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Different Cultivation Techniques on Macronutrient Utilization of Lowland Rice on Acid Sulfate Soil for Sustainable Production

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ABSTRACT
This study aimed to compare different cultivation techniques and plot levels on macronutrient utilization of lowland rice grown on acid sulfate soil for sustainable production. Cultivation technique (Modified Cultivation (MC) technique and Conventional Cultivation (CC) technique) and plot level (upper plot and lower plot) were experimental factors. Under MC technique, farmer applied 187.5 kg ha^{-1} of compound fertilizer (16-20-0) and 18.75 kg ha^{-1} of KCl (0-0-60) at planting, incorporated the previous rice stubble, transplanted rice seedlings and followed 2 weeks flooding and 1 week completely drainage system. Under CC technique, farmer applied 312.5 kg ha^{-1} of 16-20-0 compound fertilizer at planting, burned the previous rice stubble, broadcasted rice seeds and followed continuous flooding throughout the growing period. Upper plot was directly irrigated from drainage canal and lower plot was irrigated with the drained water from upper plot. Compared with CC technique, MC technique improved soil macronutrients content, especially N and P improving utilization of those nutrients by rice plant. Utilization of most macronutrients by rice was not statistically affected by plot level. It was suggested that farmers should follow MC technique to meet higher macronutrient utilization of lowland rice for sustainable production under acid sulfate soil.

Key words: Acid sulfate soil, rice production technique, conventional cultivation technique, macronutrient utilization, modified cultivation technique, sustainable rice production

INTRODUCTION

Plant growth is the result of a complex process whereby the plant synthesizes solar energy, carbon dioxide, water and nutrients from the soil (Gruhn *et al*., 2000). Acid sulfate soils have been viewed as soils that are difficult to manage for crop production because of their inherently low fertility (Shamshuddin *et al*., 2014). Ponamperuma (1984) has found that addition of organic matter to those soils improves soil nutrition.

The increased use of inorganic fertilizers alone leads to decline in soil quality and multiple nutrient deficiencies even in regions of high agronomic potential (Tsujimoto *et al*., 2009). Prasad *et al*. (1999) stated that straw burning decreases the return of Carbon (C) and nutrients, especially N, P and S, to soil. Recycling of crop residues has been suggested to improve overall soil fertility and to support sustainable rice production (Xu *et al*., 2010).

Dingkuhn *et al*. (1990, 1991) and Schnier *et al*. (1990a, b) revealed that modern high yielding varieties, if direct-seeded, exhibit various plant growth during vegetative phase but suffer nitrogen deficiency and therefore, perform poorly during the reproductive growth phase. Flooding the soil has a significant effect on the behavior of several essential plant nutrients. Some nutrients are increased in availability to the crop, whereas others are subjected to greater fixation or loss from the soil as a result of flooding (Fageria *et al*., 2003). Eriksen *et al*. (1985) and Liu *et al*. (2010) showed that alternate wet and dry irrigation can increase fertilizer loss via denitrification, whereas Khind and

Ponnamperuma (1981) and Fillery and Vlek (1982) showed that it does not enhance gaseous nitrogen loss.

Efficient and environmentally sound management practices are required for sustainable rice productivity under acid sulfate soil. Agronomic management and technological innovations are needed to lead rice productivity and sustainability in Asian countries (Ali *et al*., 2012). This study was carried out to compare different cultivation techniques and plot levels on macronutrient utilization of lowland rice grown on acid sulfate soil for sustainable production.

MATERIALS AND METHODS

This study was conducted on the rice fields of the farmer who follow Modified Cultivation (MC) technique for 15 years and on those of the farmer who follow Conventional Cultivation (CC) technique continuously. The fields were located in Pathum Tani province (latitude, 14.02°N and longitude 100.53°E), Thailand. This study was carried out with 8 observations for each level of 2 factors. The area of each observation was 1 m^2 and 10 plants were sampled from each observation area to collect the data. The duration of field experiment was from September 2012 to February 2013.

