Chapter 2

Growing upland rice on acid soil: a case study at Tee Cha village

2.1 Introduction

Soil acidity is a common yield limiting for crop production worldwide. In Thailand, acid soils are distributed in all part of the country and covered about 45% of total land area. Many of these soils are utilized for rice production both in lowland and upland rice area. In case of lowland rice which occurs on acid-sulphate soils in the Central Plain of Thailand, farmers usually manage their crops by addition of lime or marl and P fertilizer, which can effectively improved the rice yield and profit from rice farming (Charoenchamratcheep *et al.*, 1982; Maneewan *et al.*, 1982). On the other hand, in case of upland rice area which occurs on acidic and infertile soils, such soil amendments are neither practical nor economical. Small farmers, particular ethnic minority groups (e.g. Karen, Hmong, Lua and Akha, etc.) in mountainous areas who grow upland rice as a subsistence crop are unable to afford lime and fertilizer. However, the low productivity of upland rice may be improved by farmer management in rotational shifting cultivation. In this slash-and-burn system, ash from burnt biomass releases nutrients previously stored in the forest biomass onto the soil surface and makes it available for the crops during cultivation period (Juo and Manu, 1996).

In Tee Cha village, Mae Hong Son province, Northern Thailand, Karen farmers grow their upland rice crop in a one in seven year rotational shifting cultivation. A previous study in this village of Yimyam (2006) reported that crops were usually grown on acidic soils deficient in P, obtaining generally low grain yields, except where the fallow forest had high density of a fallow enriching tree, *Macaranga denticulata*. A rice diversity of local rice varieties was also found in this village (Sirabanchongkran *et al.*, 2004; Yimyam, 2006). However, there is little information on how well these different upland rice varieties perform on the problem soil of this area. Therefore, this study aimed to assess the performance of upland rice varieties on different farmers' fields, and to examine variation between rice varieties in the same field for adaptation to acidic soils and on-farm management.

2.2 Materials and methods

Experiment 2.2.1 Soil survey and crop cut on upland rice fields

The field survey was carried out at Tee Cha village, Sob Moei district of Mae Hong Son province, northern of Thailand. Information of land use and upland rice varieties in this village was recorded by Yimyam (2006) (Figure 2.1 and Table 2.1). For the survey in year 2004, six farmers who grew different upland rice varieties cooperated to evaluate yield by crop cutting. From interviewed farmers when the rice was at vegetative growth stage, farmers designated their plots as bad and good plot by visual observation (Table 2.2). At this time, soil samples of each field were collected at 0-15 cm and 15-30 cm depth with 3 replicates for determination of pH (water, 1:1).

At harvest, sample of rice crop was taken in 2m x 2m quadrants in good and bad plots with 3 replicates. Plants were cut at ground level and then number of hills and number of panicles was counted from the samples area. Samples were threshed, grain and straw were weighed separately. The grain was sun-dried for 3 days before weighing. At this time, the grain moisture content was reduced to 12%. Straw was oven dried at 80°C for 48 hours before weighing.

Experiment 2.2.2 Performance of upland rice varieties on acid soil fields

This experiment was conducted in year 2006, by sampling the upland rice crop in fields belonging to three farmers, Kan, Thongdee and Porda (designated as Field A, Field B and Field C, respectively), each of whom was growing two varieties: BB-PA in Field A, BM-PA in Field B and BB-BM in Field C. From each field, soil samples was collected for determination of pH (water, 1:1) and exchangeable Al by using atomic absorption spectrophotometer. This study was carried out into 2 parts; nutrient accumulation in plant and crop yield.

Nutrient accumulation in plant

Three plants of each replicated sample were separately collected in triplicates at three times: tillering, flowering and maturity stages. Plant samples were cut at ground level and measured for shoot length. Then, whole top plants were washed with tap water to remove soil and dirt, oven dried at 80°C for 48 hours and weight. At maturity, grain and straw were weighed separately. Grains were separated into brown rice and husk before nutrient analysis. For nutrient analysis, plant samples were oven dried at 80 °C for 48 hours and ground to pass a 1 mm mesh. They were dry-ashed at 500°C for 8 hours and dissolved in 0.1 N HCl and then P was determined by using a colorimetric assay (molybdovanado-phosphoric acid method) and a spectrophotometer (Murphy and Riley, 1962); K, Ca, Mg and Al by atomic absorption spectrophotometer. Nutrient content of each element was calculated by % concentration multiply by plant dry weight.

Crop yield

At maturity, samples of the rice crop were taken in 2m x 2m quadrants with three replicates. Plants were cut at ground level and then number of hills and number of panicles was counted from the samples area. Samples were threshed, grain and straw separated for weighing as described in Experiment 2.2.1.

