Polthanee et al., 2008).

Additionally, adventitious root formation is one of the important adaptive responses of wetland plant for replacing the existing roots that were killed or functionally suppressed under flooding conditions (Vartapetian and Jackson, 1997; Pezeshki, 2001). Production of numerous adventitious roots may be a means of increasing tolerance to excess moisture in fiber crops and, therefore, vegetative growth could be maintained and higher fiber yields could be obtained under waterlogging conditions. In response to soil waterlogging, dry weight of adventitious roots increased depending on the times of waterlogging. These adventitious roots usually emerged from the flooded stem base and elongated in the water where there was relatively high availability of oxygen. These adventitious roots may play a positive role in supplying oxygen for the activities of underground roots under prolonged flooding.

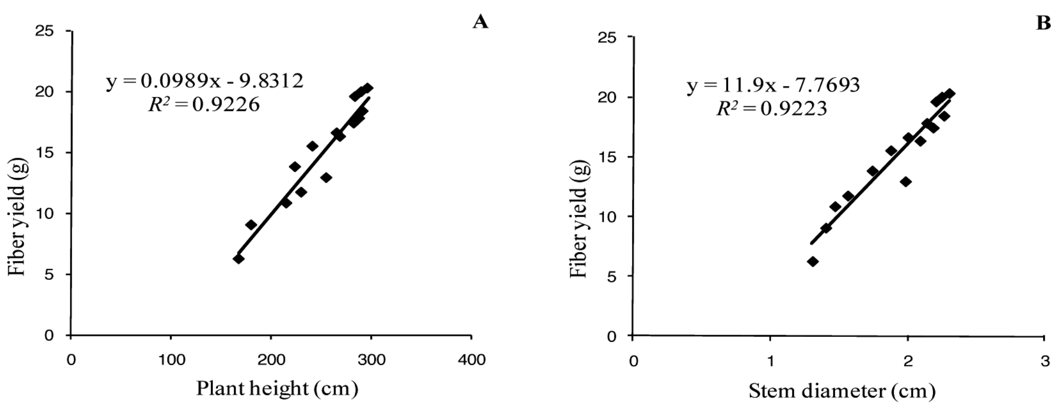

Figure 3 Relationships between fiber yield and plant height; fiber yield and stem diameter at harvest of three fiber crop species.

Acknowledgements

This research was funded by the Royal Golden Jubilee Ph.D. Program (Grant No. PHD/0132/2546). Technical Assistance was also provided by Department of Plant Science and Agricultural Resources, Faculty of Agriculture, Khon Kaen University.

References

Analytical Software. 2003. User's Manual. Analytical Software: Tallahassee, FL, USA.

Baldwin, B.S., J.E. Hollowell, J.W. Mosley and R.D. Cossar. 2006. Registration of 'Whitten' Kenaf. Crop Sci 46: 988-989.

Boulanger, J. 1990. Les Hibiscus textile en Arique Tropicale, 2eme partie: production de la textile du kenaf et de la roselle. IRCT-CIRAD. France.

Bray, R.H. and L. T. Kurtz. 1945. Determination of total organic and available form of phosphorus in soil. Soil Sci. 59: 39-45.

Bremner, J.M. 1960. Determination of nitrogen in soil by the Kjeldahl method. The J. Agri. Sci. 55: 1-23.

Burgos, M., M. Menssmer, P. Stamp and J. Schmid. 2001. Flooding tolerance of spelt (*Triticum spelta* L.) compared to wheat (*Triticum aestivum* L.)-A physiological and genetic approach. Euphytica. 122: 287-295.

Collaku, A. and S.A. Harrison. 2002. Losses in wheat due to waterlogging. Crop Sci. 42: 444-450.

Davies, C.L., D.W. Turner and M. Dracup. 2000. Yellow lupin (*Lupinnus luteus*) tolerates waterlogging better than narrow-leafed lupin (*L. angustifolius*). II. Shoot and root growth in a controlled environment. Aust. J. Agric. Res. 51: 701-709.

FAO. 2009. Selected indicators of food and agricultural development in the Asian- Pacific region 1998-2008. October 2009. FAO of the United Nations regional office for Asia and the Pacific, Bangkok.

Geigenberger, P. 2003. Response of plant metabolism to too little oxygen. Curr. Opin. in Plant Biol. 6: 247-256.

Githiri, S. M., S. Watanabe, K. Harada and R. Takahashi. 2006. QTL analysis of flooding tolerance in soybean at an early vegetative growth stage. Plant Breeding. 125: 613-618.

