TABLE OF CONTENTS

	Page
Acknowledgements	iii
Abstract (in Thai)	iv
Abstract (in English)	vii
List of Tables	xiv
List of Figures	xix
Abbreviations and Symbols	xxxii
CHAPTER 1 Introduction	1
CHAPTER 2 Literature review	4
2.1 Botanical characteristics	4
2.2 Growth of <i>Curcuma alismatifolia</i> Gagnep.	5
2.3 Seasonal production of <i>Curcuma alismatifolia</i> Gagnep.	6
2.4 Agricultural practices	8
2.5 Some factors affecting plant growth and development	13
2.6 Photosynthesis	24
CHAPTER 3 Effects of Planting Dates and Night Break Treatments on	
Growth, Dry Matter and Rhizome Quality of Curcuma	
alismatifolia Gagnep.	36

TABLE OF CONTENTS (CONTINUED)

	Page
3.1 Introduction	36
3.2 Materials and Methods	37
3.3 Results	39
3.4 Discussion	57
3.5 Conclusion	65
CHAPTER 4 Effects of Night Break Treatment on Photosynthesis and	
Growth of Curcuma alismatifolia Gagnep.	66
4.1 Introduction	66
4.2 Materials and methods	67
4.3 Results	70
4.4 Discussion	84
4.5 Conclusion	90
CHAPTER 5 Photosynthetic Light Response at Different Light Levels in	
Curcuma alismatifolia Gagnep.	91
5.1 Introduction	91
5.2 Materials and methods	92
5.3 Results	95
5.4 Discussion	98
5.5 Conclusion T S F e S e f	100

TABLE OF CONTENTS (CONTINUED)

CHAPTER 6 Effects of Planting Dates, Night Break Treatments and	
Fertilizer Application Rates on Physiological Responses of	
Curcuma alismatifolia Gagnep.	101
6.1 Introduction	101
6.2 Materials and methods	102
6.3 Results	105
6.4 Discussion	130
6.5 Conclusion	152
CHAPTER 7 General discussion	153
References	159
Appendix	184
Curriculum vitae	226

ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่ Copyright[©] by Chiang Mai University All rights reserved

LIST OF TABLES

Table		Page
3.1	Effects of planting dates and night break treatments on growth of	
	Curcuma alismatifolia at flowering stage (14 WAP).	41
3.2	Effects of planting dates and night break treatments on leaf area of	
	Curcuma alismatifolia at different growth stages.	42
3.3	Effects of planting dates and night break treatments on leaf color	
	of Curcuma alismatifolia at different growth stages.	43
3.4	Effects of planting dates and night break treatments on day of fully	
	expanded leaf of Curcuma alismatifolia at different growth stages.	44
3.5	Effects of planting dates and night break treatments on	
	inflorescence quality attributes of Curcuma alismatifolia at	
	flowering stage.	46
3.6	Effects of planting dates and night break treatments on total leaves	
	dry weight of Curcuma alismatifolia at different growth stages.	48
3.7	Effects of planting dates and night break treatments on old	
	rhizomes dry weight of Curcuma alismatifolia at different growth	
	stages. by Chiang Mai Univer	49
3.8	Effects of planting dates and night break treatments on new	
	rhizomes dry weight of Curcuma alismatifolia at different growth	
	stages.	50