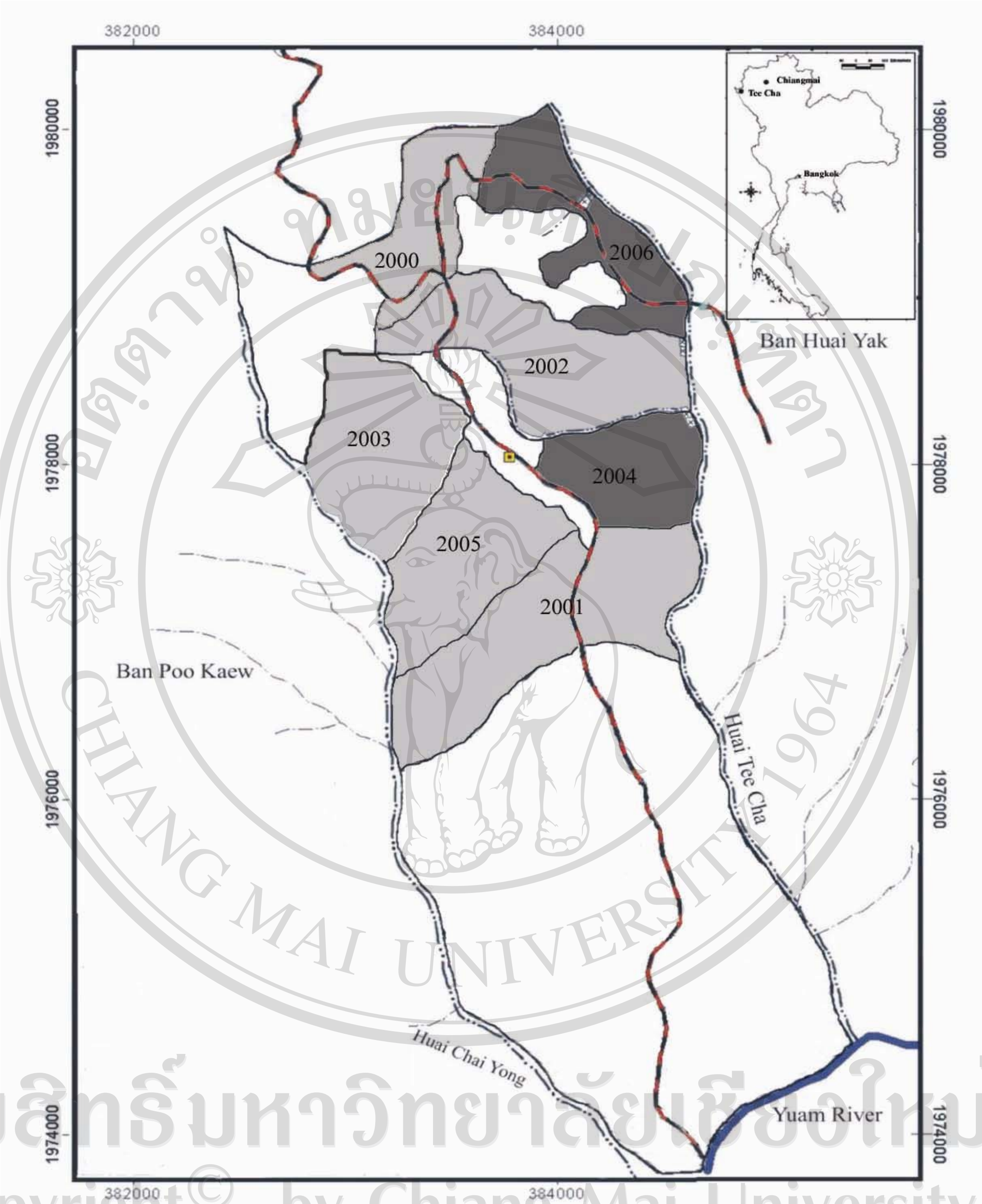

Figure 2.1 Tee Cha village's land used in 2000-2006. ■ Represent the study site in year 2004 and 2006.

Source: Yimyam (2006)

Table 2.1 Number of farmers planted to local upland rice varieties in Tee Cha village in year 2004.

Variety name	Rice type	Number of farmers
Bue Bang	Non-glutinous	8
Bue Gao	Non-glutinous	9
Bue Goal	Non-glutinous	3
Bue Kee	Non-glutinous	3
Bue Paw Low	Non-glutinous	7
Bue Pho Lae	Non-glutinous	3
Bue Mue Ta Bong	Non-glutinous	8
Bue Chu	Non-glutinous	4
Bue Khu Koo	Non-glutinous	1
Bue Tho Lae	Non-glutinous	1
Bue Care	Non-glutinous	1
Pa Ai Khu Phae	Glutinous	14
Pa Ai Ki Kal	Glutinous	1
Pa Ai Goal	Glutinous	1
Pa Ai Chai	Glutinous	1
Pa Ai Chair	Glutinous	2
Total		36

Source: Yimyam (2006)

Table 2.2 Farmer's field collecting in year 2004.

Farmer's field	Rice variety	Plant growth (visual observation)
Porda	Bue Bang (BB)	Good
	Bue Mue Ta Bong (BM)	Good
	Pa Ai Khu Phae (PA)	Bad
Kan	Bue Bang (BB)	Good
	Pa Ai Khu Phae (PA)	Bad
Nopporn	Bue Bang (BB)	Bad
Tongdee	Bue Mue Ta Bong (BM)	Good
Tucare	Bue Gao (BG)	Good
Por	Bue Paw Law (BP)	Good

Experiment 2.2.3 Response of rice in simulated slash-and-burn in pot experiment

Rice growth in slash-and-burn system at Tee Cha village was simulated by setting in pot experiment. For pot preparation, soil was collected from Tee Cha village with pH 4.68 and then adjusted to pH 4.0 by $Al_2(SO_4)_3.18H_2O$ 3 g kg^{-1} soil. Pot (25 cm diameter and 25 cm depth) was contained 15 kg soils. There were two treatments, without ash (Ash0) and with ash (Ash+; burning 200 g biomass pot^{-1} on the soil surface before planting), in completely randomized design with three replicates. Biomass for ash treatment was collected from 7-year-rotational cycle at Tee Cha village and applied at the rate equivalent to biomass in the fallow with dense population of *Macaranga*. After pot preparation, ten seeds of each of the rice varieties BB and KDML105 were grown together in the same pot. There were three replicated pots and separate sets of pots for the two harvests at 20 and 30 days after sowing.

At each harvest, maximum shoot length and tiller number were recorded and then plants were cut off at the ground level. Roots were separately collected at three soil layers, 0-5, 5-10 and 10-25 cm depths, and washed by tap water. Soil samples were also collected in each layer, air-dried and determined for soil pH (water, 1:1). Root and shoot dry weights were measured after oven drying at 70°C for 48 hours. After that, the samples were ground to pass a 1 mm mesh for nutrient analysis. One set of the plant samples were digested in sulfuric acid and analyzed by the Kjeldahl method for N. Another set of samples were determined for P, K, Ca and Mg in the same method as described in Experiment 2.2.2. For statistical analysis, data were analyzed using analysis of variance (ANOVA) to determine the effects of variety, ash treatment and interaction between variety and ash treatment. Means were compared by least significant difference (LSD) at $P < 0.05$.

2.3 Results

2.3.1 Crop cut survey on acid soil fields in year 2004

Information about upland rice growing in the village

Upland rice growing at Tee Cha village is conducted in shifting cultivation in a 7-year rotation cycle (Figure 2.2). Farmers managed their fields by slashing and burning the fallow vegetation in the seventh year, and then growing upland rice in the ash. During the fallow period, *Macaranga* (local named Pada) is the dominant species. Farmers indicated that density of *Macaranga*, sparse or dense, during the fallow period is positively related to final crop yields. Thus, good rice yield can be expected where the mature fallow was dense with *Macaranga* (4 trees/10 m^2), and poor rice yield where the trees were sparse (1 tree/10 m^2). Generally, farmers plant both glutinous and non-glutinous rice types for their household's requirement. In 2004, there were16 upland rice variety names containing 5 varieties of glutinous and 11 varieties of non-glutinous type. The most common varieties were Bue Gao (BG), Bue Bang (BB), Bue Mue Ta Bong (BM), Bue Paw Low (BP) and Pa Ai Khu Phae (PA) (Table 2.1). Usually, one farmer could grow more than 1 variety on his field depending on the condition of field and there various requirements. Farmers in this village, along with others of the Karen ethnic group, usually prefer non-glutinous rice for staple food and glutinous rice for brewing rice liquor and making deserts and other preparations for traditional and religious ceremonies.

