Chapter 6

Effects of Planting Dates, Night Break Treatments and Fertilizer Application Rates on Physiological Responses of *Curcuma alismatifolia* Gagnep.

6.1 Introduction

The growth and flowering of *C. alismatifolia* Gagnep., are affected by planting dates, photoperiod and fertilizers. In a study by Ruamrungsri *et al.* (2007), it was found that the growth of plants was different when they were grown under different planting dates (August 9, September 9, October 9 and November 9), and it was recommended that plant required night break treatments to promote flowering and maintain flower quality when planting in September to November.

C. alismatifolia is a quantitative long day plant, as long day photoperiod promotes flowering and quality of spike, while short day delays flowering (Hagiladi *et al*., 1997). Changjeraja (2009) reported that the long photoperiod at 14 hours delayed storage roots formation of this plant. On the other hand, the short day at 6 and 10 hours stimulated early storage roots formation. Chidburee *et al.* (2008) found that under low light intensity, plant height of *C. alismatifolia* grown under 13 hours photoperiod was taller than those of 10 and 7 hours. Day length at 7 hours decreased number of plants per cluster, number of new rhizomes per plant and number of storage roots per rhizome. Furthermore, flower abortion occurred under 7 and 10 hours of day length conditions. Planting in controlled room increased plant chlorophyll fluorescence at 3 and 5 weeks

after planting when compared with control treatment. In addition, day length at 7 hours decreased the concentrations of total chlorophyll, chlorophyll a, chlorophyll b, reducing sugars and potassium in rhizome. The concentrations of total nonstructural carbohydrates, reducing sugars, phosphorus and potassium in storage roots of the plant were also reduced under such condition (Chidburee *et al.,* 2008).

In an experiment on fertilizers application, Ohtake *et al.* (2006) found that the increase of nitrogen application at 50 mg L^{-1} could increase the number of flowering shoots and consequently the number of rhizomes. Ruamrungsri and Apavatjrut (2003) suggested that N played an important role on the growth and quality of curcuma rhizomes and flowers.

However, those above experiments were focused on individual factors independently. How the combination of these factors affect this plant was not clear. Therefore, the experiment was conducted in order to understand this aspect and the result would be useful information as to regulate the all year round production and should be beneficial for growers to control the yield for this plant.

6.2 Materials and methods

6.2.1 Plant materials

Rhizomes of *C. alismatifolia* cv. Chiang Mai Pink, with the diameter of 1.5-2.0 cm and each with 4 storage roots, were soaked in water for 3 days to stimulate sprouting by replacing water every day. Plants were grown in black plastic pots containing a mixture of sand: rice husk: rice hull: soil at ratio 1:1:1:1 (by volume) as growing media. After new shoot and roots emerged to about 1 inch, plants were subjected to experimental treatments with three factors. The first factor was the two times of planting dates,

i.e. 15 May 2008 (regular season: RS) and 15 November 2008 (off- season: OS). The second factor was the two night break treatments, i.e., 0 and 2 hrs at 08.00-10.00 pm, using 100 watts of incandescent lamp as the supplement light source. The third factor was the three levels of fertilizers application, i.e., 1) following Good Agricultural Practice (GAP) recommendation rate, 2) using half of GAP recommendation rate, and 3) no fertilizer application. The GAP recommendation on fertilizer application in *C. alismatifolia* was to apply 16N-16P-16K at the first pair of leaves fully expanded and at flowering stage and new rhizome developed, it should be applied with 13N-13P-21K fertilizer grade at 10 g pot^{-1} monthly until harvest (Department of Agriculture, 2006). These factorial treatments were: T1) RS/ 0 hr/ 0 GAP, T2) RS/ 2 hr/ 0 GAP, T3) RS/ 0 hr/ 1/2 GAP, T4) RS/ 2 hr/ 1/2GAP, T5) RS/ 0 hr/ 1 GAP, T6) RS/ 2 hr/ 1GAP, T7 OS/ 0 hr/ 0 GAP, T8 OS/ 2 hr/ 0 GAP, T9 OS/ 0 hr/ 1/2 GAP, T10 OS/ 2 hr/ 1/2 GAP,T11 OS/ 0 hr/ 1GAP and T12 OS/ 2hr/ 1GAP.

6.2.2 Data collection

6.2.2.1 The growth and development of plant, in terms of, plant height (cm), number of leaves per plant, number of plants per cluster and leaf area, were measured at 2-week interval. Flower quality attributes and leaf color (using chlorophyll meter Spad-502; Minolta CO., LTD) were determined at flowering stage (14 weeks after planting). Dry weight of plant was measured at 7 growth stages, i.e. the 1st fully expanded leaf (L1), the 2nd fully expanded leaf (L2), the 3rd fully expanded leaf (L3), the 4th fully expanded leaf (L4), flowering (F), flower senescence (Fs) and harvest (H) (Fig. 6.1). The number of new rhizomes per cluster, diameter of new rhizome, weight of new rhizome, number of storage roots per rhizome, size of storage root (length and diameter) and weight of storage roots were recorded at harvest. The experiment was

conducted at Lampang Agricultural Research and Training Center, Rajamangala University of technology Lanna, Thailand.

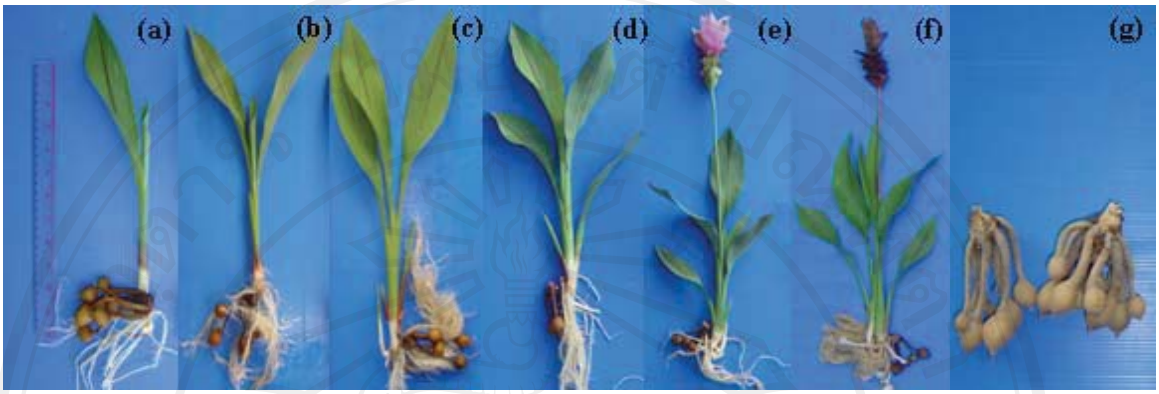

Figure 6.1 The seven growth stages of *C. alismatifolia* Gagnep.; (a) the 1st fully expanded leaf, (b) the 2nd fully expanded leaf, (c) the 3 rd fully expanded leaf, (d) the 4th fully expanded leaf, (e) flowering, (f) flower senescence and (g) harvest.

6.2.2.2 Measurement of photosynthetic efficiency variables were determined at flowering stage (F) as explained in detail in Chapter 4, at 10.00 am - 12.00 pm.

6.2.2.3 Measurement of chlorophyll fluorescence variables were followed at flowering stage (F) as explained in detail in Chapter 4, at 10.00 am - 12.00 pm.

6.2.2.4 Total nonstructural carbohydrates in leaves, rhizome, new rhizome, storage roots and spike were analyzed by the method of Smith *et al.* (1964) method.

6.2.2.5 Total nitrogen concentration in leaves, rhizome, new rhizome, storage roots and spike were analyzed by the modified method of Ohyama *et al.* (1985, 1986).

6.2.2.6 Phosphorus concentration in leaves, rhizome, new rhizome, storage roots and spike were analyzed by the modified method of Ohyama *et al.* (1991).

6.2.2.7 Potassium and calcium in leaves, rhizome, new rhizome, storage roots and spike were analyzed by Atomic Adsorption Spectrometers (Mizukoshi *et al*., 1994).

6.2.2.8 Statistical analysis

The experimental design used was a Factorial in CRD with 2 x 2 x 3 factorial treatments, and there were five replications per treatments. The statistical analysis was performed by using the Statistix program for windows. The LSD was employed to interpret significant difference of the means (<0.05).

6.3 Results

6.3.1 Plant height

The height was measured from the base of the pseudostem to the top of leaf tip when assembling all leaves together. The height was recorded at every growth period; from the first fully expanded leaf to the first flower blooms (represented as L1, L2, L3, L4 and F growth stages). The result showed that the average height of *C. alismatifolia* increased rapidly from L1 to L4 growth stages and then increased gradually until the F growth stage.

Main effects

The results showed that planting date at May, 15 (RS) gave significantly greater in plant height than that of the OS in all stages of growth (L1-F). Plant height reached a maximum of 35.3 cm in RS at flowering stage, while it attained only 24.0 cm in OS at the respective stage (Table 6.1).

Given night break for 2 hours significantly increased plant height from L2 to F growth stages (Table 6.1).

Surprisingly, fertilizer application at GAP recommendation rate and ½ GAP rate did not affect plant height when compared with control treatment (Table 6.1).

Interaction among factors

The interaction among the three factors was determined at every growth stages (Appendix 17). The interaction between planting dates and fertilizer application rates was found only at L2 growth stage (Appendix 18). Conversely, there was no interaction between night break treatments and fertilizer application rates, nor interaction among the three factors (Appendix 19 and Appendix 20). This indicated that the planting date was the major effect that affected on plant height rather than night break treatments or fertilizer application rates.

Table 6.1 Effects of planting dates, night break treatments and fertilizer application rates on plant height of *C. alismatifolia* at different growth stages.

Factors		Plant height (cm)				
		L1	L2	L3	L4	F
Planting dates	May, 15 (RS)	19.2a	24.9a	30.3a	34.5a	35.3a
	Nov,15 (OS)	7.9b	16.4b	19.0b	22.0b	24.0b
Night break	0 hr	13.5	20.0b	23.8b	27.5b	28.4b
	2 hr	13.6	21.3a	25. 6a	29.0a	30.9a
Fertilizer rates	0.0 g pot $^{-1}$	12.9	20.5	24.2	27.8	28.7
	7.5 g pot $^{-1}$	14.1	20.9	25.5	28.8	29.9
	15.0g pot $^{-1}$	13.7	20.5	24.3	28.2	30.3
Planting dates		*	*	*	*	*
Night break		ns	*	*	*	*
Fertilizer rates		ns	ns	ns	ns	ns
Planting dates x Night break		ns	*	*	*	ns
Planting dates x Fertilizer rates		ns	*	ns	ns	ns
Night break x Fertilizer rates		ns	ns	ns	ns	ns
Planting dates x Night break x Fertilizer rates		ns	ns	ns	ns	ns
CV%		10.49	6.73	7.89	7.35	6.77

Means within the factor in the same columns followed by different characters showed significantly different between treatments by LSD test at $P<0.05$.

ns : not significantly different.

