## TABLE OF CONTENTS

	Page
Acknowledgement	iii
Abstract (English)	v
Abstract (Thai)	Х
List of Tables	xxi
List of Figures	xxvi
Introduction	1
Chapter 1 Literature review	5
1.1 Acid soil problems	5
1.1.1 Extension of acid soils	5
1.1.2 Soil acidity and nutrient deficiency	9
1.2 Impact of Al toxicity on plants	12
1.2.1 Growth responses to Al toxicity	12
1.2.2 Nutrient uptake efficiency and Al toxicity	13
1.2.3 Difference in Al tolerance among crop species and genotypes	16
1.3 Tolerance mechanisms to Al toxicity in plants	17
1.3.1 External detoxification of Al 1.3.2 Internal detoxification of Al	18 20
1.3.3 Mechanisms of Al tolerance in rice <b>C C C C C C</b>	21
1.4 Management of Al toxicity and soil acidity	22
1.4.1 Amelioration of acid and Al-toxic soils	22

1.4.2 Selection for acid-soil or Al tolerant plants	25
1.5 Genetic variation for Al tolerance in rice	27
Chapter 2 Growing upland rice on acid soil: a case study at Tee Cha	30
village	30
2.1 Introduction	32
2.2 Materials and Methods	32
2.2.1 Experiment 2.2.1 Soil survey and crop cut on upland rice fields	32
2.2.2 Experiment 2.2.2 Performance of upland rice varieties on acid soil fields	32
2.2.3 Experiment 2.2.3 Response of rice in simulated slash-and-burn in pot experiment	36
2.3 Results	38
2.3.1 Crop cut survey on acid soil fields in year 2004	38
2.3.2 Performance of upland rice varieties in farmers' fields on acid soil in 2006	42
2.3.3 Effect of burned biomass on rice growth	50
2.4 Discussion 1149918198818810	55
Chapter 3 Genotypic variation in tolerance to Al toxicity in Thai rice germplasm	<sup>59</sup> Sity
A 3.1 Introduction ghts reserv	e 59
3.2 Materials and Methods	62
3.2.1 Genotypic variation among rice varieties to soil acidity and Al	62

xvii

toxicity	
Experiment 3.2.1.1 Germination of upland rice in acid soil	62
Experiment 3.2.1.2 Responses of rice to Al levels in nutrient	62
solution	
Sub experiment 1 Variation among upland rice varieties	62
<u>Sub experiment 2</u> Comparing the responses of rice to Al made	62
from different aluminum salts	
Sub experiment 3 Comparing the responses of rice to Al with	64
and without air bubbling in nutrient solution	
Sub experiment 4 Variation among improved Thai rice	64
varieties	
3.2.2 Genotypic variation within local rice varieties recognized by	68
the same name	
Experiment 3.2.2.1 Variation between and within seed lots of	68
local upland rice varieties	
Experiment 3.2.2.2 Variation between and within seed lots of	72
deep water rice	
ลิ 3.3. Results ริ มหาวิทยาลัยเชียงไห	73
3.3.1 Genotypic variation among rice varieties to soil acidity and Al toxicity	73 <b>ty</b>
Experiment 3.3.1.1 Germination of upland rice in acid soil	73
Experiment 3.3.1.2 Responses of rice in tolerance to Al toxicity	75
in nutrient solution	

Sub experiment 1 Variation among upland rice varieties	75
Sub experiment 2 Comparing the responses of rice to Al made	77
from different aluminum salts	
Sub experiment 3 Comparing the responses of rice to Al with	77
and without air bubbling in nutrient solution	
Sub experiment 4 Variation among improved Thai rice	78
varieties	
3.3.2 Genotypic variation within local rice as recognized as the same	89
variety name	
Experiment 3.3.2.1 Variation between and within seed lots of	89
upland rice varieties	
Experiment 3.3.2.2 Variation between and within seed lots of	100
deep water rice "Leung Yai"	
3.4 Discussion	106
Chapter 4 Morphological and physiological responses of upland rice	111
in tolerance to Al toxicity in nutrient solution	
4.1 Introduction	111
4.2 Materials and Methods 31313131313	113
4.3. Results 4.4 Discussion by Chiang Mai Univers	115 149
A Chapter 5 General Discussion t S reserve	155
5.1 Genotypic variation of rice in tolerance to soil acidity	155
5.2 Physiological mechanism for Al tolerance in rice	157