Crop growth and yield

Six farmer's fields which grew different rice varieties and designated to bad and good plots were chosen for this study (Table 2.2). At vegetative phase, soil pH of those fields ranged from 4.7-5.4 on the top soil and slightly decreased to 4.6-5.2 in deeper soil. The visual observation at vegetative stage as good and bad plot was associated with the strength of acidity in each field, bad plot as Nopporn's field was the lowest soil pH and good plot as Tucare's field was the highest (Table 2.3).

At maturity, yields varied among farmer's fields. Grain and straw yields of five varieties were varied from 0.8-2.8 ton ha^{-1} and 1.6-4.6 ton ha^{-1}, respectively (Table 2.4). Grain yields of BB in Porda's and Kan's fields which had soil pH in the medium ranged were three times higher than that in Nopporn's field. The low yield in Nopporn's field (pH 4.7) was relative to lower harvest index (HI) and fewer panicles (Table 2.5). On the other hand, grain yields and HI of each BM and PA showed less variation between farmer's fields, their grain yields were quite low 1.3-1.5 ton ha^{-1} of BM and 0.9-1.2 ton ha^{-1} of PA (Table 2.4).

There was variation in final crop yield between varieties in the same field. In Porda's field, grain yield of BB was the highest (2.8 ton ha^{-1}) whereas BM and PA were less than half as compared with BB. High HI of BM could not bring it to the same level as BB. In Kan's field, grain yield of BB was twice higher than PA even though their straw weigh was almost the same (Table 2.4).

Table 2.3 Soil pH of six farmer's fields during vegetative stage of the rice crop in year 2004.

Farmer's field	Soil pH	
	0-15 cm from ground level	15-30 cm from ground level
Porda	4.85	4.84
Kan	5.14	5.07
Nopporn	4.73	4.63
Tongdee	4.93	4.88
Tucare	5.43	5.20
Por	5.11	5.05

Table 2.4 Yields of upland rice varieties in different farmer's fields that grown in year 2004. Each value is the mean of 3 replicates ± SE.

Farmer's field	Variety	Yield (ton ha^{-1})			Harvest index
		Grain	Straw	Total	
Porda	BB	2.8 ± 0.3	4.6 ± 0.4	7.4 ± 0.7	37
	BM	1.3 ± 0.0	1.6 ± 0.1	3.0 ± 0.1	45
	PA	0.9 ± 0.2	2.9 ± 0.3	3.8 ± 0.4	24
Kan	BB	2.4 ± 0.4	3.1 ± 0.5	5.5 ± 1.0	44
	PA	1.2 ± 0.1	3.7 ± 0.3	4.5 ± 0.2	26
Nopporn	BB	0.8 ± 0.1	2.0 ± 0.2	2.8 ± 0.3	28
Tongdee	BM	1.5 ± 0.1	2.3 ± 0.2	3.8 ± 0.2	40
Tucare	BG	1.6 ± 0.4	1.6 ± 0.4	3.2 ± 0.7	52
Por	BP	2.6 ± 0.4	2.9 ± 0.3	5.5 ± 0.7	47

Table 2.5 Yield components of upland rice varieties in different farmer's fields that grown in year 2004. Each value is the mean of three replicates ± SE.

Farmer's filed	Variety	Yield components		
		Hills m^{-2}	Panicles $hill^{-1}$	Panicles m^{-2}
Porda	BB	7.7 ± 0.6	12.5 ± 0.5	95.3 ± 5.5
	BM	9.7 ± 2.1	7.8 ± 1.5	73.0 ± 4.6
	PA	9.3 ± 2.3	8.6 ± 1.2	79.3 ± 14.0
Kan	BB	9.0 ± 2.0	13.1 ± 0.1	118.0 ± 26.5
	PA	6.3 ± 1.5	15.2 ± 2.5	95.7 ± 26.1
Nopporn	BB	8.3 ± 1.5	5.2 ± 1.0	42.7 ± 2.1
Tongdee	BM	7.6 ± 2.4	10.9 ± 2.9	78.0 ± 7.5
Tucare	BG	6.7 ±1.5	11.7 ± 2.2	76.7 ±17.7
Por	BP	7.0 ± 2.0	13.3 ± 1.6	92.0 ± 23.6

2.3.2 Performance of upland rice varieties in farmers' fields on acid soil in 2006

Soil pH and exchangeable Al

Soil pH in farmer's fields which designated as Field A, Field B and Field C varied from 4.7 to 5.5. In Field A and Field B, soil pH in PA plot was lower than in BB and BM of each field while soil pH in Field C was not much different between variety plots. In each plot, while soil pH was slightly lower in deeper soil, exchangeable Al at 15-30 cm was twice as much as that in the top soil at 0-15 cm. Although exchangeable Al in soil varied among areas, it was almost the same between varieties in field A and C whereas it was higher in PA than in BM at field B (Table 2.6). There was negative correlation between soil pH and exchangeable Al, r = -0.662* ($P < 0.05$).

Correlation of Al concentration in plant and exchangeable Al in soil

There was differential response for Al accumulation in the rice plant. At tillering stage, Al concentration in plant of both varieties in each farmer's filed quite followed in the same trend as exchangeable soil Al. There was little difference in Al concentration between varieties in Field A whereas PA in Field B and BM in Field C were higher than the other variety of each field about 30%. However, Al concentration in the rice shoots declined by flowering time, irrespective of varieties. The difference between varieties disappeared in Field B whereas BM had twice as much Al as BB in Field C (Figure 2.2).

Plant growth and nutrient accumulation

Plant growth of three upland rice varieties; BB, BM and PA, differed between the different fields, and also showing differentiation between varieties in the same field. Plant height of PA at all three stages was lower than BB and BM in Field A and Field B. At Field C, plant height of BB was also higher than BM at all times (Figure 2.3a). Plant dry weight (whole tops) of PA was lower than the other variety, and PA appeared to have stopped growing after tillering stage in Field A and grew only slightly more in Field B. In Filed C, plant dry weight of BB was 30% higher than BM at flowering, however, their weights were not different at final harvest stage (Figure 2.3b).

Nutrient contents of the varieties in each field also showed the same trend with plant dry weight. At tillering, contents of P, K, Ca and Mg in whole top were the lowest in PA, which were only half of those in BB and BM in each fields. Moreover, the nutrient contents in PA were almost constant after tillering stage, while those of BB and BM continued to increase until maturity, particularly in P and Mg. In Field C, the accumulation of those elements was similar in BB and BM at all times (Figure 2.4).

At maturity, straw and grain parts were separated to determine nutrient accumulation. The accumulation of each element showed similar trends in all three varieties. The most of P and 50% of Mg were accumulated in grain whereas K and Ca were almost accumulated in shoot and slightly taken up to grain (Figure 2.5).