xiv

Table		Page
3.9	Effects of planting dates and night break treatments on storage	
	roots dry weight of Curcuma alismatifolia at different growth	
	stages.	51
3.10	Effects of planting dates and night break treatments on fibrous	
	roots dry weight of Curcuma alismatifolia at different growth	
	stages.	52
3.11	Effects of planting dates and night break treatments on total dry	
	weight of Curcuma alismatifolia at different growth stages.	53
3.12	Effects of planting dates and night break treatments on rhizomes	
	quality attributes of Curcuma alismatifolia at dormancy stage.	56
4.1	Growth of C. alismatifolia Gagnap. as affected by night break	
	treatments at flowering stage (13 weeks after planting).	72
4.2	Total leaves area of C. alismatifolia Gagnap. as affected by night	
	break treatments at different growth stages.	72
4.3	Leaf color (SPAD unit) of C. alismatifolia Gagnap. as affected by	
	night break treatments at different growth stages.	72
4.4	Inflorescence quality of C. alismatiflia Gagnap. as affected by	
	night break treatments at flowering stage.	273
4.5	Dry weight (g) of old storage roots, old rhizome, fibrous roots,	
	leaves, sheath leaves and new rhizome as affected by night break	
	treatments at different growth stages of C. alismatifolia Gagnap.	74

Table		Page
4.6	Dry weight of new storage roots and whole plant of C.	
	alismatifolia Gagnap. as affected by night break treatments at	
	harvest (21 weeks after planting).	75
6.1	Effects of planting dates, night break treatments and fertilizer	
	application rates on plant height of C. alismatifolia at different	
	growth stages.	106
6.2	Effects of planting dates, night break treatments and fertilizer	
	application rates on leaves number of C. alismatifolia at different	
	growth stages.	108
6.3	Effects of planting dates, night break treatments and fertilizer	
	application rates on leaf area of C. alismatifolia at different	
	growth stages.	109
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.	110
6.5	Inflorescence quality of C. alismatifolia which grown under the	
	different planting dates, night break treatments and fertilizer	
	application rates at flowering stage.	(112)

Table		Page
6.6	Rhizome quality of C. alismatifolia grown under the different	
	planting dates, night break treatments and fertilizer application	
	rates at dormancy stage.	114
6.7	Effects of planting dates, night break treatments and fertilizer	
	application rates on total dry weight of C. alismatifolia at different	
	growth stages.	116
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.	117
6.9	Effects of planting dates, night break treatments and fertilizer	
	application rates on chlorophyll fluorescence of C. alismatifolia	
	at flowering stage.	118
6.10	Effects of planting dates, night break treatments and fertilizer	
	application rates on nitrogen concentration of C. alismatifolia	
	at flowering stage.	119
6.11	Effects of planting dates, night break treatments and fertilizer	
	application rates on phosphorus concentrations of C.	
	alismatifolia at flowering stage.	E ¹²¹

xviii

Table		Page
6.12	Effects of planting dates, night break treatments and	
	fertilizer application rates on potassium concentrations of	
	C. alismatifolia at flowering stage.	123
6.13	Effects of planting dates, night break treatments and fertilizer	
	application rates on calcium concentrations of C. alismatifolia at	
	flowering stage.	124
6.14	Effects of planting dates, night break treatments and fertilizer	
	application rates on magnesium concentrations of C. alismatifolia	
	at flowering stage.	126
6.15	Effects of planting dates, night break treatments and fertilizer	
	application rates on total nonstructural carbohydrates (TNC) of	
	C. alismatifolia at flowering stage.	128
6.16	Effects of planting dates, night break treatments and fertilizer	
	application rates on TNC in leaves of C. alismatifolia at different	
	growth stage.	129

LIST OF FIGURES

Figure

Morphology of Curcuma alismatifolia Gagnep. 5 2.1 3.1 Plants measurement at four growth stages; (a) the 1st fully expanded leaf (L1), (b) the 2^{nd} fully expanded leaf (L2), (c) the 3^{rd} fully expanded leaf (L3) and (d) the 4^{th} fully expanded leaf (L4) 38 Plants measurement at four growth stages in different organs; (a) 3.2 roots, (b) old rhizome, (c) old storage roots, (d and e) leaves and 38 (f) new rhizome. 3.3 Growth of Curcuma alismatifolia Gagnep.; plant height (a), number of leaves per plant (b) and number of shoots per clump (c) of different treatments. 40 Inflorescence quality of Curcuma alismatifolia Gagnep. at 3.4 different planting dates and night break conditions; 15 November 2006 (a), 15 December 2006 (b) and 15 May 2007 (c) from various treatments. Dry weight of Curcuma alismatifolia Gagnep. at L1 to L4 3.5 growth stages; a) leaves, b) rhizome, c) new rhizome, d) storage roots, e) fibrous roots and f) total dry weight of different treatments.

