Kasetsart J. (Nat. Sci.) 49 : 687 - 699 (2015)

# Effects of Cultivation Techniques and Plot Levels on Growth, Yield and Yield Components of Lowland Rice Grown on Acid Sulfate Soil for Sustainable Production

**Phyu Thaw Tun[1,2], Pitipong Thobunluepop[1,*], Ed Sarobol[1] and Tanee Sreewongchai[1]**

## ABSTRACT

The effects of different cultivation techniques and plot levels on the productivity of lowland rice grown on acid sulfate soil were examined and a field experiment was conducted in Pathum Thani province, Thailand. Cultivation technique (modified cultivation (MC) technique and conventional cultivation (CC) technique) and plot level (upper plot and lower plot) were the experimental factors. Under the MC technique, the 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 and transplanted the rice seedlings, followed by 2 wk flooding and 1 wk of complete drainage both throughout the growing period. Under the CC technique, the farmer applied 312.5 kg.ha$^{-1}$ of compound fertilizer (16-20-0) at planting, burned the previous rice stubble and broadcast rice seeds followed by continuous flooding throughout the growing period. The upper plot was directly irrigated from a drainage canal whereas the lower plot was irrigated with the drained water from the upper plot. Compared with the CC technique, the MC technique produced significantly higher grain yield, yield components, leaf area index, plant dry weight, net assimilation rate and harvest index. The upper and lower plots had no observed effect on most yield components and plant growth parameters. Overall, the results suggested that farmers should follow the MC technique to produce a higher rice grain yield along with the improvement of soil properties such as soil pH, cation exchange capacity and organic matter and to achieve economically, environmentally and socially sustainable lowland rice production in acid sulfate soil over the long term.

**Keywords:** acid sulfate soil, conventional cultivation (CC) technique, modified cultivation (MC) technique, rice productivity, sustainable rice production

## INTRODUCTION

The enhancement of rice production and sustainability plays a vital role in grain production to benefit the world's 3 billion people who depend on rice for their livelihood and as their basic food (Fageria *et al.*, 2003). Previous studies have revealed that proper soil and water management are crucial for sustainable production of crops on acid sulfate soils (Shamshuddin *et al.*, 2014).

In order to improve resource use efficiency, it will be necessary to address the growing concerns regarding higher fertilizer costs, negative environmental impacts due to

[1] Department of Agronomy, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand.
[2] Department of Agronomy, Yezin Agricultural University, Yezin, Nay Pyi Taw, Myanmar.
[*] Corresponding author, e-mail: pitipongtho@yahoo.com

Received date : 01/07/14 Accepted date : 17/12/14

the increasing use of agrochemicals for rice production and water scarcity (Tsujimoto *et al*., 2009). Huang *et al*. (2013) revealed that crop residue retention can significantly increase the rice yield and partially substitute for inorganic fertilizers. Residue management impacts on the soil organic matter, and long-term fertility is becoming more relevant in the context of soil quality (DeveÃvre and Horwath, 2000). Chauhan *et al*. (2012) also proposed that innovations in residue management to avoid straw burning should assist in achieving sustainable productivity and allow farmers to reduce inputs, maximize yields, increase profitability, conserve the natural resource base and reduce risk due to both environmental and economic factors.

The occurrence of sterility is greatly affected by plant density (Javaid *et al.*, 2012). Compared with transplanted rice, broadcasting of direct-seeded rice resulted in less filled grains per panicle as a result of the higher plant population density (Naklang *et al.*, 1996). Flooding the soil has a significant effect on the behavior of several essential plant nutrients and on the growth and yield of rice. 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). High yields can be better achieved on well-drained fields. Although high rates of percolation cause nutrient loss, adequate rates may remove toxic substances from the rooting zone and prevent excessive soil reduction (Yoshida, 1981).

Efficient and environmentally sound management practices are required for sustainable rice productivity in 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 the productivity of lowland rice grown on acid sulfate soil for sustainable production.

## MATERIALS AND METHODS

The study was conducted on rice fields of a farmer who had followed the modified cultivation (MC) technique for 15 yr and also on those of a farmer who had followed the conventional cultivation (CC) technique continuously. The fields were located in Pathum Thani province (latitude, 14.02°N and longitude 100.53°E), Thailand. This study was carried out with eight observations for each level of two factors. The area of each observation was 1 $m^2$ and 10 plants were sampled from each observation area to collect the data. The experimental field layout is shown in Figure 1. The duration of the field experiment was from September 2012 to February 2013.