6.3.2 Number of leaves per plant

The number of leaves of *C. alismatifolia* was counted at every growth period (L1, L2, L3, L4 and F). It was rapidly increased from L1 to L4 growth stages and reached a maximum at F growth stage (Table 6.2).

Main effects

The result showed that only planting dates affected on leaves number of *C. alismatifolia* from L2 to F growth stages. Leaves number of the plant cultivated in regular season tended to be less than those of in the off-season.

Furthermore, both of night break and fertilizer application rates factors did not affect on the number of leaves per plant (Table 6.2).

Interaction among factors

The interaction was found between planting dates and night break factor at L4 growth stage, and between planting dates and fertilizer application rates at L3 growth stage (Appendix 21-24). There was no interaction among three factors in this study (Appendix 21-24).

Table 6.2 Effects of planting dates, night break treatments and fertilizer application rates on leaves number of *C. alismatifolia* at different growth stages.

Factors		Number of leaves per plant				
		L1	L2	L3	L4	F
Planting dates	May, 15 (RS)	1.0	2.0b	3.2b	3.9b	4.0b
	Nov,15 (OS)	1.0	2.5a	3.6a	4.4a	4.4a
Night break	0 hr	1.0	2.3	3.4	4.2	4.2
	2 hr	1.0	2.2	3.4	4.1	4.2
Fertilizer rates	0.0 g pot $^{-1}$	1.0	2.2	3.4	4.1	4.1
	7.5 g pot $^{-1}$	1.0	2.3	3.5	4.1	4.1
	15.0g pot $^{-1}$	1.0	2.3	3.5	4.2	4.4
Planting dates		ns	*	*	*	*
Night break		ns	ns	ns	ns	ns
Fertilizer rates		ns	ns	ns	ns	ns
Planting dates x Night break		ns	ns	ns	*	ns
Planting dates x Fertilizer rates		ns	ns	*	ns	ns
Night break x Fertilizer rates		ns	ns	ns	ns	ns
Planting dates x Night break x Fertilizer rates		ns	ns	ns	ns	ns
CV%		2.90	9.96	7.72	7.16	7.40

Means within the factor in the same columns followed by different characters showed significantly different between treatments by LSD test at $P<0.05$.
ns : not significantly different.

6.3.3 Leaf area

Main effects

Planting dates affected on leaf area at every growing period. Planting in RS significantly increased leaf area from L1 to L4 growth stages. Particularly, there was a large difference occurred in L4 growth stage, in which leaf area values were 331.37 cm^2 in RS and 189.41 cm^2 in OS (Table 6.3).

Interaction among factors

There was an interaction between planting dates and night break treatments. The interactions were found in the period of L2, L3 and L4 (Appendix 25). Interaction of planting dates and fertilizer levels was found only in L1 growth stage (Appendix 26). Meanwhile, interactions of night break treatments and fertilizer levels were found in L1,

L3 and L4 growth stages. For interaction among the three factors, there were significant differences at L3 and L4 growth stages (Appendix 27 and Appendix 28).

Table 6.3 Effects of planting dates, night break treatments and fertilizer application rates on leaf area of *C. alismatifolia* at different growth stages.

Factors		Leaf area (cm^2)			
		L1	L2	L3	L4
Planting dates	May, 15 (RS)	50.1a	167.8a	226.7a	331.4a
	Nov,15 (OS)	25.8b	57.7b	157.5b	189.4b
Night break	0 hr	37.3	121.8a	173.0b	257.7
	2 hr	38.6	103.7b	211.3a	243.1
Fertilizer rates	0.0 g pot^{-1}	36.3	95.4b	205.0a	249.0
	7.5 g pot^{-1}	39.1	119.7a	193.1ab	262.7
	15.0g pot^{-1}	38.5	123.1a	178.3b	239.5
Planting dates		*	*	*	*
Night break		ns	*	*	ns
Fertilizer rates		ns	*	*	ns
Planting dates x Night break		ns	*	*	*
Planting dates x Fertilizer rates		*	*	*	ns
Night break x Fertilizer rates		*	ns	*	*
Planting dates x Night break x Fertilizer rates		ns	ns	*	*
CV%		12.99	25.75	12.77	10.61

Means within the factor in the same columns followed by different characters showed significantly different between treatments by LSD test at $P<0.05$.
ns : not significantly different.

6.3.4 Number of shoots per clump

Main effects

Planting dates and fertilizer application rate factors affected in the number of shoots per clump at L4 to Fs growth stages (Table 6.4). Planting *C. alismatifolia* in regular season could produce more shoot number than planting in the off-season.

Fertilizer application at GAP and ½ GAP recommendation rates gave the greater number of shoots per clump than no fertilizer application (Table 6.4). However, the night break treatments factor did not affect this parameter.

Interaction among factors

There was an interaction of planting dates and night break treatments at F growth stage and the interactions between planting dates and fertilizer application rates were also found at L4 and F growth stages (Appendix 29-32).

Table 6.4 Effects of planting dates, night break treatments and fertilizer application rates on number of shoots per clump of *C. alismatifolia* at different growth stages.

Factors		Shoot per clump		
		L4	F	Fs
Planting dates	May, 15 (RS)	2.0a	2.1a	2.5a
	Nov,15 (OS)	1.1b	1.8b	1.8b
Night break	0 hr	1.6	1.9	2.1
	2 hr	1.5	2.0	2.2
Fertilizer rates	0.0 g pot $^{-1}$	1.1b	1.3b	1.6b
	7.5 g pot $^{-1}$	1.8a	2.3a	2.4a
	15.0g pot $^{-1}$	1.8a	2.2a	2.4a
Planting dates		*	*	*
Night break		ns	ns	ns
Fertilizer rates		*	*	*
Planting dates x Night break		ns	*	ns
Planting dates x Fertilizer rates		*	*	ns
Night break x Fertilizer rates		ns	ns	ns
Planting dates x Night break x Fertilizer rates		ns	ns	ns
CV%		24.76	25.60	23.45

Means within the factor in the same columns followed by different characters showed significantly different between treatments by LSD test at $P<0.05$.
ns : not significantly different.

6.3.5 Inflorescence quality

Main effects

All of the three main factors were significantly affected on inflorescence quality parameters (Table 6.5). In general, inflorescence quality of *C. alismatifolia* grown under May, 15 (RS) was better than that grown in Nov, 15 (OS) (Table 6.5). In case of supplemental lighting, it was found that night break treatments significantly increased the length of stalk length, spike length, number of green bracts and number of pink

bracts, however, it delayed flowering (Table 6.5). Surprisingly, increasing fertilizer application rate reduced inflorescence quality attributes of this plant (Table 6.5).

Interaction among factors

The interactions were found between two factors and among three factors in these parameters. Night break treatment for 2 hours could increase inflorescence quality when planting in November, 15 (Fig. 6.2 and Appendix 33-36).

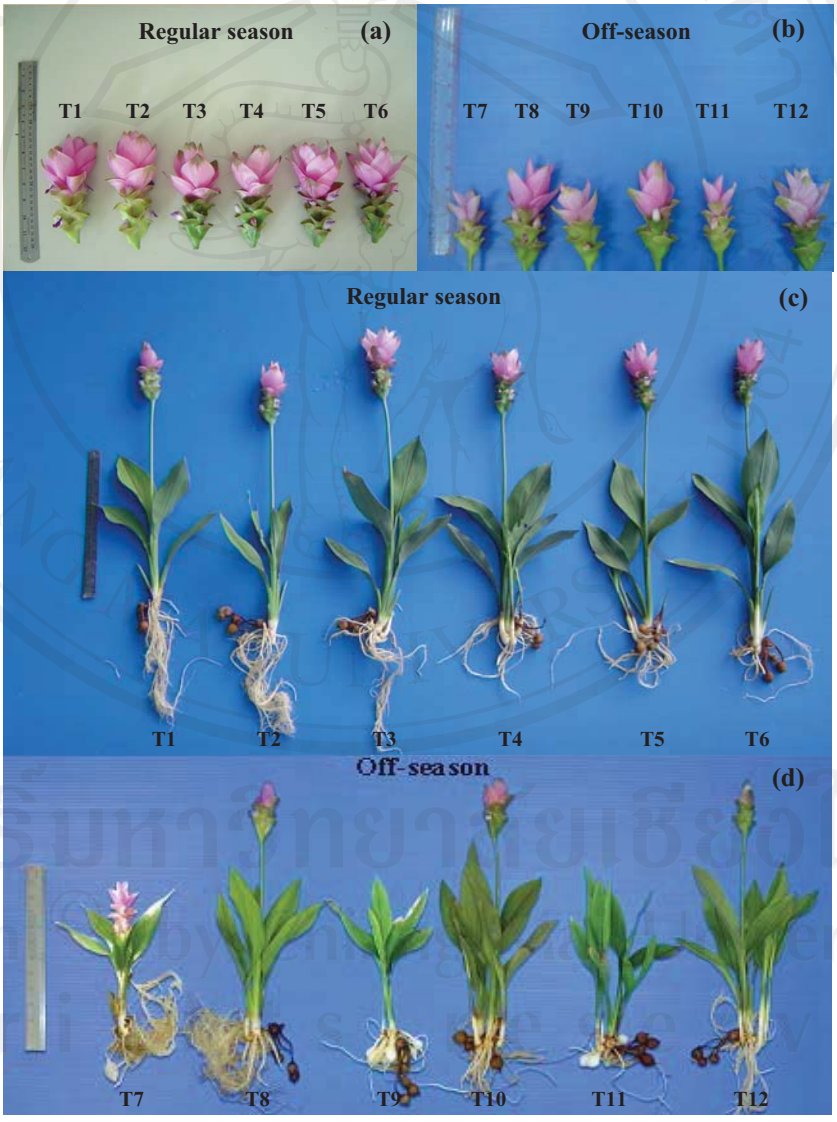

Figure 6.2 Inflorescence quality of *C. alismatifolia* Gagnep. grown under different treatments; (a and c) regular season (RS) and (b and d) off-season (OS) at flowering stage (See the treatment descriptions in p.103).

Table 6.5 Inflorescence quality of *C. alismatifolia* which grown under the different planting dates, night break treatments and fertilizer application rates at flowering stage.

Factors		Inflorescence quality				
		Stalk length (cm)	Spike length (cm)	Green bract (bract)	Pink bract (bract)	First floret opening (days)
Planting dates	May, 15 (RS)	44.3a	16.4a	9.8a	9.7a	78.0a
	Nov,15 (OS)	19.4b	6.8b	4.4b	5.6b	102.6b
Night break	0 hr	25.9b	9.6b	5.7b	5.9b	96.0a
	2 hr	37.8a	13.6a	8.4a	9.4a	84.6b
Fertilizer rates	0.0 g pot $^{-1}$	36.0a	12.9a	7.8a	8.4a	91.6
	7.5 g pot $^{-1}$	29.0c	11.2b	6.9b	7.4b	90.4
	15.0g pot $^{-1}$	30.6b	10.8c	6.6b	7.1b	89.0
Planting dates		*	*	*	*	*
Night break		*	*	*	*	*
Fertilizer rates		*	*	*	*	ns
Planting dates x Night break		*	*	*	*	*
Planting dates x Fertilizer rates		*	*	*	*	ns
Night break x Fertilizer rates		*	*	*	*	ns
Planting dates x Night break x Fertilizer rates		*	*	*	*	ns
CV%		4.60	5.87	5.56	9.68	6.59

Means within the factor in the same columns followed by different characters showed significantly different between treatments by LSD test at $P<0.05$.
ns : not significantly different.