xix

54

Page

LIST OF FIGURES (CONTINUED)

Figure Page 3.6 Rhizomes quality of Curcuma alismatifolia Gagnep. at dormancy stage from different planting dates and night break conditions; 15 November 2006 (a), 15 December 2006 (b) and 15 May 2007 (c) from different treatments. 56 Plants measurement at seven different growth stages; (a) the 1st 4.1 fully expanded leaf, (b) the 2^{nd} fully expanded leaf, (c) the 3 rd fully expanded leaf, (d) the 4th fully expanded leaf, (e) flowering, (f) flower senescence and (g) harvest. 69 Plant height (a), number of leaves per plant (b), and number of 4.2 shoots per clumps (c) of C. alismatifolia Gagnep. as affected by different night break treatments. 71 4.3 Inflorescence quality attributes of C. alismatifolia Gagnep. as affected by night break treatments. 73 4.4 New storage roots of C. alismatifolia Gagnep. under control treatment (a) and as effected by night break (b) condition at harvest. 75 Linear regression of dry weight (g plants⁻¹) of (a) old rhizome, (b) old storage roots, (c) leaves, (d) sheath leaves, (e) new rhizome, (f) fibrous roots and (g) total dry weight of C. alismatifolia as affected by night break treatment against plant growth stages. 77

|--|

Figure		Page
4.6	Photosynthetic rates of C. alismatifolia Gagnap. at L1 (a), L2	
	(b), L3 (c) and L4 (d) as affected by night break treatment	
	compared with control.	79
4.7	PAR of C. alismatifolia Gagnap. at L1 (a), L2 (b), L3 (c) and	
	L4 (d) growth stages as affected by night break treatment	
	compared with control.	81
4.8	Stomatal resistance of C. alismatifolia Gagnap. at L1 (a), L2	
	(b), L3 (c) and L4 (d) growth stages as affected by night break	
	treatment compared with control.	82
4.9	Chlorophyll fluorescence of C. alismatifolia Gagnap. at L1 (a),	
	L2 (b), L3 (c) and L4 (d) growth stages as affected by night	
	break treatment compared with control.	83
5.1	Curcuma alismatifolia Gagnep. at 3 rd fully expanded leaf.	94
5.2	Measurement of photosynthetic efficiency using leaf chamber	
	analyzer Model LCpro ⁺ , ADC BioScientific Ltd., Great	
	Amwell, Herforshire England (a) and LCA4, ADC,	
	Hoddessdon, Herts, England (b).	94
5.3	Photosynthetic rate (Pn) and stomatal resistance (Rs) of C.	
	alismatifolia Gagnep. as determined in the field condition over a	
	range of light intensity.	96

LIST OF FIGURES (CONTINUED)

Figure		Page
5.4	Light response function of C. alismatifolia Gagnep., net	
	photosynthesis as a function of photosynthetic proton flux	
	(μ molm ⁻² s ⁻¹ PPFD) as determined in the laboratory.	97
6.1	The seven growth stages of C. alismatifolia Gagnep.; (a) the 1^{st}	
	fully expanded leaf, (b) the 2^{nd} fully expanded leaf, (c) the 3 rd	
	fully expanded leaf, (d) the 4 th fully expanded leaf, (e) flowering,	
	(f) flower senescence and (g) harvest.	104
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.	111
6.3	Rhizomes of C. alismatifolia Gagnep. grown under various	
	treatments; (a) regular season (May, 15) and (b) off-season (Nov,	114
	15) at harvest.	

ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่ Copyright[©] by Chiang Mai University All rights reserved

LIST OF APPENDIX

Appendix

Page

Append	dix	Page
Table	e	
1	The interaction of planting dates and night break treatments on	
	growth of C. alismatifolia at flowering stage.	185
2	The interaction of planting dates and night break treatments on	
	leaf area of C. alismatifolia at different growth stages.	185
3	The interaction of planting dates and night break treatments on	
	leaf color of C. alismatifolia different at growth stages.	185
4	The interaction of planting dates and night break treatments on	
	fully expanded leaf of <i>C. alismatifolia</i> at different growth stages.	186
5	The interaction of planting dates and night break treatments on	
	flowers quality of C. alismatifolia at flowering stage.	186
6	The interaction of planting dates and night break treatments on	
	total leaves dry weight of C. alismatifolia at different growth	
	stages.	187
7	The interaction of planting dates and night break treatments on old	
	rhizomes dry weight of <i>C. alismatifolia</i> at different growth stages.	187
AII_8	The interaction of planting dates and night break treatments on new	
	rhizomes dry weight of C. alismatifolia at different growth stages.	187

xxiii

Appendix		Page
Table		
9	The interaction of planting dates and night break treatments on storage	
	roots dry weight of C. alismatifolia at different growth stages.	188
10	The interaction of planting dates and night break treatments on fibrous	
	roots dry weight of C. alismatifolia at different growth stages.	188
110	The interaction of planting dates and night break treatments on total	
	dry weight of C. alismatifolia at different growth stages.	188
12	The interaction of planting dates and night break treatments on	
	rhizome quality of C. alismatifolia at dormancy stage.	189
13	Environmental condition during the experimental period, year 2006 -	
	2007. Macroclimate referred to the meteorological data automatically	
	recorded at the Multiple Cropping Center: MCC, Faculty of	
	Agriculture Chiang Mai University weather station.	190
14	Environmental condition during the experimental period, year 2007.	
	Macroclimate referred to the meteorological data automatically	
	recorded at the Lampang Agricultural Research and Training	
	Centre, Lampang.	191
15	Environmental condition during the experimental period, year 2008.	
	Macroclimate referred to the meteorological data automatically	
	recorded at the Lampang Agricultural Research and Training	
	Centre, Lampang.	192

Appendix		Page
Table		
16	Environmental condition during the experimental period, year	
	2009. Macroclimate referred to the meteorological data	
	automatically recorded at the Lampang Agricultural Research	
	and Training Centre, Lampang.	193
17	Interaction of planting dates and night break treatments on plant	
	height of C. alismatifolia at different growth stages.	194
18	Interaction of planting dates and fertilizer rates on plant height of	
	C. alismatifolia at different growth stages.	194
19	Interaction of night break treatments and fertilizer rates on plant	
	height of C. alismatifolia at different growth stages.	194
20	Interaction of planting dates, night break treatments and fertilizer	
	rates on plant height of C. alismatifolia at growth stages.	195
21	Interaction of planting dates and night break treatments on	
	number of leaves of C. alismatifolia at different growth stages.	195
22	Interaction of planting dates and fertilizer rates on number of	
	leaves of C. alismatifolia at different growth stages.	196
23	Interaction of night break treatments and fertilizer rates on	
	number of leaves of C. alismatifolia at different growth stages.	196
24	Interaction of planting dates, night break treatments and fertilizer	
	rates on number of leaves of C. alismatifolia at growth stages.	197