Grain and straw yield

While there was some variation of soil condition, crop productivity was more different between varieties in each farmer's field. Straw and grain weight per plant of BB and BM were about the same in Field C, in Field A and Field B they were more than twice as those in PA. These results were confirmed by crop cutting in 2 x 2 m^2. There was variation of grain yield for the same rice varieties between fields, but greater difference between glutinous rice (PA) and non-glutinous rice (BB and BM). The grain yield of BB in Field A and BM in Field B were clearly lower than those varieties in Field C, but they were still much higher than PA, which yielded only 55% of BB in Field A and 25% of BM in Field B. However, high HI of PA could not bring it to the same levels as BB and BM (Table 2.7).

There were some different in numbers of hill and panicles of PA at both fields. The lower hill numbers in Field B were compensated by increasing panicles per hill. On the other hand, those of BB and PA were not different in Field A, higher grain yields of BB was depended on grain weight per panicle (Table 2.8).

Table 2.6 Soil pH and exchangeable Al at 0-15 and 15-30 cm soil depth from the ground level of three farmer's fields that collected at vegetative stage in year 2006. The values represent Mean ± SE.

Farmer's field		Depth (cm)	
	Variety	0-15	15-30
Soil pH (water1:1)			
Field A	BB	5.5 ± 0.2	5.0 ± 0.1
	PA	5.0 ± 0.0	5.0 ± 0.2
Field B	BM	5.4 ± 0.1	5.0 ±0.0
	PA	4.7 ± 0.1	4.8 ± 0.1
Field C	BB	5.3 ± 0.0	5.0 ± 0.1
	BM	5.1 ± 0.1	4.8 ± 0.1
Exchangeable Al (ppm)			
Field A	BB	44 ± 8	125 ± 17
	PA	54 ± 10	135 ± 3
Field B	BM	80 ± 15	136 ± 23
	PA	106 ± 16	202 ± 22
Field C	BB	56 ± 9	178 ± 29
	BM	91 ± 9	224 ± 24

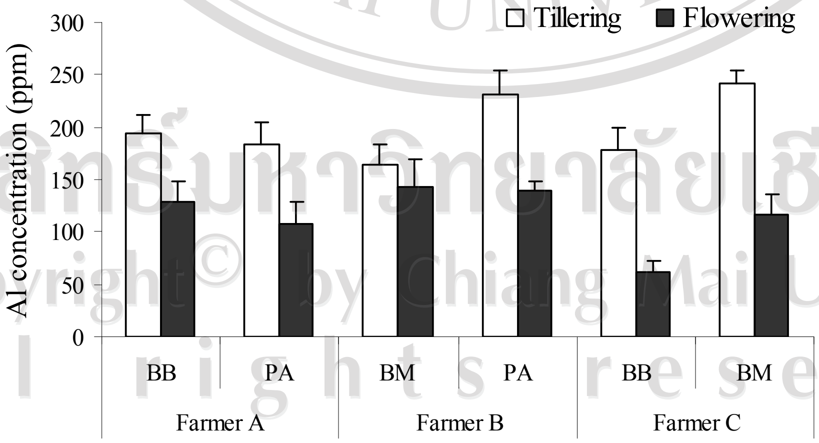

Figure 2.2 Al concentration in plant of three upland rice varieties that kept by three different farmers at tillering and flowering stages in year 2006. The error bar represent ± SE (n = 3).

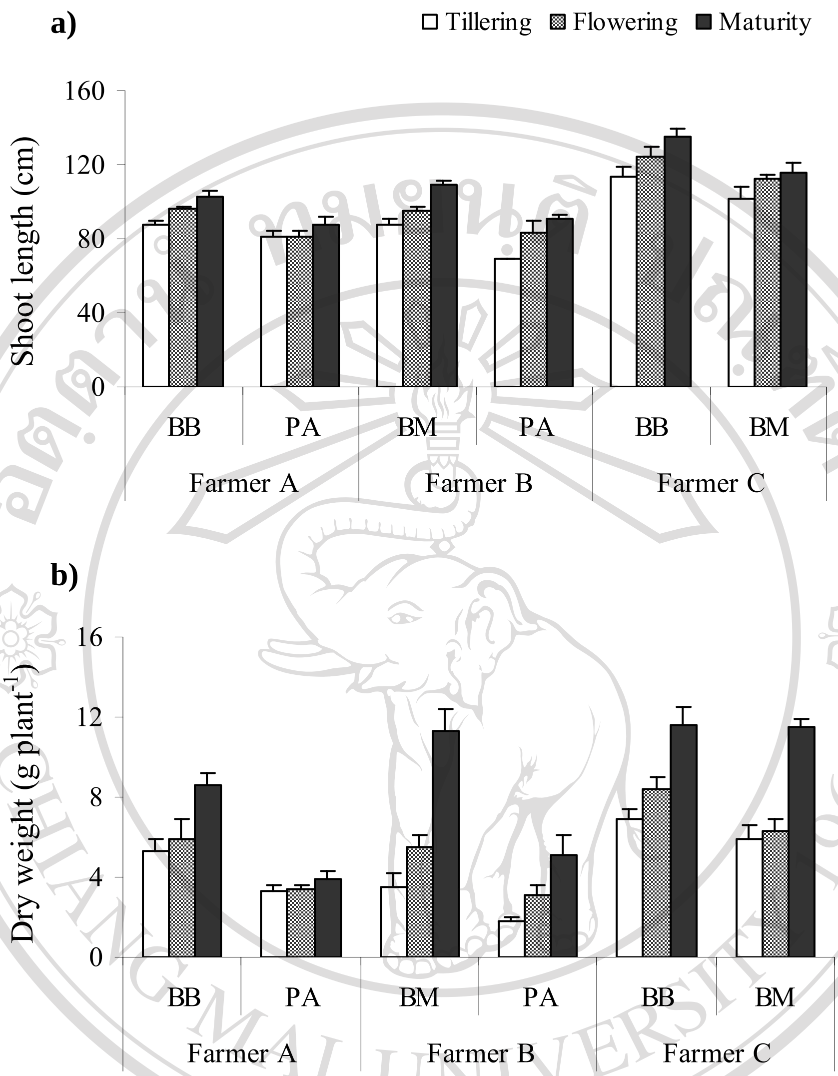

Figure 2.3 Shoot length (a) and plant dry weight (b) of three upland rice varieties that kept by three different farmers at tillering, flowering and maturity stages in year 2006. The error bar represent ± SE (n = 3).