6.3.6 Rhizomes quality and yield

Main effects

This research found that planting dates significantly influenced on the rhizome fresh weight, total fresh weight, number of rhizomes, size of storage roots and rhizomes (Table 6.6). Planting in RS gave lower rhizome fresh weight, total fresh weight and number of rhizomes than those in the OS (Table 6.6) However, the

fresh weight of storage roots and the numbers of storage roots were not different between the planting date treatments (Table 6.6).

For the night break factor, supplemental lighting for 2 hours gave lower rhizome quality than that without the night break treatment (Table 6.6).

Fertilizer application treatments generally produced better product quality as compared with the no fertilizer treatment. However, there was no difference between GAP recommendation and ½ GAP rates of fertilizer application in this trial (Table 6.6).

Interaction among factors

The interaction between planting dates and night break treatments significantly affected in fresh weight of storage roots, number of storage roots, number of rhizomes, storage roots length and rhizome size, while it had no effect on total fresh weight of rhizome or total fresh weight (Appendix 37). For the interaction of planting dates and fertilizer rates, it was significantly affected on fresh weight of storage roots, total fresh weight, number of rhizomes, length of storage roots and size of new rhizomes, whereas it did not have any effect on the number of storage roots (Appendix 38). Interaction between night break treatments and fertilizer rates had the influence on fresh weight of storage roots, total fresh weight, number of storage roots, number of rhizomes and length of storage roots, but did not affect on rhizomes size (Appendix 39). The interaction among the three factors, planting dates, night break treatments and fertilizer rates, was significantly affected on total fresh weight, length of storage roots and rhizomes size. In contrast, rhizome weight, storage roots weight and number of rhizomes were similar among treatments (Figure 6.3 and Appendix 40).

Figure 6.3 Rhizomes of *C. alismatifolia* Gagnep. grown under the various treatments; (a) regular season (May, 15) and (b) off-season (Nov, 15) at harvest.

Table 6.6 Rhizome quality parameters of *C. alismatifolia* grown under the different planting dates, night break treatments and fertilizer application rates at dormancy stage.

Factors		Rhizome quality						
		Fresh weight rhizome (g plant^{-1})	Fresh weight storage roots (g plant^{-1})	Total fresh weight (g plant^{-1})	Number of storage roots	Number of rhizome	Length of storage roots (cm)	Diameter of rhizome (cm)
Planting dates	May, 15 (RS)	16.8b	66.6	80.2b	3.7	3.6b	6.9a	2.4a
	Nov, 15 (OS)	20.2a	64.8	95.8a	3.7	5.1a	2.1b	1.9b
Night break	0 hr	19.9a	93.5a	106.0a	5.9a	3.8b	5.0a	2.2a
	2 hr	17.2b	37.9b	70.1b	1.5b	4.8a	4.0b	2.1b
Fertilizer rates	0.0 g pot $^{-1}$	10.3b	53.4b	74.2b	4.1a	2.8b	5.2a	2.0b
	7.5 g pot $^{-1}$	23.9a	70.1a	98.0a	3.2b	5.0a	4.1b	2.2a
	15.0g pot $^{-1}$	21.4a	73.6a	91.8a	3.9ab	5.2a	4.2b	2.2a
Planting dates		*	ns	*	ns	*	*	*
Night break		*	*	*	*	*	*	*
Fertilizer rates		*	*	*	*	*	*	*
Planting dates x Night break		ns	*	ns	*	*	*	*
Planting dates x Fertilizer rates		*	*	*	ns	*	*	*
Night break x Fertilizer rates		ns	*	*	*	*	*	ns
Planting dates x Night break x Fertilizer rates		ns	ns	*	ns	ns	*	*
CV%		20.09	15.31	15.28	27.55	14.48	14.39	3.34

Means within the factor in the same columns followed by different characters showed significantly different between treatments by LSD test at $P<0.05$.

ns : not significantly different.

6.3.7 Accumulation of total dry weight

Main effects

The results revealed that planting dates significantly influenced on total dry weight of *C. alismatifolia* in all stages, except at the L4 growth stage (Table 6.7).

Night break for 2 hours was significantly increased total dry weight at all stages, except at the L3 and L4 growth stages (Table 6.7).

Fertilizer application rates significantly increased total dry weight of *C. alismatifolia* from flowering (F) until harvest (H) growth stages (Table 6.7).

Interaction among factors

Two main factors between planting dates and night break treatments had an interaction on total dry weight of *C. alismatifolia* in the present experiment (Appendix 41). Interactions between planting dates and fertilizer application rates were found at L2, L3, F and Fs growth stages (Appendix 42). But the interaction between night break treatments and fertilizer application rates was found only at L3 growth stage (Appendix 43). The interaction among the three factors was significantly different at F and Fs growth stages (Appendix 44).

Table 6.7 Effects of planting dates, night break treatments and fertilizer application rates on total dry weight of *C. alismatifolia* at different growth stages.

Factors		Total dry weight (g plant^{-1})						
		L1	L2	L3	L4	F	Fs	H
Planting dates	May, 15 (RS)	4.2b	4.8b	5.3b	8.2	11.4a	13.8b	10.4b
	Nov, 15 (OS)	4.7a	5.0a	7.4a	8.4	10.1b	17.9a	21.3a
Night break	0 hr	4.2b	4.7b	6.6	8.4	10.4b	16.5a	18.2a
	2 hr	4.7a	5.1a	6.1	8.2	11.1a	15.2b	13.4b
Fertilizer rates	0.0 g pot $^{-1}$	4.5	4.9	6.5	8.5	10.5b	14.2b	12.5b
	7.5 g pot $^{-1}$	4.1	4.9	6.1	8.2	11.3a	17.0a	18.5a
	15.0g pot $^{-1}$	4.6	4.8	6.4	8.2	10.5b	16.5a	16.5a
Planting dates		*	*	*	ns	*	*	*
Night break		*	*	ns	ns	*	*	*
Fertilizer rates		ns	ns	ns	ns	*	*	*
Planting dates x Night break		ns	ns	*	ns	*	*	*
Planting dates x Fertilizer rates		ns	*	*	ns	*	*	ns
Night break x Fertilizer rates		ns	ns	ns	ns	ns	*	ns
Planting dates x Night break x Fertilizer rates		ns	ns	ns	ns	*	*	ns
CV%		10.41	9.45	13.48	14.09	7.72	10.81	22.82

Means within the factor in the same columns followed by different characters showed significantly different between treatments by LSD test at $P<0.05$.
ns : not significantly different.

6.3.4 Photosynthetic rate and chlorophyll fluorescence

Photosynthetic rate (*Pn*) and practically active radiation (*PAR*) on leaf surface

Main effects

Only planting dates factor significantly affected on photosynthetic rate (*Pn*) and *PAR* on leaf surface (Q_{leaf}) of *C. alismatifolia* at flowering stage. *Pn* and Q_{leaf} of plant grown under RS (May, 15) were greater than that grown under OS (Table 6.8). However, night break treatments and fertilizer application rates had no effect on the *Pn* or Q_{leaf} of plant (Table 6.8).

Interaction among factors

The interaction among the three factors on *Pn* and Q_{leaf} of *C. alismatifolia* at flowering stage was not found in present experiment (Appendix 45-48).

Table 6.8 Effects of planting dates, night break treatments and fertilizer application rates on photosynthetic rate (*Pn*) and *PAR* on leaf surface (Q_{leaf}) at flowering stage.

Factors		Flowering stage	
		Pn ($\mu molCO_2m^{-2}s^{-1}$)	*PAR* (Q_{leaf}) ($\mu molm^{-2}s^{-1}$)
Planting dates	May, 15 (RS)	6.3a	1018.0a
	Nov, 15 (OS)	4.3b	556.4b
Night break	0 hr	4.9	771.0
	2 hr	5.8	804.1
Fertilizer rates	0.0 g pot $^{-1}$	5.2	766.6
	7.5 g pot $^{-1}$	5.8	754.9
	15.0g pot $^{-1}$	5.0	841.3
Planting dates		*	*
Night break		ns	Ns
Fertilizer rates		ns	ns
Planting dates x Night break		ns	ns
Planting dates x Fertilizer rates		ns	ns
Night break x Fertilizer rates		ns	ns
Planting dates x Night break x Fertilizer rates		ns	ns
CV%		31.71	21.78

Means within the factor in the same columns followed by different characters showed significantly different between treatments by LSD test at P <0.05.

ns : not significantly different

Chlorophyll fluorescence

Main effects

Planting dates in RS significantly increased chlorophyll fluorescence of *C. alismatifolia* at flowering stage. Night break treatments and fertilizer rates factors did not have any effect on the chlorophyll fluorescence of this plant at flowering stage of growth (Table 6.9).

Interaction among factors

The interaction among the three factors on the chlorophyll fluorescence of *C. alismatifolia* at flowering stage was not occurred in this trial (Appendix 49-52).

Table 6.9 Effects of planting dates, night break treatments and fertilizer application rates on chlorophyll fluorescence of *C. alismatifolia* at flowering stage.

Factors		Flowering stage	
		Chlorophyll fluorescence (*Fv/Fm*)	
		10.00am	21.00pm
Planting dates	May, 15 (RS)	0.800a	0.794
	Nov, 15 (OS)	0.762b	0.799
Night break	0 hr	0.788a	0.796
	2 hr	0.773b	0.797
Fertilizer rates	0.0 g pot $^{-1}$	0.771	0.803
	7.5 g pot $^{-1}$	0.780	0.795
	15.0g pot $^{-1}$	0.791	0.793
Planting dates		*	ns
Night break		*	ns
Fertilizer rates		ns	ns
Planting dates x Night break		ns	ns
Planting dates x Fertilizer rates		ns	ns
Night break x Fertilizer rates		ns	ns
Planting dates x Night break x Fertilizer rates		ns	ns
CV%		4.22	4.38

Means within the factor in the same columns followed by different characters showed significantly different between treatments by LSD test at $P<0.05$.
ns : not significantly different.

6.3.5 Plant nutrient concentration

Nitrogen concentration

Main effects

Planting dates caused a significantly difference in nitrogen concentrations in all organs, except in the old storage roots (Table 6.10). The N concentrations of RS old rhizome, new storage roots and leaves were significantly higher than those of OS.