Appendix		Page
Table		
25	Interaction of planting dates and night break treatments on leaf	
	area of <i>C. alismatifolia</i> at different growth stages.	197
26	Interaction of planting dates and fertilizer rates on leaf area of C .	
	alismatifolia at different growth stages.	198
27	Interaction of night break treatments and fertilizer rates on leaf	
	area of C. alismatifolia at different growth stages.	198
28	Interaction of planting dates, night break treatments and fertilizer	
	rates on leaf area of <i>C. alismatifolia</i> at growth stages.	199
29	Interaction of planting dates and night breaks on number of shoots	
	per clump of C. alismatifolia at different growth stages.	199
30	Interaction of planting dates and fertilizer rates on number of	
	shoots per clump of C. alismatifolia at different growth stages.	200
31	Interaction of night break treatments and fertilizer rates on number	
	of shoots per clump of C. alismatifolia at different growth stages.	200
32	Interaction of planting dates, night break treatments and fertilizer	
	rates on number of shoots per clump of C. alismatifolia at	
	different growth stages.	201
33	Interaction of planting dates and night break treatments on flower	
	quality of C. alismatifolia at flowering stage.	201

xxvi

	٠	٠
XXV	1	1

Appendix		Page
Table		
34	Interaction of planting dates and fertilizer rates on flower quality of	
	C. alismatifolia at flowering stage.	202
35	Interaction of night break treatments and fertilizer rates on flower	
	quality of <i>C. alismatifolia</i> at flowering stage.	202
36	Interaction of planting dates, night break treatments and fertilizer	
	rates on flower quality of <i>C. alismatifolia</i> at flowering stage.	203
37	Interaction of planting dates and night break treatments on	
	underground parts quality of C. alismatifolia at dormancy stage.	203
38	Interaction of planting dates and fertilizer rates on underground	
	quality parts of C. alismatifolia at dormancy stage.	204
39	Interaction of night break treatments and fertilizer rates on	
	underground parts quality of C. alismatifolia at dormancy stage.	204
40	Interaction of planting dates, night break treatments and fertilizer rates	
	on underground parts quality of C. alismatifolia at dormancy stage.	205
41	Interaction of planting dates and night break treatments on total dry	
	weight of C. alismatifolia at different growth stages.	205
42	Interaction of planting dates and fertilizer rates on total dry weight of	
	C. alismatifolia at different growth stages.	206
43	Interaction of night break treatments and fertilizer rates on total dry	
	weight of C. alismatifolia at different growth stages.	206

/11

	•	٠	٠	
XX	V1	1	1	

Appendix		Page
Table		
44	Interaction of planting dates, night break treatments and fertilizer	
	rates on total dry weight of C. alismatifolia at different growth stages.	207
45	Interaction of planting dates and night break treatments on	
	photosynthetic rate (Pn) and PAR on leaf surface (Q_{leaf}) of	
	C. alismatifolia at flowering stage.	207
46	Interaction of planting dates and fertilizer rates on photosynthetic	
	rate (Pn) and PAR on leaf surface (Q_{leaf}) of C. alismatifolia at	
	flowering stage.	208
47	Interaction of night break treatments and fertilizer rates on	
	photosynthetic rate (Pn) and PAR on leaf surface (Q_{leaf}) of	
	C. alismatifolia at flowering stage.	208
48	Interaction of planting dates, night break treatments and fertilizer	
	rates on photosynthetic rate (Pn) and PAR on leaf surface (Q_{leaf}) of	
	C. alismatifolia at flowering stage.	209
49	Interaction of planting dates and night break treatments on	
	chlorophyll fluorescence of C. alismatifolia at flowering stage.	209
50 5	Interaction of planting dates and fertilizer rates on chlorophyll	
	fluorescence of C. alismatifolia at flowering stage.	210
51	Interaction of night break treatments and fertilizer rates on	
	chlorophyll fluorescence of C. alismatifolia at flowering stage.	210