Factor A was cultivation technique, consisting of either the modified cultivation (MC) technique or the conventional cultivation (CC) technique. Under the MC technique, the farmer applied 187.5 $kg.ha^{-1}$ of compound fertilizer (16-20-0; 30 $kg.ha^{-1}$ N and 37.5 $kg.ha^{-1}$ P as $P_2O_5$) and 18.75 $kg.ha^{-1}$ of KCl (0-0-60; 11.25 $kg.ha^{-1}$ K as $K_2O$) at planting, incorporated the stubble of the previous rice crop into the soil 1 mth before planting the successive rice crop, transplanted 20-day-old seedlings at five per hill using a transplanting machine, and 2 wk irrigation and 1 wk of complete drainage both throughout the growing period. Under the CC technique, the farmer applied 312.5 $kg.ha^{-1}$ of compound fertilizer (16-20-0; 50 $kg.ha^{-1}$ N and 62.5 $kg.ha^{-1}$ P as $P_2O_5$) at planting, burned the stubble of the previous rice crop, followed by a manual broadcasting method using pre-germinated seeds and continuous flooding of the field throughout the growing period. Factor B was the plot level, consisting of either the upper plot which was directly irrigated from a drainage canal or the lower plot which was irrigated with the drained water from the upper plot.

In the MC technique, the upper plot was 45 cm higher than the middle plot which was

45 cm higher than lower plot. The upper plot was directly irrigated from a drainage canal and then drained to the lower plot through the middle plot. In the CC technique, the upper plot was 45 cm higher than the farm road which was 45 cm higher than the lower plot. The upper plot was directly irrigated from a drainage canal and then drained to the lower plot via the farm road. The 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 using general soil analysis methods to evaluate soil pH, electrical conductivity (EC; measured in $dS.m^{-1}$), cation exchange capacity (CEC; mq) and organic matter content. The data collected were plant height (cm), number of leaves per plant, leaf area index (LAI), plant fresh weight (g), plant dry weight (g), net assimilation rate ($g.m^{-2}.d^{-1}$), panicle length (cm), number of spikelets per panicle, filled grain percentage (%), 1,000 grains weight (g), harvest index (HI) and grain yield ($t.ha^{-1}$). The growth parameters were collected from 10 sample plants from each observation area, which were randomly selected, at two-weekly intervals during the vegetative period.

Analysis of variance was done based on a completely randomized design using the SPSS statistical package (version 16.0; SPSS Inc. Chicago, IL, USA) to test for the existence of statistical differences in growth parameters, yield components and the yield between the two techniques as well as 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.