Night break treatments significantly increased N concentrations in new rhizome and inflorescence, but decreased in new storage roots (Table 6.10).

Fertilizer application rates increased nitrogen concentrations in all organs of *C. alismatifolia* at flowering stage (Table 6.10).

Interaction among factors

The interactions between two main factors and three factors were found in different organs of *C. alismatifolia* at flowering stage. The interactions between planting dates and night break treatments on N concentration were found in various organs, except in the leaves (Appendix 53). The interactions between planting dates and fertilizer rates on nitrogen concentration were found in all organs (Appendix 54). The interactions of night break treatments and fertilizer rates were found in some organs, except on the old storage roots and leaves (Appendix 55). The interactions among three main factors were found in all organs, except in leaves (Appendix 56).

Table 6.10 Effects of planting dates, night break treatments and fertilizer application rates on nitrogen concentrations of *C. alismatifolia* at flowering stage.

Factors		Nitrogen concentration (mg gDW^{-1})					
		Old rhizome	New rhizome	Old storage roots	New storage roots	Inflorescence	Leaves
Planting dates	May, 15 (RS)	17.4b	35.8a	10.0	0.0b	11.0a	9.9b
	Nov,15 (OS)	28.7a	23.0b	9.7	5.8a	9.7b	22.3a
Night break	0 hr	22.9	28.3b	9.7	5.8a	6.8b	15.9
	2 hr	23.3	30.6a	10.1	0.0b	13.9a	16.4
Fertilizer rates	0.0 g pot^{-1}	7.9c	13.3c	6.6c	1.1b	9.3b	9.5b
	7.5 g pot^{-1}	27.6b	35.9b	10.1b	3.7a	11.9a	19.3a
	15.0g pot^{-1}	33.7a	39.0a	13.0a	4.0a	9.9b	19.6a
Planting dates		*	*	ns	*	*	*
Night break		ns	*	ns	*	*	ns
Fertilizer rates		*	*	*	*	*	*
Planting dates x Night break		*	*	*	*	*	ns
Planting dates x Fertilizer rates		*	*	*	*	*	*
Night break x Fertilizer rates		*	*	ns	*	*	ns
Planting dates x Night break x Fertilizer rates		*	*	*	*	*	ns
CV%		8.29	10.34	17.52	36.34	17.69	18.38

Means within the factor in the same columns followed by different characters showed significantly different between treatments by LSD test at $P<0.05$.

ns : not significantly different.

Phosphorus concentration

Main effects

Planting dates influenced on the concentration of phosphorus in all organs of *C. alismatifolia* at flowering stage. Planting in May increased P concentrations in old and new rhizome, old storage roots and inflorescence. But P concentrations in new storage roots and leaves were significantly lower than those in RS (Table 6.11).

Night break treatments significantly increased P concentration only in new storage roots, but decreased in inflorescence (Table 6.11).

Fertilizer application rates at GAP significantly increased P concentration in all organs, except that in the inflorescence (Table 6.11).

Interaction among factors

The interactions between planting dates and night break treatments were found in old rhizome, new storage roots, inflorescence and leaves of *C. alismatifolia* at flowering stage (Appendix 57). The interaction between planting dates and fertilizer rates was shown to have an effect on P concentration in all organs (Appendix 58). Night break treatments and fertilizer rates interaction also influenced on P concentrations in some organs of the *C. alismatifolia* at flowering stage, i. e. the old and new rhizome, new storage roots and inflorescence, but not in the old storage roots or leaves (Appendix 59). In addition, the interactions among the three factors were found in new storage roots and inflorescence of *C. alismatifolia* (Appendix 60).

Table 6.11 Effects of planting dates, night break treatments and fertilizer application rates on phosphorus concentrations of *C. alismatifolia* at flowering stage.

Factors		Phosphorus concentration (mg gDW^{-1})					
		Old rhizomes	New rhizomes	Old storage roots	New storage roots	Inflorescence	Leaves
Planting dates	May, 15 (RS)	4.9a	6.8a	6.9a	0.0b	2.6a	1.9b
	Nov, 15 (OS)	3.7b	4.3b	3.4b	1.8a	1.4b	2.5a
Night break	0 hr	4.4	5.6	5.2	1.8a	1.9b	2.3
	2 hr	4.2	5.5	5.2	0.0b	2.3a	2.2
Fertilizer rates	0.0 g pot^{-1}	2.9c	5.3	4.8b	0.7b	2.2a	1.8c
	7.5 g pot^{-1}	4.7b	5.6	4.7b	1.0a	1.9b	2.3b
	15.0g pot^{-1}	5.3a	5.7	5.9a	1.0a	1.9b	2.6a
Planting dates		*	*	*	*	*	*
Night break		ns	ns	ns	*	*	ns
Fertilizer rates		*	ns	*	*	*	*
Planting dates x Night break		*	ns	ns	*	*	*
Planting dates x Fertilizer rates		*	*	*	*	*	*
Night break x Fertilizer rates		*	*	ns	*	*	ns
Planting dates x Night break x Fertilizer rates		ns	ns	ns	*	*	ns
CV%		11.16	15.28	17.30	41.83	12.33	14.45

Means within the factor in the same columns followed by different characters showed significantly different between treatments by LSD test at $P<0.05$.
ns : not significantly different.

Potassium Concentration

Main effects

Planting dates significantly affected K concentrations in old and new rhizome, old and new storage roots, inflorescence and leaves. Planting in May (RS) led to have the lower of K concentrations in the new rhizome, old and new storage roots, and leaves of *C. alismatifolia* at flowering stage than that in November (OS) (Table 6.12).

Night break treatment for 2 hours also caused higher K concentrations in new rhizome, old storage roots and inflorescence, but lower in the new storage roots of *C. alismatifolia* than that without the night break treatment (Table 6.12).

Fertilizer application at ½ GAP and GAP recommendation rates increased K concentrations in old rhizome, new storage roots and leaves, but decreased

them in new rhizome and inflorescence of *C. alismatifolia* at flowering stage (Table 6.12).

Interaction among factors

The interaction between planting dates and night break treatments, similar to that between the planting dates and fertilizer rates, caused significantly differences in K concentrations in all organs, except K that in leaves of *C. alismatifolia* at flowering stage (Appendix 61).

The interactions between night break treatments and fertilizer application rates were found in old and new rhizome, new storage roots and inflorescence. However, the K concentrations in old storage roots and leaves were not different (Appendix 62 and Appendix 63).

The interactions among the three factors were found in new rhizomes, new storage roots and inflorescence, however, such interactions were not found in old rhizome, old storage roots and leaves of *C. alismatifolia* at flowering stage (Appendix 64).

Table 6.12 Effects of planting dates, night break treatments and fertilizer application rates on potassium concentrations of *C. alismatifolia* at flowering stage.

	Factors	Potassium concentration (mg gDW^{-1})					
		Old rhizomes	New rhizomes	Old storage roots	New storage roots	Inflorescence	Leaves
Planting dates	May, 15 (RS)	19.2b	31.2a	54.2b	0.0b	43.4a	25.3b
	Nov, 15 (OS)	23.9a	23.9b	62.7a	27.4a	37.0b	38.3a
Night break	0 hr	21.9	25.2b	60.4a	27.4a	30.2b	30.8
	2 hr	21.1	29.8a	56.5b	0.0b	50.2a	32.8
Fertilizer rates	0.0 g pot^{-1}	18.3b	38.4a	55.0b	11.9b	52.2a	27.1b
	7.5 g pot^{-1}	20.0a	23.4b	62.6a	14.9a	34.4b	32.9a
	15.0g pot^{-1}	23.3a	20.7c	57.7b	14.2a	34.1b	35.4a
Planting dates		*	*	*	*	*	*
Night break		ns	*	*	*	*	ns
Fertilizer rates		*	*	*	*	*	*
Planting dates x Night break		*	*	*	*	*	ns
Planting dates x Fertilizer rates		*	*	*	*	*	ns
Night break x Fertilizer rates		*	*	ns	*	*	ns
Planting dates x Night break x Fertilizer rates		ns	*	ns	*	*	ns
CV%		10.14	13.95	7.28	20.91	6.19	20.24

Means within the factor in the same columns followed by different characters showed significantly different between treatments by LSD test at $P<0.05$.
ns : not significantly different.

Calcium concentration

Main effects

Ca concentrations in the old and new rhizomes, old and new storage roots of *C. alismatifolia* plants grown in November, 15 (OS) were significantly higher than those grown in May, 15 at the flowering stage (Table 6.13). In contrast, the Ca concentrations in the new rhizomes and inflorescence of the OS plants were significantly lower than those of RS.

Night break treatment for 2 hours decreased the concentrations of Ca in the old and new storage roots, while that in the other organs were comparable (Table 6.13).

The increase in fertilizer rates significantly increased Ca concentration in the old rhizome but decreased in the new rhizome and inflorescence of *C. alismatifolia* at flowering stage (Table 6.13).

Interaction among factors

The interactions of planting dates and night break treatments were found in old rhizome, new storage roots, and inflorescences of *C. alismatifolia* at flowering stage (Appendix 65). The interactions between night break treatments and fertilizer rates were also found in the new rhizome and inflorescences (Appendix 66). Furthermore, the interactions among the three factors were found in new rhizome and inflorescence of *C. alismatifolia* at flowering stage (Appendix 67-68).

Table 6.13 Effects of planting dates, night break treatments and fertilizer application rates on calcium concentrations of *C. alismatifolia* at flowering stage.

Factors		Calcium concentration (mg gDW^{-1})					
		Old rhizomes	New rhizomes	Old storage roots	New storage roots	Inflorescence	Leaves
Planting dates	May, 15 (RS)	19.2b	31.2a	54.2b	0.0b	11.8a	25.3
	Nov,15 (OS)	23.9a	23.9b	62.7a	27.4a	3.4b	38.3
Night break	0 hr	21.9	25.2	60.4a	27.4a	7.7	30.8
	2 hr	21.1	29.8	56.5b	0.0b	7.4	32.8
Fertilizer rates	0.0 g pot^{-1}	18.3b	38.4a	55.0b	11.9	10.7a	27.1
	7.5 g pot^{-1}	20.0a	23.4b	62.6a	14.9	3.7c	32.9
	15.0g pot^{-1}	23.3a	20.7c	57.7b	14.2	8.4b	35.4
Planting dates		*	*	*	*	*	*
Night break		ns	ns	*	*	ns	ns
Fertilizer rates		*	*	*	ns	*	*
Planting dates x Night break		ns	ns	*	*	*	ns
Planting dates x Fertilizer rates		*	*	*	ns	*	*
Night break x Fertilizer rates		ns	*	ns	ns	*	ns
Planting dates x Night break x Fertilizer rates		ns	*	ns	ns	*	ns
CV%		35.65	33.38	14.10	16.95	17.26	15.46

Means within the factor in the same columns followed by different characters showed significantly different between treatments by LSD test at $P < 0.05$.

ns : not significantly different.