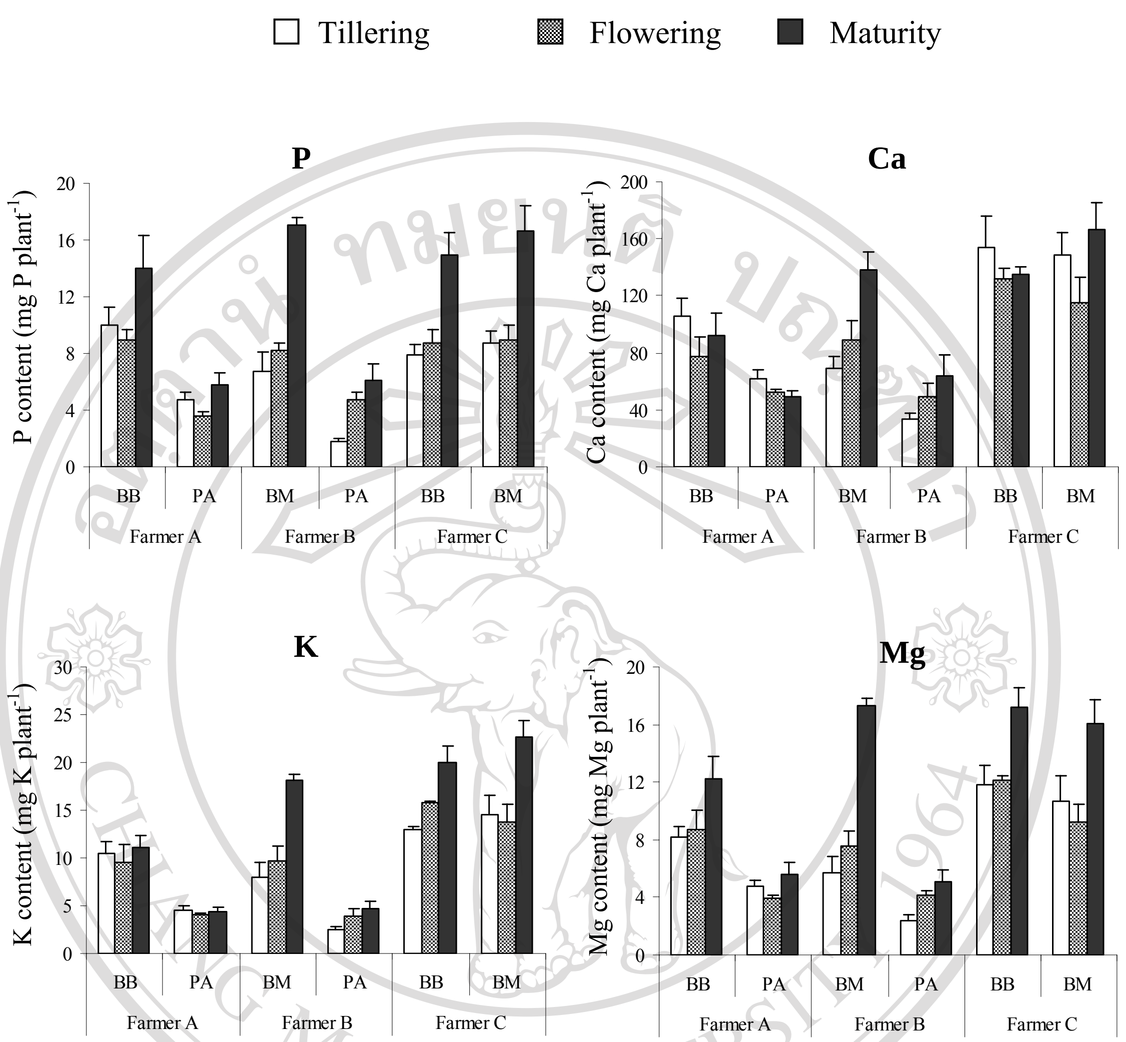

Figure 2.4 Nutrient contents of P, K, Ca, and Mg in whole plant top of three upland rice varieties that kept by three different farmers at tiller, flowering and maturity in year 2006. The error bar represent ± SE (n = 3).

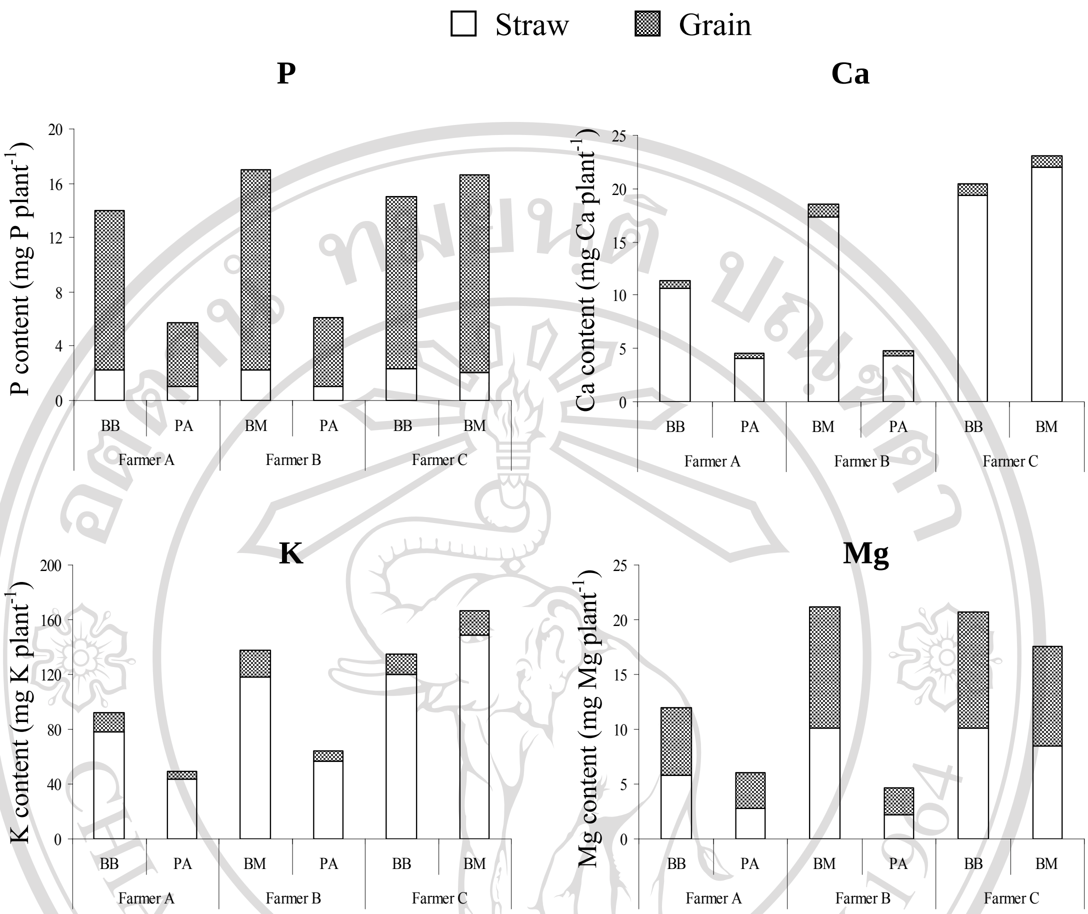

Figure 2.5 Nutrient contents of P, K, Ca and Mg in straw and grain of three upland rice varieties that kept by three different farmers in year 2006.