Under MC technique, farmer applied 187.5 kg ha^{-1} of compound fertilizer (16-20-0) (30 kg N ha^{-1} and 37.5 kg P ha^{-1} as P_2O_5) and 18.75 kg ha^{-1} of KCl (0-0-60) (11.25 kg K ha^{-1} as K_2O) at planting, incorporated the stubble of the previous rice crop into the soil one month before planting of successive rice crop, transplanted 20-day-old 5 seedlings using transplanting machine and followed two weeks irrigation and one week completely drainage system. Under CC technique, farmer applied 312.5 kg ha^{-1} of compound fertilizer (16-20-0) (50 kg N ha^{-1} and 62.5 kg P ha^{-1} as P_2O_5) at planting, burned the stubble of the previous rice crop, followed manual broadcasting method using pre-germinated seeds and continuously flooded the field throughout the growing period. Factor B was plot level: Upper plot which was directly irrigated from drainage canal and lower plot which was irrigated with the drained water from upper plot. For MC technique, upper plot was 45 cm higher than middle plot which was 45 cm higher than lower plot. Upper plot was directly irrigated from drainage canal and then drain to lower plot through the middle plot. For CC technique, upper plot was 45 cm higher than farm road which was 45 cm higher than lower plot. Upper plot was directly irrigated from drainage canal and then drain to lower plot through the farm road. Cultural practices of different cultivation techniques and plot levels are shown in Table 1.

Eight soil samples of 1 kg each were randomly collected from each experimental plot before planting and after harvesting and analyzed to evaluate soil pH, Electrical Conductivity (EC) (dS m^{-1}), Cation Exchange Capacity (CEC) (mq), organic matter content and macronutrient contents. Macronutrients (N, P, K, Ca, Mg and S) content in plant and grain were analyzed after harvesting to evaluate macronutrient utilization of rice. Soil, plant and grain analyses were done following the methods by NCERA-13 (2012).

Statistical analysis: Analysis of variance (ANOVA) was done based on Completely Randomized Design (CRD) using Statistical Package for the Social Sciences (SPSS) (version 16.0) software program (SPSS., 2007) to test for the existence of statistical differences in soil pH, Electrical Conductivity (EC) (dS m^{-1}), Cation Exchange Capacity (CEC) (mq), organic matter content and macronutrient contents of soil, plant and grain between the two techniques as well as

Table 1: Cultural practices of different cultivation techniques and plot levels

	Modified Cultivation (MC) technique		Conventional Cultivation (CC) technique	
Cultural practices	Lower plot	Upper plot	Lower plot	Upper plot
Farmer's field area (ha)	1.60 (175.98×90.92 m)	1.60 (175.98×90.92 m)	1.28 (155.70×82.21 m)	1.28 (155.70×82.21 m)
Time of land preparation	20/9/2012 to 25/9/2012	20/9/2012 to 25/9/2012	20/9/2012 to 25/9/2012	30/9/2012 to 5/10/2012
Time of planting	1/10/2012	1/10/2012	22/10/2012	2/11/2012
Seeding rate (kg ha^{-1})	62.5	62.5	125	125
Name of cultivar	RD 47	RD 47	RD 47	RD 47
Sowing method	Transplanting using machine	Transplanting using machine	Direct seeding (manually)	Direct seeding (manually)
Plant spacing (cm×cm)	30×15	30×15	-	-
Age of seedlings (days)	20	20	-	-
No. of seedlings per hill	5	5	Broadcasting	Broadcasting
Basal fertilizer (kg ha^{-1})	16-20-0 (187.50) 0-0-60 (18.75)	16-20-0 (187.50) 0-0-60 (18.75)	16-20-0 (312.50)	16-20-0 (312.50)
Residue management	Incorporating the stubble	Incorporating the stubble	Burning the stubble	Burning the stubble
Water management (Alternate irrigation and drainage)	1-14* 23-36* 44-57* 65-78*	15-22** 37-43** 58-64** 79-96**	Continuous flooding	
Time of harvesting	5/1/2013	5/1/2013	4/2/1013	24/2/2013

*: Irrigation (Days after transplanting), **: Drainage (Days after transplanting)

between the two plot levels. Cultivation technique, with two levels (MC technique and CC technique), was used as factor A. Plot level, with two levels (upper plot and lower plot), was used as factor B. Eight observations were used as replicates.

RESULTS AND DISCUSSION

Soil chemical properties before planting and after harvesting under different cultivation techniques and plot levels: Soil analysis before planting and after harvesting showed that higher soil pH, CEC and organic matter under MC technique compared with CC technique. Soil EC was higher under CC technique than that under MC technique. Higher soil pH and EC were observed under upper plot and larger amount of organic matter was recorded under lower plot. Cation exchange capacity was not affected by plot level Table 2.