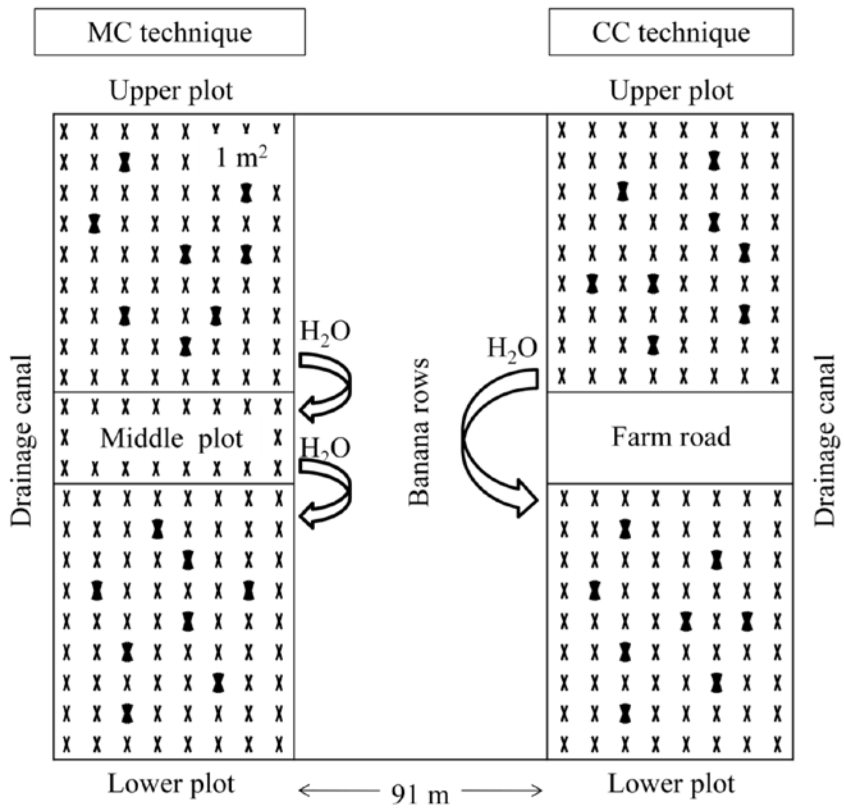



**Figure 1** Experimental field layout.

## 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 were obtained from the MC technique compared with the CC technique. The soil EC was higher under the CC technique than that under the MC technique. Higher soil pH and EC values were observed in the upper plot and a

**Table 1** Practices of different cultivation techniques and plot levels.

| Practice | Modified cultivation technique | | Conventional cultivation technique | |
|---|---|---|---|---|
| | Lower plot | Upper plot | Lower plot | Upper plot |
| Farm field area (ha) | 1.60 (175.98 m × 90.92 m) | 1.60 (175.98 m × 90.92 m) | 1.28 (155.70 m × 82.21m) | 1.28 (155.70 m × 82.21 m) |
| Time for land preparation | 20 Sep 2012 to 25 Oct 2012 | 20 Sep 2012 to 25 Oct 2012 | 20 Sep 2012 to 25 Oct 2012 | 30Sep 2012 to 5 Oct 2012 |
| Time of planting | 1 Oct 2012 | 1 Oct 2012 | 22 Oct 2012 | 2 Oct 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 (d) | 20 | 20 | - | - |
| Number 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 stubble | Incorporating stubble | Burning stubble | Burning stubble |
| Water management | Alternate irrigation and drainage | | Continuous flooding | |
| | Irrigation (days after transplanting) | Drainage (days after transplanting) | | |
| | 1–14 | 15–22 | | |
| | 23–36 | 37–43 | | |
| | 44–57 | 58–64 | | |
| | 65–78 | 79–96 | | |
| Time of harvesting | 5 Jan 2013 | 5 Jan 2013 | 4 Feb 1013 | 24 Feb 2013 |

larger amount of organic matter was recorded in the lower plot. The CEC was not affected by the plot level (Tables 2 and 3).

**Plant height**

The CC technique produced significantly taller plants than the MC technique at 21 and 49 d after planting (Figure 2). In each growing period, the lower plot produced taller plants compared with the upper plot (Figure 3). The taller plants from the CC technique were probably due to the competition for incident solar radiation among the adjacent plants resulting from the closer spacing in the broadcasting method. This assumption is supported by Hasanuzzaman *et al.* (2009) who observed that plants tended to be taller if

**Table 2** Soil chemical properties before planting under the modified cultivation technique (MC) and the conventional cultivation technique (CC) and the upper plot and the lower plot.

| Cultivation factor | Soil pH | Soil electrical conductivity ($dS.m^{-1}$) | Soil cation exchange capacity (mq) | Soil organic matter (%) |
|---|---|---|---|---|
| Rice cultivation technique (Factor A) | | | | |
| MC technique | $5.29^{a}$ | $0.41^{b}$ | $29.85^{a}$ | $5.49^{a}$ |
| CC technique | $4.95^{b}$ | $0.49^{a}$ | $26.06^{b}$ | $4.61^{b}$ |
| *F* test | ** | ** | ** | ** |
| Plot level (Factor B) | | | | |
| Upper plot | $5.27^{a}$ | $0.48^{a}$ | $28.69^{a}$ | $4.76^{b}$ |
| Lower plot | $4.97^{b}$ | $0.42^{b}$ | $27.23^{a}$ | $5.33^{a}$ |
| *F* test | ** | ** | ns | ** |
| Coefficient of variation (%) | 0.87 | 0.83 | 8.12 | 2.26 |