Table 2.7 Dry weight of straw and grain of plant samples (collected three plants for each replicate) and grain yield in 2m x 2m quadrants of three upland rice varieties that kept by different farmers at maturity. Each value is the mean of 3 replicates ± SE.

Farmer's field	Variety	Dry weight (g plant^{-1})		Grain yield (ton ha^{-1})	HI
		Straw	Grain		
A	BB	4.4 ± 0.5	4.2 ± 0.2	1.42 ± 0.03	52
	PA	2.3 ± 0.2	1.6 ± 0.3	0.80 ± 0.14	49
B	BM	5.9 ± 0.3	5.4 ± 0.8	1.98 ± 0.25	63
	PA	2.5 ± 0.6	2.6 ± 0.5	0.53 ± 0.09	55
C	BB	6.5 ± 0.4	5.1 ± 0.6	3.59 ± 0.39	45
	BM	6.5 ± 0.4	5.0 ± 0.4	2.78 ± 0.35	44

Table 2.8 Yield components of three upland rice varieties that kept by different farmers at maturity. Each value is the mean of 3 replicates ± SE.

Farmer's field	Variety	Yield component			
		Hills m^{-2}	Panicles hill^{-1}	Panicle m^{-2}	Grain weight (g) panicle^{-1}
A	BB	7.3 ± 0.6	7.5 ± 0.5	54.8 ± 4.2	1.3 ± 0.1
	PA	7.5 ± 1.3	7.0 ± 0.4	53.5 ± 12.0	0.8 ± 0.2
B	BM	6.0 ± 0.3	10.6 ± 1.5	62.8 ± 6.1	1.6 ± 0.3
	PA	3.3 ± 0.2	9.8 ± 0.6	32.7 ± 3.4	0.8 ± 0.1
C	BB	6.7 ± 0.4	15.0 ± 1.6	100.5 ± 14.3	1.8 ± 0.2
	BM	7.0 ± 0.0	11.2 ± 1.1	78.7 ± 7.6	1.9 ± 0.3

2.3.3 Effect of burned biomass on rice growth

Growth response

The soil amended by burning biomass on the soil surface increased soil pH on the top soils (Table 2.9) and enriched of essential nutrient from ash i.e. Ca, K and Mg (Table 2.10) which increased rice growth. At 20 days, the ash treatment (Ash+) increased shoot dry weight of both varieties by about 50% as compared with no ash treatment(Ash0) but there was no difference in root dry weight between Ash+ and Ash0. From 20 days to 30 days, shoot and root dry weights in Ash+ were increased several times, irrespective of varieties, but were almost constant in Ash0 (Figure 2.6).

At 30 days, there was differential response between varieties to ash treatments. In Ash0, BB produced more root dry weight than KDML105. In Ash0 roots of BB were distributed more in deeper soil layer than those of KDML105, with BB having about three times more roots (measured in dry weight) at 10-25 cm soil depth than KDML105. Although the difference in total root dry weight of the two rice varieties did not differ in Ash+, BB was still penetrating to deeper soils whereas KDML105 distributed most of its roots in the first 0-5 cm of the surface soil (Figure 2.7). With the same amount of root dry weight in Ash+, KDML105 produce about 30% more shoot dry weight than BB (Figure 2.6).

Nutrient accumulation in the rice plant

Adding ash increased nutrient accumulation to plant. The uptakes of N, P, K, Ca and Mg in Ash+ were much higher than in Ash0. In Ash0, nutrient contents of the two varieties were not different, but those of KDML105 were higher than BB in Ash+ except Mg (Figure 2.8).

Table 2.9 Soil pH collected at three soil depths at 30 days after sowing of rice grown in acid soils without (Ash0) and with adding ash (Ash+).

Treatment	Variety	Soil depth (cm)		
		0-5	5-10	10-25
Ash0	Bue Bang	4.27	4.25	4.19
	KDML105	4.26	4.22	4.25
Ash+	Bue Bang	4.62	4.28	4.28
	KDML105	4.58	4.27	4.24

Table 2.10 Nutrient concentrations and nutrient contents of ash from biomass burning. The biomass was collected from 7-yearr-rotational cycle at Tee Cha village.

Element	**Concentration (%)**	**Content (kg ha^{-1})**
Nitrogen	0.68	32
Phosphorus	0.83	39
Potassium	7.27	342
Calcium	12.31	580
Magnesium	3.29	154

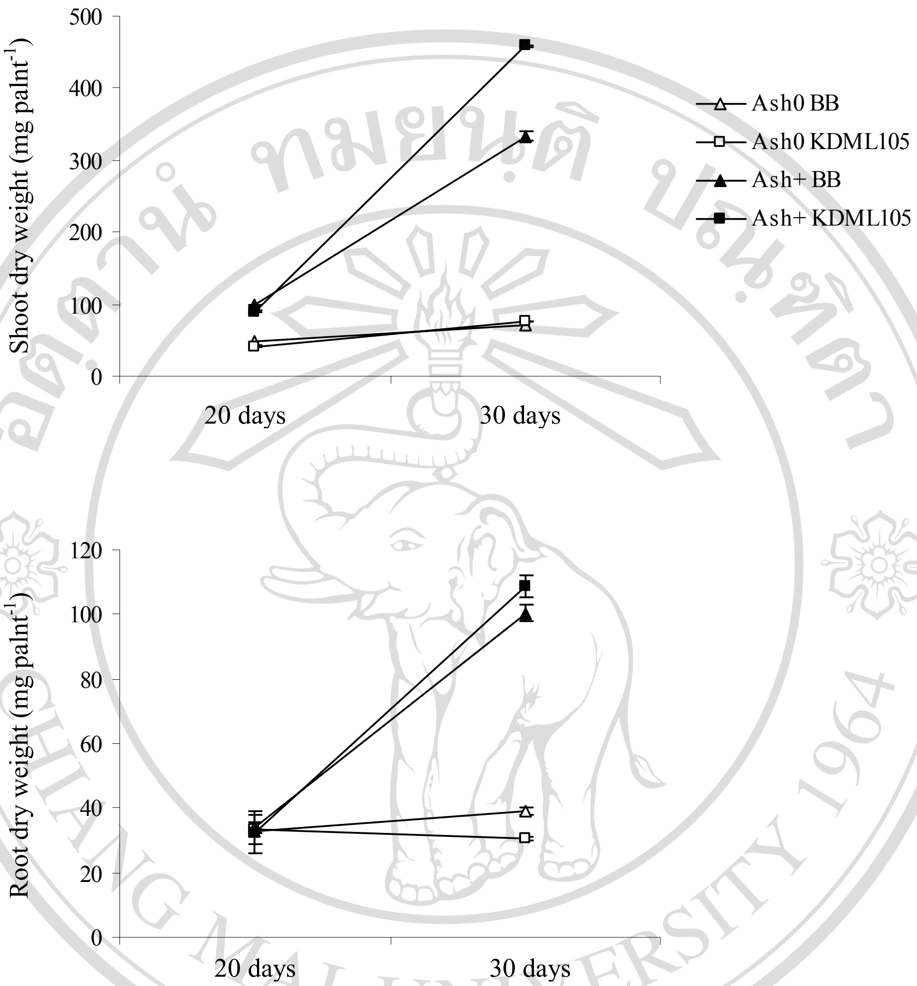

Figure 2.6 Shoot and root dry weight of BB and KDML105 when grown in acid soils without (Ash0) and with adding ash (Ash+) on the soil surface comparing at 20 and 30 days after sowing. The error bar represent ± SE (n = 3).