Macronutrients content in soil, plant and grain under different cultivation techniques and plot levels

Nitrogen (N): Soil analysis before planting and after harvesting revealed that soil N significantly increased under MC technique over CC technique. Upper plot showed higher N content than lower plot before planting. However, no statistical difference in soil N content was observed under different plot levels after harvesting (Table 2). Long-term application of crop residues under MC technique might increase soil N content. The result agreed with Yadvinder-Singh *et al.* (2005), who found that long-term application of crop residues increased the organic matter, total N content and availability of several nutrients in soils as well as biological N fixation by phototrophic and heterotrophic bacteria. Drainage and soil aeration during the rice-growing season of MC technique might promote the decomposition of crop residues and the subsequent nutrient releases Olk *et al.* (2009). Continuous flooding of CC technique might favor the reduction of NO_3 to NH_4^+, subsequently N loss through volatilization as NH_3 or N_2O (Reddy and DeLaune, 2008; Banach *et al.*, 2009). Lower soil N content before planting under lower plot was probably due to N leaching into drained water.

The data presented in Table 3 showed that N contents in plant and grain were higher under MC technique than those under CC technique. Plot level had no effect on plant N content. Upper plot showed higher grain N content than lower plot. Application of fertilizer N with rice straw under MC technique might stimulate its decomposition, thereby increasing the mineralization of straw N and subsequent recovery by rice plants (Yadvinder-Singh *et al.*, 2005). Continuous flooding of CC technique might lead to N loss via denitrification. Fageria *et al.* (2003) stated that rice plant under continuous flooding does not absorb large amounts of NO_3 because the NO_3 is rapidly lost via denitrification after flooding. Application of N fertilizer alone of CC technique may lead to decrease in soil N availability and plant uptake, subsequently decrease grain N content. Continuous flooding of CC technique might produce H_2S which retards translocation of N (Yoshida, 1981) to the grain. Increased soil N under upper plot before planting might be absorbed by rice plant resulting higher grain N content of that plot.

Phosphorus (P): Before planting and after harvesting, significantly higher soil P content was observed under MC technique compared to CC technique. Soil P content before planting was not affected by different plot levels. After harvesting, upper plot showed higher soil P content than lower plot (Table 2). Early decomposition of rice straw under MC technique might increase organic soil P availability.

Table 2: Soil macronutrient content before planting and after planting under different cultivation techniques and plot levels

	Soil macronutrients (%)					
Cultivation factors	N	P	K	Ca	Mg	S
Before planting						
Rice cultivation technique (Factor A)						
MC technique	1.57[a]	0.42[a]	6.47[a]	0.74[a]	0.029[a]	0.176[a]
CC technique	0.95[b]	0.23[b]	3.97[b]	0.45[b]	0.031[a]	0.128[b]
F-test	**	*	*	*	ns	**
Plot level (Factor B)						
Upper plot	1.52[a]	0.35[a]	5.32[a]	0.60[a]	0.028[b]	0.163[a]
Lower plot	1.00[b]	0.30[a]	5.12[a]	0.60[a]	0.031[a]	0.142[a]
F-test	**	ns	ns	ns	*	ns
CV (%)	23.81	46.95	35.99	14.04	7.110	20.810
After planting						
Rice cultivation technique (Factor A)						
MC technique	1.84[a]	0.005[a]	0.015[a]	0.091[b]	0.607[a]	0.106[a]
CC technique	0.77[b]	0.001[b]	0.017[a]	0.108[a]	0.454[b]	0.145[a]
F-test	**	**	ns	*	**	ns
Plot level (Factor B)						
Upper plot	1.40[a]	0.004[a]	0.015[a]	0.094[a]	0.608[a]	0.126[a]
Lower plot	1.21[a]	0.002[b]	0.016[a]	0.105[a]	0.453[b]	0.124[a]
F-test	ns	**	ns	ns	**	ns
CV (%)	13.87	7.360	17.180	4.560	8.440	25.300

Values in column followed by the different letters are significantly different, **Significantly different at $p \leq 0.01$, *Significantly different at $p \leq 0.05$, ns: Not significantly different

Table 3: Plant and grain macronutrient content under different cultivation techniques and plot levels