Magnesium concentration

Main effects

Planting in November, 15 (OS) significantly increased the concentrations of Mg in all organs of *C. alismatifolia* at flowering stage (Table 6.14).

Giving night break for 2 hours decreased the amounts of Mg in the old and new storage roots, and inflorescence. However, there were no differences in Mg concentrations in the old rhizome, new rhizome or leaves of *C. alismatifolia* at flowering stage (Table 6.14).

Fertilizer application at ½ GAP and GAP recommendation rates decreased Mg contents in the new rhizome, inflorescence and leaves of this plant as compared with the control (Table 6.14).

Interaction among factors

The interactions between planting dates and night break treatments on the concentrations of Mg were found in the old storage roots, new storage roots and inflorescence of *C. alismatifolia* at flowering stage (Appendix 69). The interactions between planting dates and fertilizer application rates also affected the concentrations of Mg in the old and new rhizomes, inflorescence and leaves of *C. alismatifolia* at flowering stage (Appendix 70). The interaction between night break treatments and fertilizer rates on Mg content was found only in the inflorescence (Appendix 71). The interactions among the three factors were found in new rhizome and inflorescence of *C. alismatifolia* at flowering stage (Appendix 72).

Table 6.14 Effects of planting dates, night break treatments and fertilizer application rates on magnesium concentrations of *C. alismatifolia* at flowering stage.

Factors		Magnesium concentration(mg gDW^{-1})					
		Old rhizome	New rhizome	Old storage roots	New storage roots	Inflorescence	Leaves
Planting dates	May, 15 (RS)	2.3b	3.4b	2.8b	0.0b	3.1b	4.1b
	Nov, 15 (OS)	20.9a	24.4a	19.5a	7.9a	16.1a	17.2a
Night break	0 hr	11.6	13.6	11.9a	7.9a	6.3b	10.6
	2 hr	11.6	14.2	10.4b	0.0b	12.9a	10.6
Fertilizer rates	0.0 g pot^{-1}	10.7b	17.0a	10.9	4.2	16.6a	12.4a
	7.5 g pot^{-1}	12.6a	13.2b	11.6	3.9	6.3b	9.9b
	15.0g pot^{-1}	11.6b	11.4c	11.1	3.8	5.9b	9.5b
Planting dates		*	*	*	*	*	*
Night break		ns	ns	*	*	*	ns
Fertilizer rates		*	*	ns	ns	*	*
Planting dates x Night break		ns	ns	*	*	*	ns
Planting dates x Fertilizer rates		*	*	ns	ns	*	*
Night break x Fertilizer rates		ns	ns	ns	ns	*	ns
Planting dates x Night break x Fertilizer rates		ns	*	ns	ns	*	ns
CV%		12.26	11.26	9.65	17.78	7.66	9.28

Means within the same columns followed by different characters showed significantly different between treatments by LSD test at $P < 0.05$.
ns : not significantly different.

6.3.6 Total nonstructural carbohydrates at flowering stage

Main effects

Planting dates influenced the concentrations of TNC in old rhizome, old storage roots and inflorescence of *C. alismatifolia* at flowering stage. The TNC concentrations in plant grown in RS were greater in the old storage roots and inflorescence than that grown in the OS. In contrast, TNC concentrations in old rhizome and new storage roots of *C. alismatifolia* were lower than that in plants grown in OS (Table 6.15).

Night break treatment for 2 hours increased TNC concentrations in old rhizome, new rhizome and new storage roots of *C. alismatifolia* at flowering stage (Table 6.15).

Fertilizer application at ½ GAP and GAP recommendation rates significantly increased TNC concentration in all organs of Patumma (Table 6.15).

Interaction among factors

There were interactions found between planting dates and night break treatments in most major organs, except in new rhizome of *C. alismatifolia* at flowering stage (Appendix 73).

Planting dates interacted with fertilizer rates on the TNC concentration in all organs of this plant (Appendix 74). The similar result was also found on the interaction between night break treatments and fertilizer rates (Appendix 75). The interactions among the three factors were found in most major organs, except in the old rhizome of Patumma at flowering stage (Appendix 76).

Table 6.15 Effects of planting dates, night break treatments and fertilizer application rates on total nonstructural carbohydrates (TNC) of *C. alismatifolia* at flowering stage.

Factors		TNC (mg-D-glucose gDW^{-1})				
		Old rhizome	New rhizome	Old storage roots	New storage roots	Inflorescence
Planting dates	May, 15 (RS)	32.6b	25.2	22.8a	0.0b	21.8a
	Nov, 15 (OS)	41.0a	23.8	6.9b	16.6a	14.6b
Night break	0 hr	45.7a	30.2a	14.1b	16.6a	15.9b
	2 hr	27.8b	18.8b	15.6a	0.0b	20.6a
Fertilizer rates	0.0 g pot^{-1}	62.6a	44.1a	35.4a	17.2a	19.6a
	7.5 g pot^{-1}	26.5b	12.7c	4.3b	4.2b	14.2b
	15.0g pot^{-1}	21.2c	16.7b	4.9b	3.5b	20.8a
Planting dates		*	ns	*	*	*
Night break		*	*	*	*	*
Fertilizer rates		*	*	*	*	*
Planting dates x Night break		*	ns	*	*	*
Planting dates x Fertilizer rates		*	*	*	*	*
Night break x Fertilizer rates		*	*	*	*	*
Planting dates x Night break x Fertilizer rates		ns	*	*	*	*
CV%		14.25	18.53	14.77	63.66	21.65

Means within the factor in the same columns followed by different characters showed significantly different between treatments by LSD test at $P < 0.05$.

ns : not significantly different

Total nonstructural carbohydrates in leaves at plant growth stages

Main effects

TNC concentration in leaves at L2, L3 and L4 growth stages of *C. alismatifolia* significantly increased in plants grown in November, 15 (OS) (Table 6.16).

Night break treatment for 2 hours increased TNC in leaves at L3 growth stage (Table 6.16).

Fertilizer application at GAP recommendation rate increased TNC in leaves at L2, L3 and L4 growth stages. The reverse result was found at L1 growth stage (Table 6.16).

Interaction among factors

The interaction between planting dates and night break treatments was found only at L4 growth stage (Appendix 77). Planting dates interacted with fertilizer rates at L1, L2, L3 and L4 growth stages (Appendix 78).The interactions between night break treatments and fertilizer rates were found at L1 and L4 growth stages (Appendix 79). In addition, the interactions among the three factors were found at L2 and L4 growth stages of *C. alismatifolia* (Appendix 80).

Table 6.16 Effects of planting dates, night break treatments and fertilizer application rates on TNC in leaves of *C. alismatifolia* at different growth stages.

Factors		TNC (mg-D-glucose gDW^{-1})			
		$L1^{st}$	$L2^{nd}$	$L3^{rd}$	$L4^{th}$
Planting dates	May, 15 (RS)	11.4	6.3b	6.1b	14.3b
	Nov, 15 (OS)	13.3	16.6a	27.2a	45.4a
Night break	0 hr	12.6	11.5	15.3b	31.1
	2 hr	12.1	11.3	18.1a	28.6
Fertilizer rates	0.0 g pot^{-1}	16.1a	9.9b	12.5b	29.9ab
	7.5 g pot^{-1}	12.5b	11.7ab	14.7b	27.1b
	15.0g pot^{-1}	8.4c	12.7a	22.8a	32.6a
Planting dates		ns	*	*	*
Night break		ns	ns	*	ns
Fertilizer rates		*	*	*	*
Planting dates x Night break		ns	ns	ns	*
Planting dates x Fertilizer rates		*	*	*	*
Night break x Fertilizer rates		*	ns	ns	*
Planting dates x Night break x Fertilizer rates		ns	*	ns	*
CV%		33.99	27.03	21.56	19.09

Means within the factor in the same columns followed by different characters showed significantly different between treatments by LSD test at P <0.05.
ns : not significantly different

6.4 Discussion

6.4.1 Plant growth and development

In this study, it was aimed to explore the combined effects of planting dates, night break treatments and fertilizer application rates on physiological responses of *C. alismatifolia* Gagnep. It was found that planting in May, 15 significantly increased the growth of plant, in terms of plant height, total leaf area and number of shoots per clump, but decreased the number of leaves per plant as compared with that planting in Nov, 15. It was observed that planting in May (regular season; RS) was the most suitable planting time to promote growth and flowering. This was probably due to that the regular season provided the appropriate temperature and photoperiod conditions which were the most favorable for vegetative growth and enhancing the formation of photosynthetic products. Similarly, Gunnlaugsson and Adalsteinsson (2006) found that in winter season the natural irradiation was extremely low in the period from November to February and even on overcast days in the middle of the summer, extra light was needed for adequate photosynthesis. Dorais *et al.* (2006) showed that in fall and winter season, assimilation lighting increased shoot growth of alfalfa. Thus, planting in May, 15 could lead to increase growth of *C. alismatifolia.* Earlier studies showed planting in regular season (rainy season) increased many plant growth responses compared with off-season (winter season) (Swanson and Wilhelm, 1996).

Giving night break treatment significantly increased plant height and leaf area (L2 to L3 growth stages), while it did not affect the number of leaves per plant or number of shoots per clump of *C. alismatifolia* from various treatments. Similar to Ruamrungsri *et al.* (2007), which reported that the growth of *C. alismatifolia* was different when the plant was grown under different planting dates and recommended

that plant required night break treatments to promote flowering and to maintain flower quality, when planting in September to November. Similarly, Yamada *et al.* (2008a) showed that growth of *Eustoma grandiflorum* (Raf) Shinn. was promoted by a night break treatment from light sources. Treder (2003) suggested that supplementary lighting improved plant quality in terms of high stem weight, sturdiness, large leaf area and leaf coloration. A similar result, Zimmer (1976) founded that night break treatment increased leaf size of *Echeveria harmsii*. *Cucumber* plants, were given supplemental lighting by having photosynthetic photon flux up to 300 $\mu molm^{-2}s^{-1}$ were shown to increase the number of leaves, leaf thickness, stem length, dry matter content of plants (Dorais, 2003). This might be due to day length had an important influence on the rates of translocation and respiration, on the accumulation of photosynthesis, and on carbon partitioning between soluble sugars and starch (Grange, 1985). Chin (2007) determined that rhizomes of *C. alismatifolia* which were grown under five treatments of long days, i. e. at 12, 14, 16, 18 and 20 hours. Treatments were supplemental lighting with incandescent bulb of 0, 2, 4, 6 and 8 hours after 07.00 pm. The results showed that 16 hours photoperiod produced the best growth rate. Plants at 16 hours also gave the best quality flowers with suitable plant height as potted plants, uniform flowering and intense flower color as well.