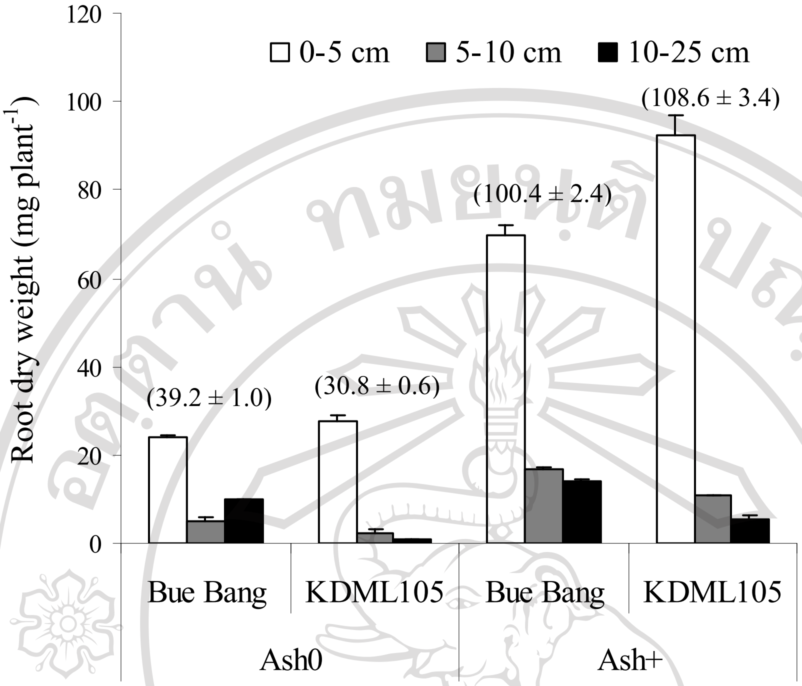

Figure 2.7 Root growth distribution of Bue Bang and KDML105 when grown in acid soil without (Ash0) and with ash (Ash+) at 30 days after planting in three soil layers; 0-5 cm, 5-10 cm and 10-30 cm depth from the top soil. The values in brackets above the bars represent total root dry weight (g) for each variety in each soil treatment ± SE.

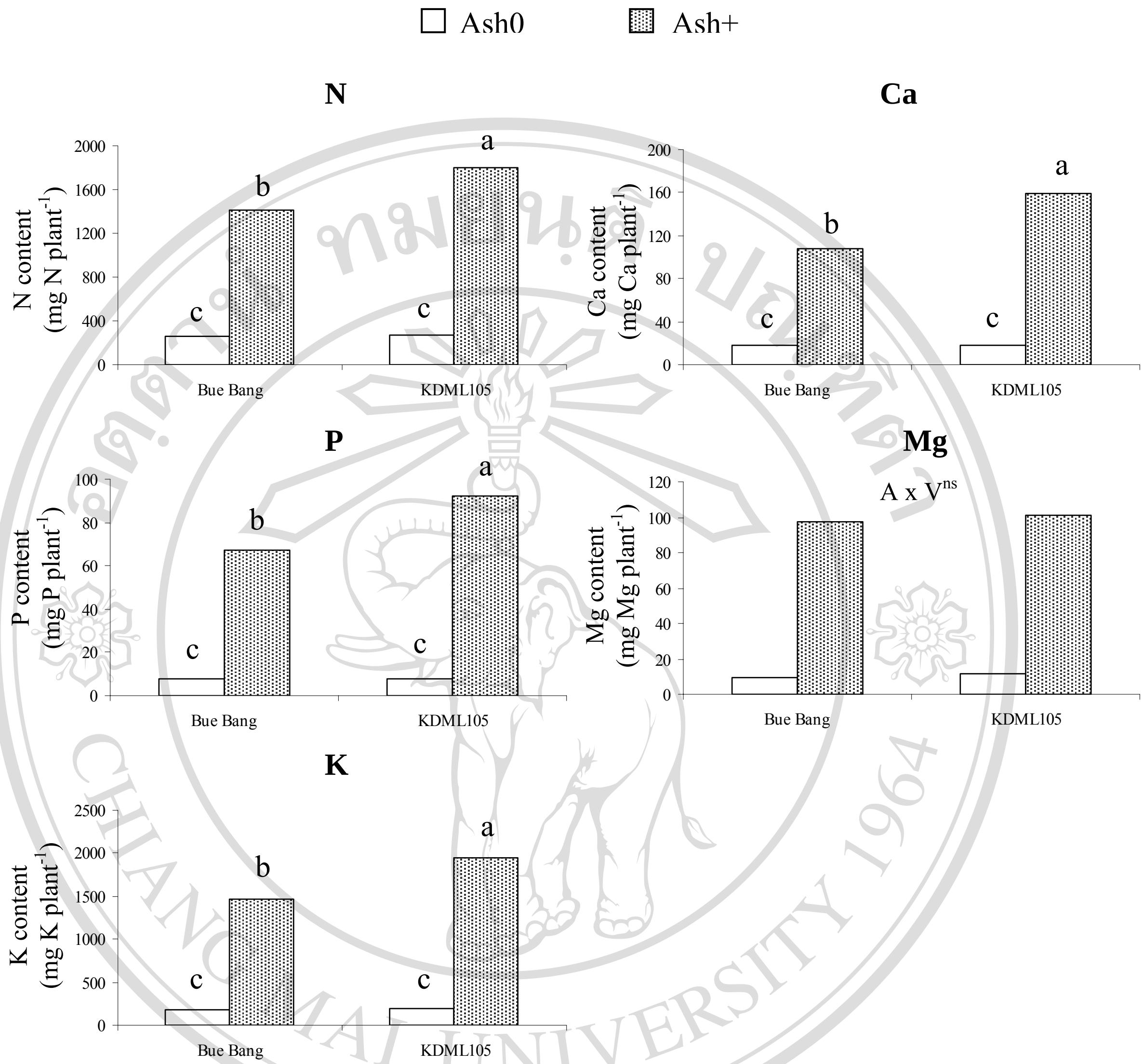

Figure 2.8 Nutrient contents of N, P, K, Ca and Mg of Bue Bang and KDML105 grown in acid soils without (Ash0) and with ash (Ash+) at 30 days after sowing. The different letters showed significant different between variety and ash treatment interaction effect by LSD ($P < 0.05$).