5.2.1 Effect of Al on germination	157
5.2.2 Effect of Al on root growth	158
5.2.3 Inhibited nutrient uptake and induced deficiency	159
5.2.4 Al accumulation in plant part	160
5.3 Acid tolerance for upland rice production on acidic soils in the	161
highlands	
5.3.1 Farmer's management on upland field	161
5.3.2 Performance of upland rice varieties on acidic soils	163
5.4 General conclusion	164
5.5 Further research	165
References	166
Curriculum vitae	183
AI UNIVERSI	

ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่ Copyright<sup>©</sup> by Chiang Mai University All rights reserved

## LIST OF TABLES

Table		Page
1.1	The range of Al tolerance in field crops	17
2.1	Number of farmers planted to local upland rice varieties in Tee	35
	Cha village in year 2004	
2.2	Farmer's field collecting in year 2004	36
2.3	Soil pH of six farmer's fields during vegetative stage of the rice	40
	crop in year 2004	
2.4	Yields of upland rice varieties in different farmer's fields that	40
	grown in year 2004	
2.5	Yield components of upland rice varieties in different farmer's	41
	fields that grown in year 2004	
2.6	Soil pH and exchangeable Al at 0-15 and 15-30 cm soil depth	45
	from the ground level of three farmer's fields that collected at	
	vegetative stage in year 2006	
2.7	Dry weight of straw and grain of plant samples (collected three	49
	plants for each replicates) and grain yield in 2m x 2m quadrants of	
ີລິບສີ	three upland rice varieties that kept by different farmers at	КIJ
Convr	maturity by Chiang Mai Univer	sitv
2.8	Yield components of three upland rice varieties that kept by	49
	different farmers at maturity C C C C C C C C C C C C C C C C C C C	e a
2.9	Soil pH collected at three soil depths at 30 days after sowing of	51
	rice grown in acid soils without (Ash0) and with adding ash	

	(Ash+)	
2.10	Nutrient concentrations and nutrient contents of ash from biomass	51
	burning; biomass collected from 7-yearr-rotational cycle at Tee	
	Cha village	
3.1	Nutrient concentration of Kimura B solution	66
3.2	Preparation of Kimura B solution	66
3.3	Characteristic of popular improved Thai rice varieties	67
3.4	Chromosomal locations, primer sequences, repeat motif and	71
-35	annealing temperature of six microsatellite primers	
3.5	Root and shoot growth of six rice varieties at three treatments in	79
	nutrient solution at 14 days after treatments	
3.6	Relative values of root and shoot growth of six rice varieties that	80
	grown in Al <sub>0</sub> -pH4 compared with Al <sub>0</sub> -pH7 (pH effect), Al <sub>30</sub> -pH4	
	compared with Al <sub>0</sub> -pH4 (Al effect) and Al <sub>30</sub> -pH4 compared with	
	Al <sub>0</sub> -pH7 (pH + Al effect)	
3.7	Correlation coefficients between relative root length (RRL) with	81
	root and shoot lengths, and plant dry weights by pH effect, Al	
ຄິບສີ	effect and pH + Al effect	<b>1</b>
3.8	Root length, shoot length, root dry weight and shoot dry weight of	84
	KDML105 growing in 2 Al-form in nutrient solution at 21 days	LY
	after treatments <b>ITS IESEIVE</b>	C
3.9	Root length (cm) of five varieties growing in nutrient solution	85
	without and with oxygen supply by air bubbling (B0 and B+) in	

xxii

		$Al_0$ and $Al_{30}$ at 21 days after treatment	
	3.10	Root dry weight (mg plant <sup>-1</sup> ) of five varieties growing in nutrient	86
		solution without and with oxygen supply by air bubbling (B0 and	
		B+) in Al <sub>0</sub> and Al <sub>30</sub> at 21 days after treatment	
	3.11	Shoot dry weight (mg plant <sup>-1</sup> ) of five varieties growing in nutrient	87
		solution without and with oxygen supply by air bubbling (B0 and	
		B+) in Al <sub>0</sub> and Al <sub>30</sub> at 21 days after treatment	
	3.12	Root length and relative root length (RRL) of 10 rice varieties to	88
		Al toxicity in nutrient solution at 21 days after treatments	
	3.13	Morphological characters and genetic variation between and	93
		within seed lot as recognized as the same variety names of BB,	
		BM and PA that obtained 2 seed lots of each variety	
	3.14	Root length of each two seed lots (obtained 20 progeny lines each)	94
		recognized as the same variety names of BB, BM and PA with 2	
		Al levels, 0 and 30 mg Al L <sup>-1</sup> , in nutrient solution for 21 days	
	3.15	Relative root length of each two seed lots (obtained 20 progeny	95
		lines each) recognized as the same variety names of BB, BM and	
â	Jai	PA in response to Al toxicity	IJ
C	3.16	Allele frequencies of two upland rice varieties	96
	3.17	Gene diversity $(H_e)$ of BB and BM populations based on six	97
A		microsatellite loci <b>N T S F E S E F V E</b>	C
	3.18	Partition of genetic diversity within and between population of	98