Increasing levels of fertilizer application significantly increased number of leaves per plant up to 7.5 g pot^{-1} (½ GAP), but decreased leaf area. These results were probably due to the salt toxicity from excessive fertilizer application, and that might be accounted for the slightly reduced growth of plants which were applied with the nutrient uptake at the 15.0 g pot^{-1} rate. Similarly, EL-Gendy (1995) found slightly reduced growth at the 8.0 g pot^{-1} rate, as compared with that of 6.0 g pot^{-1} rate in *Dracaena draco*. However, there

were no differences in plant height, number of shoots per clump compared with 0 GAP recommenced rate. Surprisingly, fertilizer did not influence plant height. Similarly, Lessa *et al.* (2009) found that the application with the mixture of fertilizers did not interfere the plant height, or the interactions among NPK and the mixture applied did not promote differences in the plant height of *Kalanchoe luciae* Raym. either. This could be due to fertilizer application at full and half recommendation rates promoted the greater number of shoots per clump than rather the plant height in *C. alismatifolia.* Moreover, application of full and half rates of GAP recommended, 15.0 and 7.5 g pot^{-1}, respectively, did not increase the plant height performance, probably because the amount of nutrients applied were too high, that resulting in luxury consumption of nutrients in the treated plants and promoted them to respond differently. Similar trends had been observed by Attoe and Osodeke (2009) indicated that the ginger responded significantly and positively to NPK fertilizer application, in terms of plant height and number of shoots. The present investigation on the influence of GAP fertilization showed that application rates of ½ GAP recommended could lead to the increase in some growth parameters of *C. alismatifolia*.

The combined effects of planting dates, night break treatments and fertilizer application rates on growth of *C. alismatifolia* showed that the interaction among these factors were significantly different on the leaf area at L3 and L4 growth stages. Especially, plant grown in May, 15 with night break 2 hours and ½ GAP recommended rates significantly increased leaf area, but there was no interaction among the three factors on plant height or number of shoots per clump. Interaction effects of planting dates and night break treatments were found to be significant only for plant height at L2 growth stage, leaf area at L2, L3 and L4 growth stages and number of shoots per clump at

F growth stage. Reversely, there was no interaction between night break treatments and fertilizer application rates on plant height. Similar trend was reported by Poole and Conover (1991), who found no interaction between light intensity and fertilizer rate on plant height of *Syngonium podophyllum* 'Pink Allusion'. Meanwhile, there were interactions of night break treatments and fertilizer levels on leaf area and number of shoots per clump.

This study indicated that the planting in May, 15 did not require night break to improve plant growth, while it was necessary to give night break when planting in Nov, 15. In addition, fertilizer application at 7.5 g pot^{-1} rate encouraged better growth of this plant. This was probably due to planting date was the major factor affecting on plant height and shoots per clump rather than night break treatments and/or fertilizer application rates.

6.4.2 Inflorescence quality

In general, *C. alimatifolia* flowers production in regular season required long day condition. Flowering was delayed after September when short day condition commenced (Chidburee, 2008). In the present study, all of the three main factors were significantly affected on inflorescence quality parameters.

The results showed that inflorescence quality of *C. alismatifolia* grown under May, 15 (RS) was better than Nov, 15 (OS). Similar to gladiolus, in which long day treatment promoted flowering percentage, and enhanced flower quality features, e.g. length of stem and spike, and number of florets per spike (Shillo *et al.,* 1981).

Night break treatment for 2 hours could increase inflorescence quality when planting in Nov, 15. In case of supplemental lighting, it was found that night break treatment significantly increased flower stalk length, spike length, number of green bracts

and number of pink bracts, however, it delayed flowering in plant grown on Nov, 15. Long day promoted flowering indirectly by extending the period of flower development, thus increasing the total solar irradiance absorbed by the plants and the total photosynthates available to the plants at the sensitive stages of early flower development (Shillo and Halevy 1981; 1976). Generally, reproductive initiation could be triggered primarily by photoperiod, but might be slightly modified by temperature and precipitation (Dahl and Hyder 1977; Dahl 1995). Duration of light affected plant growth and leaves bud acted as sensory receptors, especially pigmented areas that detected day length and night length and could activate one or more hormones and enzyme systems that brought about physiological responses. Long day plants reached the flowering stage after exposed to a critical photoperiod and during the period of increasing daylight (Llewellyn, 2001). *C. alismatifolia* should be classified as quantitative long day plants, since long day condition using supplement light sources could promote flowering of this plant but delay or inhibit by short day condition (Hagiladi *et al.,* 1997a). This indicated that photoperiod was the major effect which retarded inflorescence quality and the night break treatment could compensate long day for promoting inflorescence quality under the same low temperature condition in the off-season. Similarly, providing additional light for 3 hrs in middle of the night, started after day length was shortened could break dormancy and continually produced flowers, provided that enough humidity and nutrient were given (Chomchalow, 2004).

Not only extending photoperiod, but supplemental lighting also expanding photosynthesis period at night time for a plant. According to Treder (2003) suggested that the supplementary lighting completely prevented flower bud abortion of 'Laura Lee'. Flower disorder could be avoided by supplementary lighting with light applied from

November to February when greenhouse irradiance was at the lowest (Miller, 1992). Shillo and Halevy (1976) reported that long day promoted flowering indirectly by extending the period of flower development by increasing the total solar irradiance absorbed by the plants and the total photosynthates available to the plants at the sensitive stages of early flower development. Similarly, Yamada *et al.* (2008b) founded that flowering of *Eustoma* plants could be promoted by night break treatment using different types of light sources.

The fertilizer application rates gave poor inflorescence quality were possibly due to the excess or deficiency of fertilizers used. The number of burn leaves increased when plants were supplied with excess level of fertilizers, possible caused of the salt toxicity from excessive fertilizer application. The GAP recommended rate of fertilizer was applied at the level of 15.0 g pot^{-1} did not promote flowering and conversely reduced inflorescence quality. This phenomenon occurred perhaps due to salt toxicity that comprised osmotic and ionic components both of which could severely affect root and shoot growth (Rengel, 1992). Osmotic upset because the physiological changes, such as stomatal conductance, transpiration, photosynthesis, chlorophyll content, root and leaf activity, could contribute to the reduction of flower quality (color, size, stem thickness and length) and yield (Küçükahmetler, 2002). Khan *et al.* (2004) reported that emergence of first flower in *Zinnia elegans* was delayed, while number of flowers per plant, size of flowers and blooming period were generally decreased at higher level of nitrogen. Ruamrungsri and Apavatjrut (2003) found that nitrogen deficiency in curcuma resulted in stunted growth with decreased leaf area, caused leaf yellowing and reduced flower quality.

The interactions were found between two factors (planting dates and night break treatments) and among the three factors in inflorescence quality parameters. The seasonal variations brought about the differences in the time of planting, soil moisture, temperature, etc., these factors affected on different growth parameters. Especially, in summer, the growth mentioned above could be executed much faster by the plant, because summer season provided more daylight hours, that allowing more photosynthesis (Biology-Online, 2010). However, plant grown in November along with 2 hours night break treatment and ½ GAP recommended fertilizer rate could promote flowering and increase inflorescence quality, in terms of flower size and length of flower stalk, when compared with no night break and fertilizer rate, in the same time, but this did not affect on plant grown in May.

6.4.3 Rhizomes quality and yield

Planting dates influenced on the quality of rhizome, in terms of fresh weight, total fresh weight, number of rhizomes, size of storage roots and rhizomes. Planting in RS gave lower rhizomes fresh weight, total fresh weight and number of rhizomes than those of OS. However, the storage roots fresh weight and the number of storage roots were not different between the planting dates treatments.

Generally, rhizomes of *C. alismatifolia* become dormant in winter when the weather conditions turned to be dry with short day length from September to February (Khuankaew *et al.,* 2007). The increase of rhizome yield in OS planting date might be caused by the favorable climates for rhizome formation, such as low temperature and short day length. Soil temperature could influence water and nutrient uptake, as well as, metabolic processes and roots and shoot growth consequently (Toselli *et al.,* 1999; McMichael and Burke 1998). In addition, soil temperature could strongly influence root

initiation, root growth and nutrient uptake, and subsequently could have the impact on shoot development and mineral nutrient accumulation of plants (McMichael and Burke 1998; Tagliavini *et al.* 1991).

The night break gave lower of rhizome quality than that of the no night break treatment. The different responses of rhizome quality attributes by planting dates and night break treatments which probably due to sink and source partitioning. Similar report by Ruamrungsri *et al*. (2004) found that the light interruption for 2 hours of night break could inhibit storage roots formation of curcuma plant, although it was in winter. The partitioning of assimilates to storage organ caused by interaction between light, darkness and circadian rhythm of photosynthesis process and sucrose biosynthesis which appeared to be mediated by phytochrome (Thomas and Vine-Prue, 1997). Moreover, photoperiod was reported to play a key role in induction of *in vitro* storage organs, such as tubers in potato (*Solanum tuberosum* L.) (Hussey and Stacey, 1984) and bulbs in yams (*Dioscorea alata* L. 'Brazo fuerte and 'Florida' and *D. abyssinica* Hoch) (Jean and Cappadocia, 1991). Similarly, Changjeraja (2009) reported that curcuma plants were grown at 14 hours photoperiod (long day) did not have new storage roots, or delayed storage roots formation. Korovkin, (1985) suggested that factors that limited carbohydrate supply inhibited rhizome formation.

Increasing fertilizer application rates up to 7.5 g pot^{-1} (½ GAP rate) produced a good product quality compared with no fertilizer treatment (Table 6.6). Similar trends had been observed by several researchers, the ginger responded positively to NPK fertilizer application in yield parameters (fresh weight of plants and rhizome yield) (Attoe and Osodeke, 2009; Chukwu and Emehute, 2001). Singh *et al.,* (1998) also showed that increasing rates of potassium application had a positive and significant

effect on fresh rhizome yield. The increase in number of rhizome per plant with increased fertilizer application could be attributed to the increase of physiological processes in crop plants leading to higher growth and increased photosynthates to sinks. This might be due to better utilization of N P K supply (Selvaraju and Iruthayaraj, 1994).

The interactions were found between two factors and among the three factors in rhizome quality parameters. Planted in both seasons along with night break treatment decreased fresh weight of storage roots, number of storage roots, storage roots length and rhizome size, but increased number of rhizomes, while they did not significantly affect on fresh weight of rhizome or total fresh weight.

The interaction of planting dates and fertilizer rates significantly affected on fresh weight of storage roots, total fresh weight, number of rhizomes, length of storage roots and size of new rhizomes, whereas they did not have any effect on number of storage roots. Interaction of night break treatments and fertilizer rates influenced the decrease of storage roots and total fresh weight, number of storage roots, length of storage roots and number of rhizomes but they did not affect on rhizomes size.

The interactions among the three factors between planting dates, night break treatments and fertilizer rates significantly affected on total fresh weight, length of storage roots and rhizomes size. In contrast, rhizomes and storage roots weights and number of rhizomes were not different between treatments.