Jackson M.B. and T.D. Colmer. 2005. Response and adaptation by plants to stress. Ann. Bot. 96: 501-505.

Lee, K.H., S.W. Park and Y.W. Kwon. 2003. Enforced early development of adventitious roots increases flooding tolerance in soybean. Japan J. Crop Sci. 72: 82-88.

Linkemer, G., J.E. Board and M.E. Musgrave. 1998. Waterlogging effects on growth and yield components in late-planted soybean. Crop Sci. 38: 1576-1584.

Malik, A.I., T.D. Colmer, H. Lamber, T.I. Settler and M. Schortmeyer. 2002. Short-term waterlogging has long-term effects on the growth and physiology of wheat. New Phytol. 153: 225-236.

Ogbonnaya, C.I., M.C. Nwalozie, H. Roy-Macauley and D.J.M. Annerose. 1998. Growth and water relations of Kenaf (*Hibiscus cannabinus* L.) under water deficit on a sandy soil. Ind. Crops and Prod. 8: 65-76.

Olgun, M., M.A. Kumlay, C.M. Adiguzel and A. Caglar. 2008. The effect of waterlogging in wheat (*T. aestivum* L.). Acta Agriculturae Scandinavica Section B – Soil and Plant Science. 58: 193-198.

Orchard, P.W. and R.S. Jessop. 1984. The response of sorghum and sunflower to short-term waterlogging. I. Effects of stage of development and duration of waterlogging on growth and yield. Plant Soil. 81: 119-132.

Pezeshki, S.R. 2001. Wetland plant response to soil flooding. Environ. Exp. Bot. 46: 299-312.

Polthanee, A. 1989. Field-level drainage requirement of pre-rice mungbean crop in a waterlogged prone environment. Ph.D. thesis, Graduate School University of the Philippines Los Banos Philippines.

Polthanee, A., T. Changdee, J. Abe and S. Morita. 2008. Effects of flooding on Growth, yield and aerenchyma development in adventitious roots in four cultivars of kenaf (*Hibiscus cannabinus* L.). Asian J. Plant Sci. 7: 544-550.

Robert, W. and V. Russo. 1991. Time of flooding and cultivar affect sweet potato yield. HortScience. 26: 1473-1481.

Schollerger, C.J. and R.H. Simmon. 1945. Determinate of exchange capacity and exchangeable bases in soil-ammonium acetate method. Soil Sci. 59: 39-45.

Sermsri, N., C. Pecharaburanin and Y. Murata. 1987. Studies on roselle (*Hibiscus saffdarifa* var *ultissima* L.) cultivation in Thailand. Japan. J. Crop Sci. 56: 210-214.

Umaharan, P., R.P. Ariyanayagum and S.Q. Haque. 1997. Effect of short-term waterlogging applied at various growth phases on growth, development and yield in *Vigna unguiculata*. J. Agri. Sci. (Cambridge) 128: 189-198.

Vartapetian, B.B. and M.B. Jackson. 1997. Plant adaptation to anaerobic stress. Ann. Bot. 79: 3-20.

Walkley, A. and I. A. Black. 1934. An examination of dichromate method for determining soil organic matter and proposed modification of the chromic acid titration method. Soil Sci. 37: 29-38.

Wilson, F.D., T.E. Summers, J.F. Joyner, D.W. Fishler and C.C. Seale. 1965. Everglade 41 and Everglade 71, Two New Varieties of Kenaf (*Hibiscus cannabinus* L.) for the Fibre and Seed. Florida Agriculture Experiment, Station Cir. S-168.

Yetisir, H., E.M. Caliskan, S. Soylu and M. Sakar. 2006. Some physiological and growth responses of watermelon [*Citrullus lanatus* (Thunb.) Matsum. and Nakai] grafted on *Lagenaria siceraria* to flooding. Environ. Exp. Bot. 58: 1-8.

Zaidi, P.H., S. Rafique, P.K. Rai, N.N. Singh and G. Srinivasan. 2004. Tolerance to excess moisture in maize (*Zea mays* L.): susceptible crop growth stage and identification of tolerant genotypes. Field Crops Res. 90: 189-202.

Zhou, W. and X. Lin. 1995. Effect of waterlogging at different growth stages on physiological characteristic and seed yield of winter rape (*Brassica napus* L.). Field Crops Res. 44: 103-110.