upland rice BB and BM based on six microsatellite loci

3.19	Genetic differentiation among population ( $F_{ST}$ ) matrix values	99
	determined across six microsatellite loci of local upland rice BB	
	and BM	
3.20	Seed characters and Shannon's Index of 15 seed lots of a variety	102
	rcognized as Leung Yai that kept by different farmers	
3.21	Grain length between and within seed lots recognized as the same	103
	variety name as Leung Yai collected from 15 farmers' seed lots.	
3.22	Root length of 15 seed lots of deep water rice "Leung Yai" that	104
-35	grown in nutrient solution with 2 Al levels, 0 and 30 mg $L^{-1}$ at 21	
	days after treatments	
4.1	Root length of four rice varieties when grown in nutrient solution	122
	with four Al levels for 30 and 45 days	
4.2	Shoot length of four rice varieties when grown in nutrient solution	123
	with four Al levels for 30 and 45 days	
4.3	Root number of four rice varieties when grown in nutrient solution	124
	with four Al levels for 30 and 45 days	
4.4	Root dry weight (mg plant <sup>-1</sup> ) of four rice varieties when grown in	125
ลิขสา	nutrient solution with four Al levels for 30 and 45 days	hIJ
4.5	Shoot dry weight (mg plant <sup>-1</sup> ) of four rice varieties when grown in	126
	nutrient solution with four Al levels for 30 and 45 days	
<b>A</b> 4.6	Correlation coefficients between relative root length (RRL) with	129
	relative values of shoot length (RSL), root number (RRN), root	
	dry weight (RRW), shoot dry weight (RSW) and total dry weight	

(RTW) at  $Al_{10}$ ,  $Al_{20}$  and  $Al_{30}$  relative to  $Al_0$  at 30 and 45 days after treatments

- 4.7 Aluminum concentration in root and shoot of BB and KDML105 130
   with comparing at Al<sub>0</sub> and Al<sub>30</sub> in nutrient solution at 45 days after
   treatment
- 4.8 Nitrogen content (mg plant<sup>-1</sup>) in whole plant of four rice varieties 138 when grown in nutrient solution with four Al levels for 30 and 45 days

4.9 Phosphorus content (mg plant<sup>-1</sup>) in whole plant of four rice
varieties when grown in nutrient solution with four Al levels for
30 and 45 days

- 4.10 Potassium content (mg plant<sup>-1</sup>) in whole plant of four rice varieties 140 when grown in nutrient solution with four Al levels for 30 and 45 days
- 4.11 Calcium content (mg plant<sup>-1</sup>) in whole plant of four rice varieties
   when grown in nutrient solution with four Al levels for 30 and 45
   days

4.12 Magnesium content (mg plant<sup>-1</sup>) in whole plant of four rice 142 varieties when grown in nutrient solution with four Al levels for 30 and 45 days
4.13 Correlation coefficient between RRL with relative nutrient 146 contents of N, P, K, Ca and Mg at Al<sub>10</sub>, Al<sub>20</sub> and Al<sub>30</sub> relative to

Al<sub>0</sub> at 30 days after treatments

## LIST OF FIGURES

Fi	gure	Page
1.1	1 World acid soils	7
1.2	2 Extent and distribution of Ultisols and Alfisols in Thailand	8
1.3	3 Relative activities of mononuclear Al species of soluble Al as a	10
	function of pH	
1.4	4 Organic acids able to form 5- or 6-membered ring structures with	19
	Al <sup>3+</sup> protect plants from Al toxicity	
1.5	5 A model showing how Al-activated malate efflux protects wheat	20
	root tips from Al toxicity	
2.1	1 Tee Cha village's land used in 2000-2006	34
2.2	2 Al concentration in plant of three upland rice varieties that kept	45
	by three different farmers at tillering and flowering stages in year	
	2006	
2.3	3 Shoot length (a) and plant dry weight (b) of three upland rice	46
	varieties that kept by three different farmers at tillering, flowering	
	and maturity stages in year 2006	-
<b>a</b> 22.4	4 Nutrient contents of P, K, Ca, and Mg in whole plant top of three	47
Con	upland rice varieties that kept by three different farmers at tiller,	reitv
	flowering and maturity in year 2006	ISILY
<b>A</b> 2.5	5 Nutrient contents of P, K, Ca and Mg in straw and grain of three	e <sub>48</sub>
	upland rice varieties that kept by three different farmers in year	
	2006.	