6.4.4 Accumulation of total dry weight

The results showed that planting dates and night break for 2 hours were significantly influenced on total dry weight of *C. alismatifolia* almost all stages, except at the L3 and L4 growth stages (Table 6.7). Fertilizer application rates significantly increased total dry weight of *C. alismatifolia* from flowering (F) until harvest (H)

growth stages (Table 6.7). Increased dry matter production with increased fertilizer application was certainly due to the role of NPK in determining the use efficiency of sunshine by the increased biomass, where any inadequacy of nitrogen reduced the sunshine use efficiency or ability of photosynthesis as reported by Wadsworth (2002). In addition, dry matter could also be increased with increasing P levels up to a certain limit (Savani *et al.,* 1995).

Two main factors between planting dates and night break treatments were shown to have some interactions in present experiment. Interactions of planting dates and fertilizer application rates were found at the L2, L3, F and Fs growth stages. However, the interaction between night break treatments and fertilizer application rates was found only at the L3 growth stage. The interaction among three factors was significantly different at F and Fs growth stages. Conover and Flohr (1994) reported that for patio type tomato 'Micro Tom', the cultivar most affected by light level, increasing fertilizer rate increased yields when plants were grown in full sun or in 70 % light, but decreased yields for plants were in 50 % light.

6.4.5 Photosynthetic rate and chlorophyll fluorescence

Only planting dates factor significantly affected on photosynthetic rate (*Pn*), *PAR* on leaf surface (Q_{leaf}) and chlorophyll fluorescence of *C. alismatifolia* at flowering stage. *Pn* and Q_{leaf} of plant grown under RS (May, 15) was greater than that grown in OS (Table 6.8). Ejieji (2003) reported that sugarcane was affected by seasonal change as some plant grew best during the rainy season, while others thrived better during the dry season. Sylvain (1958) suggested that seasonal changes were associated with several environmental factors, such as temperature, photoperiod, irradiance, water and nutrient supply. Furthermore, the sensitivity of photosynthesis to changes in T_{AIR}

depended on particular physiological mechanisms that might be constraining photosynthesis during the active and reduced growth periods (Schwarz *et al.,* 1997).

The summer season might has *a priori* environmental characteristics that was more conducive to the photosynthetic activity of Patumma plants compared to the winter season. The environmental conditions as related to the macroclimate, air temperature was also higher in summer, when maximum values were greater than 34.0 ^{o}C (Appendix 15). The greatest difference between winter and summer was in minimum T_{AIR}, which reached 16.9 ^{o}C in winter and 23.0 ^{o}C in summer. The minimum % RH was 45.4 and 61.8 in winter and summer, respectively.

Night break treatments and fertilizer application rates were not differences between treatments (Table 6.8). There was no interaction among the three factors, either. The reasons for this could be related to other features of the environment e.g., the diurnal fluctuation of temperature, relative humidity and sunshine duration. Effects of two main factors had also been studied on red fescue (*Festuca rubra* ssp. *commutata*) and revealed that nitrogen fertilization levels in autumn and early spring did not have any effect on the photosynthesis rate of the flag leaf at seed milk maturity in the first or the second production years (Szczepanek, 2010).

6.4.6 Plant nutrient concentrations

Nitrogen concentration

Nitrogen fertilizer generally increased root-shoot ratio (Barbar, 1984). N was involved in chlorophyll formation, and it influenced stomatal conductance, as well as, photosynthetic efficiency (Ivonyi *et al.,* 1997; Mazid, 1993). N was estimated to be responsible for 26 – 41 % of crop yields (Maier *et al.,* 1994; Mazid, 1993).

Planting dates caused significantly differences in nitrogen concentration of all organs of *C. alismatifolia* at flowering stage. The nitrogen concentrations in organs of RS old rhizome, new storage roots and leaves were significantly higher than those of OS. Borjigidai *et al.* (2006) suggested that the photosynthesis was influenced by seasonal environment and affected plant growth of rice (*Oryza sativa*). In pasture soil, nitrate-N accumulated over summer and declined over winter and spring. It could decrease rapidly over winter but began to accumulate during late spring (Peverill *et al.,* 2010).

Night break treatments significantly increased N concentrations in new rhizome and inflorescence. Treder (2001) suggested that plants grown with supplementary lighting was shown to have a greater nutrient demands. Increased fertilization at low light levels led to higher accumulation of nutrients in growing media. Borjigidai *et al.* (2006) demonstrated that as plant mass increased, nutrient supply from the soil would become relatively insufficient, leading to a nitrogen deficiency to the plant body. In the later stages of the life cycle, reallocation of nitrogen to reproductive organs would also decrease nitrogen in the vegetative parts. Nitrogen concentration in new rhizome was higher than in storage roots. Ruamrungsri *et al.* (2001) reported that rhizome of *C. alismatifolia* was the principal organ for N storage and the storage root was the major organ for carbohydrate reserve, such as starch and soluble sugar. Increasing of nitrogen compound in storage roots that caused by N application would probably played an important role in the storage of N in the storage roots (Ohtake *et al.,* 2006).

Fertilizer application rates increased nitrogen concentration in all organs of *C. alismatifolia* at flowering stage (Table 6.10). In general, the proportion of soluble nitrogen increased with elevated level of nitrogen supply and was higher in leaves and

storage organs with high water content, but low in grains and seeds (Marschner, 2008). The investigations carried out by Tittonell *et al*. (2003) on lettuce demonstrated that water content and nitrate accumulation in leaf tissues increased with nitrogen application. Prsa *et al.* (2007) found that the leaf N content was efficiently increased with application of fertilizer in 'Golden Delicious' apple trees.

The interactions between two mains factors and among the three factors were found in different organs of *C. alismatifolia* at flowering stage. The interactions between planting dates and night break treatments on N concentration were found in various organs, except leaves (Appendix 53). The interactions between planting dates and fertilizer rates on nitrogen concentration were found in all organs (Appendix 54). The interactions of night break treatments and fertilizer rates were found in some organs, except old storage roots and leaves (Appendix 55). The interactions among three main factors were found in all organs, except in leaves.

Phosphorus concentration

In this experiment, planting dates had the influence on the concentrations of phosphorus in all organs of *C. alismatifolia*. Planting in May (RS) increased P concentrations in old and new rhizomes, old storage roots and inflorescence. But P concentrations in new storage roots and leaves were lower than those in OS. Pasture soil had general pattern of high available phosphorus in summer to early autumn, and followed by decreasing concentrations through winter and spring. Crop soil, minimum concentrations occurred in autumn with slight increases over winter and without a clear trend in spring (Peverill *et al.,* 2010). Seasonal effects of P concentration in plants might have been caused by the influence of different soil moisture and temperature on related

microorganism that brought about the difference of P uptake (Mississipi State University extension service, 2010).

Night break treatments significantly increased P concentration only in new storage roots. Similarly, Khuankaew *et al*. (2010) reported that the accumulation of P in new organs in *Curcuma* was increased. The function of P as a constituent of macromolecular structures was most prominent in nucleic, as a unit of DNA molecule, and as a unit of RNA (Marschner, 1986).

Fertilizer application at GAP recommended rates significantly increased P concentration in all organs (Table 6.11). The solubility of the various inorganic phosphorus compounds directly affected the availability of phosphorus for plant growth (Mississipi State University extension service, 2010). Marschner (2008) reported that when phosphorus supply was increased from the deficiency to the sufficiency range, the major phosphorus fractions in vegetative plant organs also usually increased as shown in a typical example for leaves.

The interactions between planting dates and night break treatments on P concentration were found in old rhizome, new storage roots, inflorescence and leaves (Appendix 57). The interactions between planting dates and fertilizer rates affected on P concentration in all organs (Appendix 58). Night break treatments and fertilizer rates also showed the interactions in old and new rhizome, new storage roots and inflorescence, but not in old storage roots or leaves (Appendix 59). Moreover, interactions among the three factors were found in new storage roots and inflorescence of *C. alismatifolia*.

In *Stylosanthes hamata* under phosphorus deficiency, shoot growth declined rapidly but roots continued to grow, not only because of retaining most phosphorus but also

of the additional net translocation of phosphorus from the shoot to the roots (Smith and Whitelam 1990).

Potassium Concentration

Planting dates significantly affected K concentrations in old and new rhizome, old and new storage roots, inflorescence and leaves of *C. alismatifolia* at flowering stage. Planting in May (RS) gave the lower of K concentrations in new rhizome, old and new storage roots, and leaves than those in OS. In pasture soil, the general trend of extractable K concentrations were at the highest in summer or autumn, declining to the lowest levels in spring (Peverill *et al.,* 2010). Additionally, spring and fall were the most important times of the year to make potassium fertilizer applications. In the spring, turfgrass plants were often developed an entirely new root system. Potassium was a key nutrient in the development of new root growth. In the fall, levels of potassium in plant tissue were very critical in preparing the plants for winter survival. Low K levels in plant tissue in the fall to early winter months could dramatically increase the potential for winter injury to turfgrass plants (McAfee, 2010). Moreover, potassium uptake was most rapid on warm, moist soils that were well aerated and had a slightly acidic to neutral pH. As soil temperature raised, plant metabolic activity also increased which enhanced root growth and root activity. Warmer soil temperatures also increased the diffusion rate of potassium in the soil solution which accelerated potassium uptake by the root system (McAfee, 2010).

Night break treatments gave higher K concentrations in new rhizome, old storage roots and inflorescence, but lower in the new storage roots in *C. alismatifolia*. Both of fertilizer rates increased K concentrations in old rhizome, new storage roots and leaves, but decreased K in new rhizome and inflorescence (Table 6.12). By increasing the potassium

supply to plant roots it was relatively easy to increase the potassium content of various organs, except in grains and seeds. When the potassium supply was abundant 'luxury consumption' of potassium often occurred, which deserved attention for its possible interference with the uptake and physiological availability of magnesium and calcium (Marschner, 2008). Furthermore, application of potassium fertilizer would be determined by factors, such as soil potassium level, soil type, time of the year and use activity for the site. As with any nutrient, potassium programs should be based on soil test results (McAfee, 2010).

The interactions between planting dates and night break treatments was the same as planting dates and fertilizer rates, which caused significantly differences in K concentration in all organs, except in leaves of *C. alismatifolia* (Appendix 61). The interactions between night break treatments and fertilizer application rates were found in old and new rhizome, new storage roots or inflorescence. However, there were no differences in K concentration in old storage roots and leaves. The interactions among three factors were found in new rhizomes, new storage roots and inflorescence. However, there were no such interactions in old rhizome, old storage roots or leaves of *C. alismatifolia*.