	Macronutrients (%)					
Cultivation factors	N	P	K	Ca	Mg	S
Plant macronutrient						
Rice cultivation technique (Factor A)						
MC technique	1.24^a	0.068^a	1.75^a	1.11^a	0.576^a	0.164^a
CC technique	0.66^b	0.058^b	1.26^b	1.10^a	0.599^a	0.137^a
F-test	**	*	**	ns	ns	ns
Plot level (Factor B)						
Upper plot	0.99^a	0.057^b	1.47^a	1.06^a	0.602^a	0.142^a
Lower plot	0.90^a	0.069^a	1.54^a	1.10^a	0.574^b	0.159^a
F-test	ns	**	ns	ns	*	ns
CV (%)	12.93	1.180	5.16	7.17	1.200	21.080
Grain macronutrient						
Rice cultivation technique (Factor A)						
MC technique	1.49^a	0.232^a	0.476^a	0.924^a	0.637^a	0.181^a
CC technique	1.34^b	0.185^b	0.452^a	0.921^a	0.634^a	0.144^b
F-test	**	*	ns	ns	ns	*
Plot level (Factor B)						
Upper plot	1.45^a	0.190^a	0.451^a	0.895^a	0.628^a	0.148^a
Lower plot	1.38^b	0.226^a	0.477^a	0.949^a	0.644^a	0.177^a
F-test	**	ns	ns	ns	ns	ns
CV (%)	0.42	21.500	6.820	10.290	4.970	19.400

Values in column followed by the different letters are significantly different, **Significantly different at $p \leq 0.01$, *Significantly different at $p \leq 0.05$, ns: Not significantly different

Incorporation of the rice straw shortly after the harvest of rice accelerated aerobic decomposition of crop residues and re-oxidation of ferrous iron and other reduced substances, leading to increased P availability (Yadvinder-Singh *et al*., 2005). An increase in pH of upper plot might be the reason of increased P availability. Golez and Kyuma (1997) reported that soil acidification depressed availability of P because the decrease in pH increased exchangeable Fe and Al and decreased available P due to precipitation of phosphate ions (PO_4^{3-}) by large amounts of Fe^{3+} and Al^{3+}, thereby, leading to the deficiency of this nutrient.

Plant and grain P contents increased under MC technique over CC technique. Plant P was higher under lower plot while grain P was not affected by plot level (Table 3). Straw incorporation under MC technique might also be a reason of increased P content in the plant. Yadvinder-Singh *et al*. (2005) reported that the availability of P in the soil and P use efficiency increased on straw-amended soils. As the rice grain becomes a strong sink for P (Fageria *et al*., 2003), larger amount of available P in the soil and plant uptake from the organic matter source by incorporation of the rice straw might lead to subsequent increase in grain N content under MC technique. Under CC technique, continuous flooding leading to reductive condition might release H_2S and appear to retard translocation of P (Yoshida, 1981) resulting decreased P content in the grain.

Potassium (K): Soil K was not influenced by different cultivation technique after harvesting despite significant increase in soil K under MC technique over CC technique before planting. Before planting and after harvesting, it was not significantly different in soil K under different plot levels (Table 2). Chatterjee and Mondal (1996) found that crop residues contain large quantities of K and their recycling can markedly increase K availability in soils. Incorporation of straw residue which contains large amount of K might be the reason of increased soil K content under MC technique over CC technique. Reduced soil conditions by continuous flooding of CC technique might result in the displacement of exchangeable K from the exchange complex into the soil solution and may also enhance the potential for K leaching on some soils (Fageria *et al*., 2003).

The data revealed that higher K content under MC technique compared to CC technique. The concentration of K in the plant was not affected by plot levels. The data revealed that grain K content was not affected by both cultivation technique and plot level (Table 3). Straw incorporation under MC technique might be reflected not only in the increase in soil K but also in plant uptake (Beye, 1977). Highly reductive condition by continuous flooding of CC technique might produce toxic substances such as H_2S which inhibit K uptake by the plant and less soil K release resulting from poorly drained conditions of that technique might also lead to K deficiency (Yoshida, 1981). Lack of K fertilizer application and burning of straw containing high amount of K might decrease plant K uptake by the plant under CC technique.

Calcium (Ca): Before planting, soil Ca increased under MC technique as compared to CC technique. Soil Ca increased under CC technique as compared to MC technique after harvesting. Soil analysis before planting and after harvesting indicated that there was no significant difference in soil Ca content under different plot levels (Table 2). Straw incorporation under MC technique might be the reason of increased soil Ca of that technique. In addition to N, P and K, crop residues also contain substantial amounts of secondary nutrients (Ca, Mg and S) (Yadvinder-Singh *et al*., 2005).

Alternate irrigation and drainage under MC technique might also increase soil Ca content as a result of the weathering of Ca and Mg bearing compounds contained in the soil by strong acidity during the rapid oxidation of pyrite, acid sulphate soil (Golez and Kyuma, 1997). Increased soil Ca content under CC technique after harvesting might be due to the weathering of Ca bearing compounds contained in the soil by lower pH of CC technique (Golez and Kyuma, 1997).