2.6 52 Shoot and root dry weight of BB and KDML105 when grown in acid soils without (Ash0) and with adding ash (Ash+) on the soil surface comparing at 20 and 30 days after sowing 2.7 Root growth distribution of Bue Bang and KDML105 when 53 grown in acid soil without (Ash0) and with ash (Ash+) at 30 days after planting in three soil layers; 0-5 cm, 5-10 cm and 10-30 cm depth from the top soil. 2.8Nutrient contents of N, P, K, Ca and Mg of Bue Bang and 54 KDML105 grown in acid soils without (Ash0) and with ash (Ash+) at 30 days after sowing. 3.1 Percentage of survived seedlings when grown in soil with two pH 74 levels; 5.8 (A) and 3.5 (B) 3.2 Root growth of six rice varieties at 14 days after treatments that 82 grown in Al<sub>0</sub> (left) and Al<sub>30</sub> (right) in nutrient solution with pH4 3.3 83 The symptoms of Al toxicity in rice; A) leaf symptom at  $Al_{30}$ , B) root growth at  $Al_0$ , C) root growth of Al-tolerant variety at  $Al_{30}$ , D) and E) root growth of Al-sensitive variety at  $Al_{30}$ . Microsatellite amplification products of BB population that detected by primer RM335. Lane 1-20 population of BB1, M 25 bp ladder, Lane 21-35 population of BB2 Genetic distance among population determined across six microsatellite loci of local upland rice BB and BM by UPGMA

methods using the MEGA2 program

xxviii

3.6	Root growth of Leung Yai seed lots in response to Al toxicity in	105
	nutrient solution; A) comparing root growth between $Al_0$ and	
	Al <sub>30</sub> ; B) and C) variation among individual plants within seed lot	
	at Al <sub>30</sub>	
4.1	Relative root length (RRL) of four rice varieties at $Al_{10}$ , $Al_{20}$ and	127
	$Al_{30}$ compared with $Al_0$ in nutrient solution at 30 (A) and 45 (B)	
	days after treatments	
4.2	Relative total dry weight of four rice varieties at $Al_{10}$ , $Al_{20}$ and	128
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	$Al_{30}$ compared with $Al_0$ in nutrient solution at 30 (A) and 45 (B)	
Į Ž	days after treatments	
4.3	Relative nutrient uptake of nitrogen of four rice varieties at Al <sub>10</sub> ,	143
	$Al_{20}$ and $Al_{30}$ compared with $Al_0$ in nutrient solution at 30 and 45	
	days after treatments	
4.4	Relative nutrient uptake of phosphorus of four rice varieties at	143
	$Al_{10}$ , $Al_{20}$ and $Al_{30}$ compared with $Al_0$ in nutrient solution at 30	
	and 45 days after treatments	
4.5	Relative nutrient uptake of potassium of four rice varieties at $Al_{10}$ ,	144
ລິບສີ	$Al_{20}$ and $Al_{30}$ compared with $Al_0$ in nutrient solution at 30 and 45	หม
Convi	days after treatments	sitv
4.6	Relative nutrient uptake of calcium of four rice varieties at $Al_{10}$ ,	144
	$Al_{20}$ and $Al_{30}$ compared with $Al_0$ in nutrient solution at 30 and 45	ea
	days after treatments	

- 4.7 Relative nutrient uptake of magnesium of four rice varieties at 145
   Al<sub>10</sub>, Al<sub>20</sub> and Al<sub>30</sub> compared with Al<sub>0</sub> in nutrient solution at 30
   and 45 days after treatments
- 4.8 Nutrient uptake efficiency of N, P, K, Ca and Mg (A, B, C, D, E)
   147 of four rice varieties in culture solution at four Al levels at 30 days after treatments



ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่ Copyright<sup>©</sup> by Chiang Mai University All rights reserved