Values in a column followed by 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** Soil chemical properties after harvesting under the modified cultivation technique (MC) and the conventional cultivation technique (CC) and the upper plot and the lower plot .

| Cultivation factor | Soil pH | Soil electrical conductivity ($dS.m^{-1}$) | Soil cation exchange capacity (mq) | Soil organic matter (%) |
|---|---|---|---|---|
| Rice cultivation technique (Factor A) | | | | |
| MC technique | $5.20^{a}$ | $0.38^{b}$ | $29.67^{a}$ | $5.20^{a}$ |
| CC technique | $4.85^{b}$ | $0.46^{a}$ | $25.92^{b}$ | $4.26^{b}$ |
| *F* test | ** | ** | ** | ** |
| Plot level (Factor B) | | | | |
| Upper plot | $5.18^{a}$ | $0.45^{a}$ | $28.54^{a}$ | $4.37^{b}$ |
| Lower plot | $4.86^{b}$ | $0.39^{b}$ | $27.05^{a}$ | $5.08^{a}$ |
| *F* test | ** | ** | ns | ** |
| Coefficient of variation (%) | 1.09 | 0.89 | 8.19 | 4.78 |

Values in a column followed by different letters are significantly different.
** = Significantly different at $P \leq 0.01$, * = Significantly different at $P \leq 0.05$, ns = Not significantly different.

they received light in a closed place. The taller plants in the lower plot were perhaps also due to greater nutrient uptake, especially nitrogen, from the leached nutrient in the drainage water from the upper plot resulting in increased vegetative growth. Awan *et al.* (2011) stated that the increase in plant height with increased nitrogen application might be primarily due to enhanced vegetative growth resulting from greater nitrogen supply to the plant.

**Number of leaves per plant**

Leaf production under the two cultivation techniques was not significantly different until 35 d after planting. After this period, the MC produced a significantly higher leaf number; however, it was not numerically different (Figure 4). The results illustrated in Figure 5 show there was no significant difference in the number of leaves produced in the two plot levels at 21 d after planting. Although there was no numerical

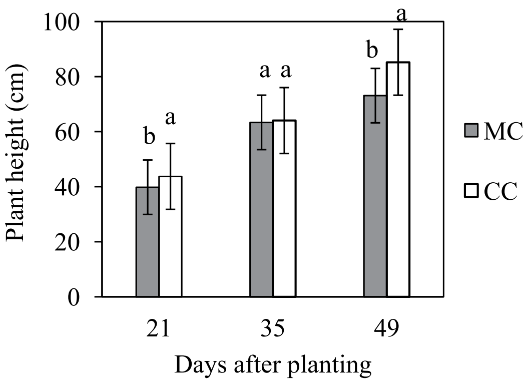



**Figure 2** Mean plant height of rice under the modified cultivation (MC) technique and the conventional cultivation (CC) technique. Bars in each pair of plant heights with the same lower case letter are not significantly different at $P < 0.05$; error bars indicate ± SE.

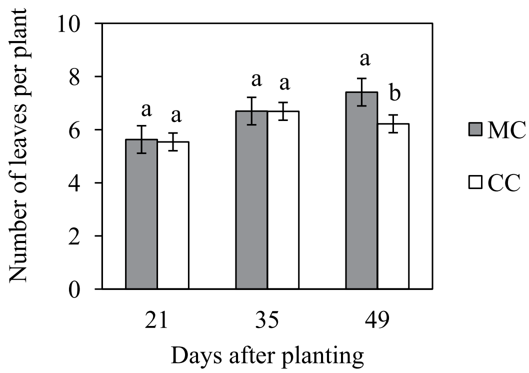



**Figure 4** Mean number of leaves per plant of rice under the modified cultivation (MC) technique and the conventional cultivation (CC) technique. Bars in each pair of results with the same lower case letter are not significantly different at $P < 0.05$; error bars indicate ± SE.