2.4 Discussion

The field survey of farmers' rice crop at Tee Cha village confirmed that upland rice on shifting cultivation in this area is cropped on acid soils with pH as below as 5.0. By visual observation, plant growth showed differentiation between farmer's fields and also variation between varieties within a field at earlier growth stage. Plants were different partly caused by varying in soil conditions i.e. soil pH, soil fertility and slope area. From slashed and burned system in this village, fertility of acid soils on farmer's fields may be improved by ash from burning above ground biomass particular dominant *Macaranga* species which release adequate nutrients necessary to maintain yield of upland rice (Yimyam, 2006). From farmers' interview, the designating as good and bad plots by farmers was associated with the amount of *Macaranga* in densely and sparsely before cropping. The previous study of Yimyam (2006) in the same village suggested that density of *Macaranga* was relative to grain yield of upland rice. Following densely populated *Macaranga* in the fallow, upland rice yielded twice as much grain as the grown in patches where *Macaranga* had been sparse during the fallow.

However, there was also genotypic differentiation in the same field which had the same amount of *Macaranga*. This difference may depend on ability of the rice varieties to adapt to soils with low pH and fertility. The study in 2004, crop yield of PA was much lower than other varieties in the same field such as in Porda's and Kan's fields. The sensitivity of PA was confirmed in year 2006 when compared with BB and BM in each farmer's field. The acid-soil tolerant BB and BM took up twice as much P, K, Ca and Mg and produced twice as much above ground dry matter as the sensitive PA. This difference is likely to have contributed towards yield difference, in which grain yield of PA was only one quarter of BM or one half of BB in the same field. Surprisingly sensitive PA is the most popular rice variety in this village (Sirabanchongkran *et al*., 2004). Glutinous rice PA is a special rice variety, grown in very small mounts for special ceremonial food preparations including for home brewing of rice liquor. So perhaps yield is not as critical as for non-glutinous rice such as BB, BG, BM and BP which together provided the bulk of the village's, rice harvest.

The exchangeable Al in soils was closely correlated with Al concentration in shoot part at tillering stage (r = 0.80; $P < 0.05$). However, by the time of flowering, the shoot Al concentration had declined considerably, showing no clear relationship with growth or yield. All of the upland rice varieties had Al concentration in the shoot at tillering exceeded 100 mg Al kg^{-1} DW considered to be critical value for Al toxicity by some authors (Dobermann and Fairhurst, 2000). Growth of PA was much lower than BB in Field A but they were not different in Al concentration whereas Al concentration of PA was higher than BM in Field B. The grain yield obtained in Field C for both BB and BM were considered high in the village and for upland rice in general. However the yield of 3.6 ton ha^{-1} for BB was associated with 178 mg Al kg^{-1} in the shoot at tillering and the 2.8 ha^{-1} for BM was associated with an even higher Al concentration in the shoot at tillering, with 241 mg Al kg^{-1}. These results suggested the yield measured in Field C either (a) reflected a significant adverse impact of Al toxicity, so indicating high yield potential for BB and BM, or (b) there was no significant yield depression by Al toxicity, suggesting tolerance to these high levels of Al in the shoot in BB and BM. These results suggested that the relationship between shoot Al and plant growth and yield may not be so direct and straight forward, and response to Al in the shoot is still poorly understood for rice.

It is well known that one primary effect vegetation burning in shifting cultivation is to make the nutrients accumulated in biomass available to the crop and also liming effect for acid soils (Juo and Manu, 1996). The soil amendment effect was confirmed by simulating burning biomass on the top soil in the pot experiment. In Ash+, in which the same amount of biomass as in densely *Macaranga*'s fields burnt on the soil surface, plant dry weight and nutrient uptake of the varieties were much higher than that grown on soil with no burning of biomass, Ash0. Although, root dry weight of two varieties were not different in Ash+, the rooting pattern over soil depth indicated major genotypic variation that may play a key role in adaptation to acid soil of upland rice. This may partly explain how KDML105 had higher dry weight of the shoot and up take of nutrients than BB, as the dense surface roots would enable KDML105 to mop up all the essential nutrients mobilized by burning. However, greater root distribution in the deeper soil profile of BB should be advantageous in the field. Yoshida (1981) suggested that the soil starts drying from the surface but the deep soil horizon may remain wet and able to supply water to the plant's roots. The deep root portion may be more meaningful than shallow root portions for drought resistance. Moreover, the deeper roots of BB may be adapted more effectively to high slope on upland fields. This difference in rooting patterns of BB and KDML105 may be associated with the variety types. Yoshida (1981) suggested that lowland varieties have very high root density around the plant base but limited in the deep soils whereas upland varieties have a well-spaced lateral root distribution and penetration deeper into the soil profile. In addition to its ability to grow more deeper-roots in general, BB was able to do this even in Ash0, whereas KDML105 grew hardly any roots below 5 cm in the non-amended, acidic soil. These results suggested that rooting depth may be important to tolerance to soil acidity and Al toxicity in upland rice just as it has been shown to be the case for soybean (Ferrufino *et al.*, 2000).

The application of ash in crop would be beneficial in reducing Al and Mn toxicity and supplying nutrient in acid soils. Ash is generally considered as a rich source of K, Ca, Mg and P, as well as micronutrient (Nkana *et al.*, 1998; Saarsalmi *et al.*, 2001). However, the composition of ash varies in dependent on tree species and local conditions on which a tree was growing (Górecka *et al.*, 2006). The amount of nutrient elements from ash in this study was equivalent to 580 kg Ca ha^{-1}, 342 kg K ha^{-1}, 154 kg Mg ha^{-1}, 39 kg P ha^{-1} and 32 kg N ha^{-1} plus an effect of soil pH increased from 4.0 to 4.5, which was a similar trend as other reports by different location and plant species (Juo and Manu, 1996). The utility of ash was also depended on capacity of the soils to retain and store these elements in forms that are available to plants.

In this chapter I have established clearly that 1) upland rice varieties differed in performance on acidic and infertile soils, 2) the acid soil tolerant BB and BM showed remarkable tolerance to high Al in shoot, and 3) the tolerance to acid soils is associated with root distribution in the deeper soil layer. However, genotypic variation of these upland rice varieties in the field condition is often influenced by other factors than Al toxicity, therefore, the genotypic different to Al toxicity should be clear in controlled condition.