Most of the *Curcuma* plants at flowering stage, the above ground parts (leaves and inflorescence) were important sink organs, but the underground part organs (new rhizomes, storage roots and fibrous roots) were not yet had sink function. Fertilizer level contributed to increase biomass (dry weight) of the upper ground parts which might be concerned with changes in nitrogen and potassium allocation from underground to upper ground part organs. Therefore, it was affected on decreasing total nitrogen and potassium content in underground part organs (Chidburee *et al.,* 2008). Similarly, Khuankaew (2010) reported that during planting to flowering, large amounts of

K in old storage root were utilized about 75 % of the content at planting stages. The K in old storage roots rapidly decreased, whereas it increased in new plants organs, particularly in leaves, flower and flower stalk during first leaf open to flowering stage. This indicated that during initiation of growth to flowering, most of the accumulation of K in new organ, particularly in leaves, was translocated from old storage roots, the major K preservative organ. Additionally, potassium might have an even greater effect on root development. A deficiency in potassium would negatively affect on root system. Potassium shortage influenced root length in the same way. The length of seminal roots for plants grown without potassium was only 15% of those that had an adequate supply at 16 days after seeding. This compared to those of 70% for phosphorus and 98% for nitrogen (International Plant Nutrition Institute, 2010).

Calcium concentration

Calcium (Ca) concentrations in old and new rhizome, old and new storage roots of *C. alismatifolia* at flowering stage, plants grown in November, 15 (OS) were significantly higher than those grown in May, 15. In contrast, the concentrations of Ca in new rhizome and inflorescence of the RS plants were significantly lower than those of RS. Although Ca in pasture soil was relatively stable throughout the year (Peverill *et al.,* 2010), Ca availability was also related to soil pH. As the soil pH increased above pH 7.0, free or un-combined Ca began to accumulate in the soil. This Ca was available to interact with other nutrients. Soluble P was an anion, meaning it had a negative charge. Any free Ca reacted with P to form insoluble (or very slow soluble) Ca-P compounds that were not readily available to plants. Since there was typically much more available Ca in the soil than P, this interaction nearly always resulted in less P availability (Spectrum Analytic Inc., 2010).

Night break treatment for 2 hours decreased Ca concentrations in old and new storage roots of *C. alismatifolia*, while Ca in the others organ were not different. The increase of fertilizer rates significantly increased Ca in old rhizome, but decreased in new rhizome and inflorescence (Table 6.13). Many fruit and tuber crops, such as apple and potato, had a very narrow window for calcium uptake. Ninety percent of the calcium taken up by potato tubers or apple fruit occurred within a four- to six-week period after bloom for apple or during budding for potato. Nitrogen-use efficiency of urea-containing fertilizers was also increased with soluble calcium sources, such as calcium nitrate (Easterwood, 2010).

The interactions of planting dates and night break treatments were found in old rhizome, new storage roots, and inflorescences (Appendix 65). The interactions between night break treatments and fertilizer rates were found in new rhizome and inflorescences (Appendix 66). The interactions among the three factors were found in new rhizome and inflorescence of *C. alismatifolia* (Appendix 67-68).

As reviewed by Marschner (2008), an increase in the concentration of Ca^{2+} in the external solution led to an increase in the calcium content in the leaves, but not necessarily in low-transpiring organs, such as fleshy fruits and tubers, supplied predominantly via the phloem.

Magnesium concentration

Planting in November, 15 (OS) significantly increased Mg concentrations in all organs of *C. alismatifolia* at flowering stage (Table 6.14). It was reported that in pasture soil, Mg tended to be the lowest in late spring or early summer (Peverill *et al.,* 2010).

Night break treatment decreased Mg in old and new storage roots, and inflorescence, but not in the old rhizome, new rhizome or leaves of *C. alismatifolia* (Table 6.14). Fertilizer rates at ½ GAP and GAP recommendation rates decreased Mg

in new rhizome, inflorescence and leaves (Table 6.14). Increased potassium fertilization or availability, relative to magnesium, would inhibit magnesium absorption and accumulation and *vice versa*. The degree of this antagonistic effect varied with potassium and magnesium fertilization rates, as well as the ratio of the two nutrients to one another (Lasa *et al.,* 2000). Moreover, phosphorus uptake was often enhanced when the Mg fertilizer was applied. However, mixing some liquid or suspension sources of P and Mg could lead to a reaction that resulted in the formation of a large amount of precipitated material, to the point of near solidification of the mixture (Spectrum Analytic Inc., 2010).

The interactions between planting dates and night break treatments were found in old storage roots, new storage roots and inflorescence (Appendix 69). Planting dates interacted with fertilizer rates in old and new rhizome, inflorescence and leaves (Appendix 70). The interaction between night break treatments and fertilizer rates was found in inflorescence (Appendix 71). The interactions among three factors were found in new rhizome and inflorescence of *C. alismatifolia* (Appendix 72).

6.4.7 Total nonstructural carbohydrates (TNC)

Planting dates influenced the concentration of TNC in old rhizome, old storage roots and inflorescence of *C. alismatifolia*. TNC concentrations of plant grown in RS were higher in old storage roots and inflorescence than in OS. In contrast, TNC concentrations in old rhizome and new storage roots were lower than those of plants grown in RS. Photosynthesis and total nonstructural carbohydrates (TNC) content of the aboveground tissues were the greatest during vegetative growth. Photosynthesis gradually declined over the growing season, whereas TNC decreased sharply during flowering, followed by a gradual decline between midsummer and autumn. Leaf starch increased dramatically to midsummer before declining sharply throughout late summer

and early autumn, whereas sucrose content responded inversely, indicating a mobilization of starch reserves and export of sugars to overwintering belowground sink tissues. Because newly formed underground adventitious buds showed a continuous increase in TNC from midsummer through autumn, export of sugars from the aboveground tissues likely contributed to the increase in TNC (Gesch *et al.,* 2007). Chatterton *et al.* (2006) found that cool-season grasses, those of temperate origin, grown under cool temperatures, accumulated soluble sugars, starch, and fructan, while warm-season grasses accumulated soluble sugars and starch, but no fructan. Thus, cool-season and warm-season grasses might have different metabolic pathways by which they fixed and stored carbon.

Night break treatment for 2 hours increased TNC concentrations in new storage roots and new and old rhizome of *C. alismatifolia*. Pronounced changes in all carbohydrate pools were observed in all plant parts (leaves, petioles, stems, and roots) of vegetative soybean plants during the normal photosynthetic period; however, starch accumulation within leaves which accounted for more than 80% of the nonstructural carbohydrates (starch, sucrose, and hexose sugars) accumulated by the plant during the light period. Efficiency of utilization of starch and sucrose during the normal dark period differed among organs, with leaves being most efficient in mobilizing starch reserves and roots being most efficient in utilizing sucrose reserves (Kerr *et al.,* 1985).

Fertilizer rates at ½ GAP and GAP recommendation rates significantly increased TNC concentrations in all organs of *C. alismatifolia* (Table 6.15). Khuankaew (2010) found that the starch concentration and starch content in curcuma root were greater in N free than N supplying.

There were interactions between planting dates and night break treatments on the increase in TNC concentrations in most of major organs, except in new rhizome. Especially, planting in November without night break remained to have lower TNC in old rhizome and inflorescence as compared with different treatments (Appendix 73). Similarly, Jutamanee and Krisanapook (2009) found that TNC in Jasmine (*Jasminums sambac*) during cool season, with limiting in day length and low temperature, temperature had a greater effect on the improvement of jasmine flower quality than photoperiod. Low temperature also caused a low carbohydrate content in flower which contributed to a poor quality of jasmine flower. Planting dates interacted with fertilizer rates on TNC concentrations in all organs of *C. alismatifolia* (Appendix 74). The similar results were also found between night break treatments and fertilizer rates (Appendix 75). The interaction among three factors were also found in many organs, expect in old rhizome (Appendix 76).

Total nonstructural carbohydrates in leaves

TNC concentration in leaves at L2, L3 and L4 significantly increased in plants grown in November, 15 (OS). Night break treatment for 2 hours increased TNC in leaves at L3 stage. Fertilizer rates at GAP recommendation rate increased TNC in leaves at L2, L3 and L4 stages, where a reverse result was found at L1 stage (Table 6.16). The L2, L3 and L4 stages were the vegetative stages, which plant synthesized food for growth and flowering at the next stage. Plants used starch and/or sugars as resources to support reproductive activity (Chapin *et al.,* 1990), carbohydrate patterns in relation to reproduction in tropical plants had been variable. Marquis *et al.* (1997) found that stored carbohydrates played a major role in reproduction of the tropical *Piper* shrub, as current photosynthate was inadequate to support reproduction.

Furthermore, Newell *et al.* (2002) reported that seasonal variation in carbon was more influenced by carbon gains (i.e., photosynthesis) than by reproduction in four tropical tree species. Leaves subtending reproductive structures might supply carbohydrates to support flower and fruit production, but carbohydrates could also be mobilized from other structures, such as roots and stems (Mooney, 1972). The increase in subtending leaf starch concentrations suggested that these carbohydrates were not utilized to support flower production, but were accumulating as stored reserves for potential use in fruit production or new vegetative growth (Yee and Tissue, 2005). The relationship between fertilizer supply and carbohydrate in plant was reported by Zhao and Oosterhuis (2000). The leaves of the low N plants had significantly lower sucrose, higher starch, and higher total nonstructural carbohydrate concentrations at both measuring times (21 July and 7 August) three weeks after the initiation of N fertilizer compared to high N treated plants. These results indicated that N deficiency during fruiting reduced cotton leaf photosynthesis and also photo assimilate translocation from leaves to fruits.

The interaction between planting dates and night break treatments was found only at L4 stage of *C. alismatifolia* (Appendix 77). Planting dates interacted with fertilizer rates at L1, L2, L3 and L4 growth stages (Appendix 78). The interaction between night break treatments and fertilizer rates were found at L1 and L4 growth stages (Appendix 79). The interactions among three factors were found at L2 and L4 growth stages (Appendix 80).

In this plant, the relationship among the three main factors on TNC was not clear. However, it seemed to be associated with fertilizer-deficient and carbohydrates accumulation. The accumulation of nonstructural carbohydrates (starch, sugars) was a typical feature in source leaves of magnesium-deficient plants (Fischer and Bussler, 1988).

Accumulation of carbohydrates in source leaves of magnesium-deficient plants, for example, in *Phaseolus vulgaris*, was correlated with a distinct decrease in carbohydrate content at sink sites, such as the pods (Fischer and Bussler, 1988) and the roots (Marschner, 2008). When magnesium was deficient and the export of carbohydrates from source to sink sites impaired, there was also a decrease in the starch content of storage tissue, such as oregano, *Phaseolus vulgaris* and potato (Dordas, 2009; Fischer and Bussler, 1988). Accumulation of starch was also found in phosphorus-deficient leaves but somewhat associated with high chlorophyll content of the leaves (Marschner, 2008).

6.5 Conclusion

The effect of planting dates, night break treatments, and fertilizer application rates on physiological responses of *C. alismatifolia* revealed that the increase of growth, inflorescence and rhizomes quality in plant occurred in plant grown in regular season (May). However, plant gown in off season with supplement light at night time by night break for 2 hours could promote growth (plant height and number of shoots per clump) and inflorescence quality (flower stalk) of plant. In addition, fertilizer application rates could increase growth of this plant. The optimum fertilizer application rate for *C. alismatifolia* should be at 7.5 g pot^{-1} (½ GAP) recommended.