Although, there was no significant difference in plant and grain Ca content, MC technique has the opportunity to increase soil Ca content, plant Ca uptake and subsequently grain Ca content (Table 3).

Magnesium (Mg): Soil Mg content was not influenced by different cultivation techniques before planting. After harvesting, MC technique gave higher soil Mg content than CC technique. Soil Mg was higher under lower plot as compared to upper plot before planting and it was higher under upper plot than lower plot after harvesting (Table 2). Strong acidity must have weathered Ca and Mg bearing compounds contained in the soil consequently Mg increased in additional to Ca (Golez and Kyuma, 1997). Therefore, increase in soil Mg under lower plot before planting might be the reason of lower soil pH causing soil acidity under that plot. Increased Mg contents under MC technique and upper plot after harvesting might be as the results of higher pH levels and decrease in that nutrient under CC technique and lower plot might be due to lower pH conditions. Golez and Kyuma (1997) also revealed that the loss of Mg was enhanced by acidification.

The data showed that plant Mg content was not statistically different under different cultivation techniques. However, plant Mg content was higher under upper plot as compared with lower plot. Grain Mg content was not affected by both cultivation technique and plot level (Table 3). Increased Mg content in the plant under upper plot might be due to the increase soil Mg content of that plot with lower pH. The loss of Mg was enhanced by acidification (Golez and Kyuma, 1997).

Sulfur (S): MC technique gave higher soil S content than CC technique before planting while soil S content after harvesting was not statistically different. There was no influence of plot levels upon soil S content before planting and after harvesting (Table 2). Incorporation of rice straw under MC technique might improve soil S content. Naklang *et al.* (1999) reported an improvement in the S balance with the incorporation of rice straw over removal. Continuously reduced condition and burning of straw, reducing soil organic matter, under CC technique might decrease soil S content under that technique. The result agreed with (Fageria *et al.*, 2003), who found that the soil SO_4 concentration declines after flooding and may be accompanied by the accumulation of S^{2+} which can be toxic to plants and may also be lost from the soil as H_2S gas. Thus, the availability of soil S decreases as soil reduction proceeds.

Plant S content was not statistically different under different cultivation techniques and plot levels. The result indicated that grain S content increased under MC technique over CC technique while it was not affected by plot level (Table 3). Under MC technique, application of rice straw improved soil available S and rice plant could uptake large amount of S from the soil (Fageria *et al.*, 2003) and then seem to transport to the grain resulting increased grain S content. An improvement in the S balance with the incorporation of rice straw was also observed by Naklang *et al.* (1999). Under CC technique, continuously reduced condition might decrease soil S content by the accumulation of S^{2-} which can be toxic to plants and may also be lost from the soil as H_2S gas (Fageria *et al.*, 2003). As a result of decreased soil S content, grain S content under CC technique decreased as compared to MC technique.

CONCLUSION

Before planting, higher soil N, P, K, Ca and S were observed under MC technique and soil N, P and Mg were higher under that technique after harvesting. Conventional cultivation technique gave higher soil Ca after harvesting. Under upper plot, soil N was higher before planting and soil P and Mg were higher after harvesting. Increased soil Mg was obtained from lower plot before planting. Plants under MC technique showed higher N, P and K as compared with CC technique. Other plant macronutrients such as Ca, Mg and S contents were not statistically different between two cultivation techniques. Despite higher plant P under lower plot and higher plant Mg under upper plot, plant N, K, Ca and S contents were not affected by plot level. Grain N, P and S contents were higher under MC technique than CC technique and grain K, Ca and Mg contents were not significantly different between MC and CC techniques. Except grain N content was higher under upper plot, other grain macronutrients such as P, K, Ca, Mg and S contents were not affected by plot level. In long-term, MC technique might improve soil macronutrients content, especially N and P improving utilization of those nutrients by rice plant. Modified cultivation technique might lead to economic sustainability reducing fertilizer and seed costs and increasing the profit from higher macronutrients utilization of rice, environmental sustainability reducing the use of agrochemical fertilizers and environmental pollution by stubble burning and social sustainability avoiding the risks from agrochemicals and dusts from stubble burning. From this study, it was suggested that farmers should follow MC technique to meet higher macronutrient utilization of lowland rice with the achievement of economically, environmentally and socially sustainable lowland rice production under acid sulfate soil.

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