		٠	
X	Х	1	X

Appendix		Page
Table		
52	Interaction of planting dates, night break treatments and fertilizer rates	
	on chlorophyll fluorescence of C. alismatifolia at flowering stage.	211
53	Interaction of planting dates and night break treatments on nitrogen	
	concentrations of <i>C. alismatifolia</i> at flowering stage.	211
54	Interaction of planting dates and fertilizer rates on nitrogen	
	concentrations of C. alismatifolia at flowering stage.	212
55	Interaction of night break treatments and fertilizer rates on nitrogen	
	concentrations of C. alismatifolia at flowering stage.	212
56	Interaction of planting dates, night break treatments and fertilizer rates	
	on nitrogen concentrations of C. alismatifolia at flowering stage.	213
57	Interaction of planting dates and night break treatments on	
	phosphorus concentrations of C. alismatifolia at flowering stage.	213
58	Interaction of planting dates and fertilizer rates on phosphorus	
	concentrations of C. alismatifolia at flowering stage.	214
59	Interaction of night break treatments and fertilizer rates on	
	phosphorus concentrations of C. alismatifolia at flowering stage.	214
60	Interaction of planting dates, night break treatments and	
	fertilizer rates on phosphorus concentrations of C. alismatifolia	
	at flowering stage.	215

Appendix		Page
Table		
61	Interaction of planting dates and night break treatments on potassium	
	concentrations of C. alismatifolia at flowering stage.	215
62	Interaction of planting dates and fertilizer rates on potassium	
	concentrations of <i>C. alismatifolia</i> at flowering stage.	216
63	Interaction of night break treatments and fertilizer rates on potassium	
	concentrations of C. alismatifolia at flowering stage.	216
64	Interaction of planting dates, night break treatments and fertilizer rates	
	on potassium concentrations of C. alismatifolia at flowering stage.	217
65	Interaction of planting dates and night break treatments on calcium	
	concentrations of C. alismatifolia at flowering stage.	217
66	Interaction of planting dates and fertilizer rates on calcium	
	concentrations of C. alismatifolia at flowering stage.	218
67	Interaction of night break treatments and fertilizer rates on calcium	
	concentrations of C. alismatifolia at flowering stage.	218
68	Interaction of planting dates, night break treatments and fertilizer rates	
	on calcium concentrations of C. alismatifolia at flowering stage.	219
69	Interaction of planting dates and night break treatments on	
	magnesium concentrations of C. alismatifolia at flowering stage.	219
70	Interaction of planting dates and fertilizer rates on magnesium	
	concentrations of C. alismatifolia at flowering stage.	220

Appendix		Page
Table		
71	Interaction of night break treatments and fertilizer rates on magnesium	
	concentrations of C. alismatifolia at flowering stage.	220
72	Interaction of planting dates, night break treatments and fertilizer rates	
	on magnesium concentrations of C. alismatifolia at flowering stage.	221
73	Interaction of planting dates and night break treatments on TNC of	
	C. alismatifolia at flowering stage.	221
74	Interaction of planting dates and fertilizer rates on TNC of	
	C. alismatifolia at flowering stage.	222
75	Interaction of night break treatments and fertilizer rates on TNC of	
	C. alismatifolia at flowering stage.	222
76	Interaction of planting dates, night break treatments and fertilizer	
	rates on TNC of C. alismatifolia at flowering stage.	223
77	Interaction of planting dates and night break treatments on TNC of	
	C. alismatifolia at different growth stages.	223
78	Interaction of planting dates and fertilizer rates on TNC of	
	C. alismatifolia at different growth stages.	224
79	Interaction of night break treatments and fertilizer rates on TNC of	
	C. alismatifolia at different growth stage.	224
80	Interaction of planting dates, night break treatments and fertilizer	
	rates on TNC of C. alismatifolia at different growth stages.	225

ABBREVIATIONS AND SYMBOLS

°C	:	Degree Celsius
cm	:0	Centimeter
g	:	Gram
hrs	:	Hours
μ	:	Micro
RH	:	Relative humidity
%	:	Percent
PAR	:	Photosynthetically active radiation
TNC	:	Total nonstructural carbohydrates
Pn	:	Photosynthetic rate
Rs		Stomatal resistance

ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่ Copyright[©] by Chiang Mai University All rights reserved

xxxii