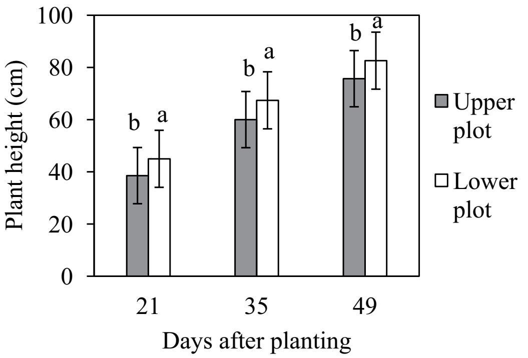



**Figure 3** Mean plant height of rice in the upper plot and lower plot. Bars in each pair of plant heights with the same lower case letter are not significantly different at $P < 0.05$; error bars indicate ± SE.

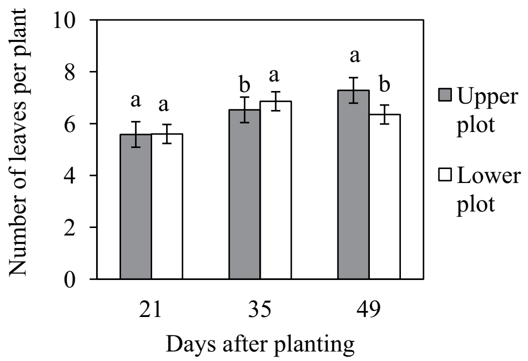



**Figure 5** Mean number of leaves per plant of rice in the upper plot and lower plot. Bars in each pair of results with the same lower case letter are not significantly different at $P < 0.05$; error bars indicate ± SE.

difference in the number of leaves, plants in the lower plot produced a statistically higher number of leaves at 35 d after planting and the production of leaves in that plot statistically decreased at 49 d after planting, whereas the leaf production in the upper plot constantly increased.

**Leaf area index**

The results showed that the MC technique produced a significantly higher LAI compared with the CC technique until 35 d after planting. However, at 49 d after planting, there was no significant difference in the LAI between the MC and CC techniques. (Figure 6). A significant difference between the upper and lower plots was found only at 35 d after planting, where the lower plot produced a greater LAI than the upper plot (Figure 7).

As the LAI is the ratio of total functional leaf area to ground area where the leaves have been collected, the higher number of leaves under the MC technique might support a larger functional leaf area per unit land area resulting in an increase in the LAI. The smaller LAI in the CC technique was possibly the result of the smaller functional leaf area per unit land area resulting from the lower number of leaves.

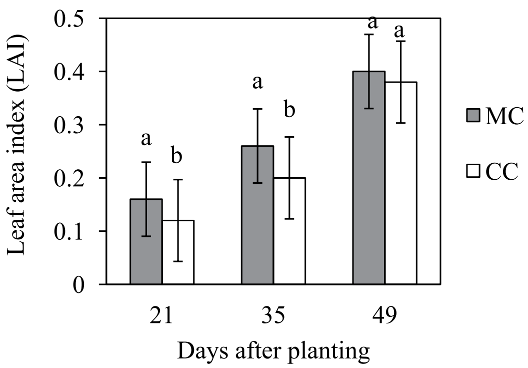



**Figure 6** Mean leaf area index of rice under the modified cultivation (MC) technique and the conventional cultivation (CC) technique. Bars in each pair of results with the same lower case letter are not significantly different at $P < 0.05$; error bars indicate ± SE.

**Plant fresh weight**

The results indicated a significant increase in the plant fresh weight under the MC technique compared to the CC technique throughout the growing period (Figure 8). At 21 and 35 d after planting, the plant fresh weight in the lower plot was significantly higher than that in the upper plot. However, there was no significant difference in the plant fresh weight between the two techniques at 49 d after planting (Figure 9).

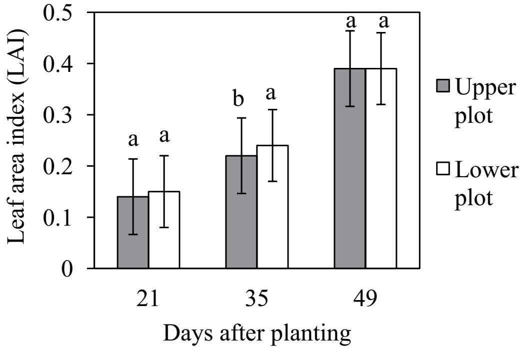



**Figure 7** Mean leaf area index of rice in the upper plot and lower plot. Bars in each pair of results with the same lower case letter are not significantly different at $P < 0.05$; error bars indicate ± SE.

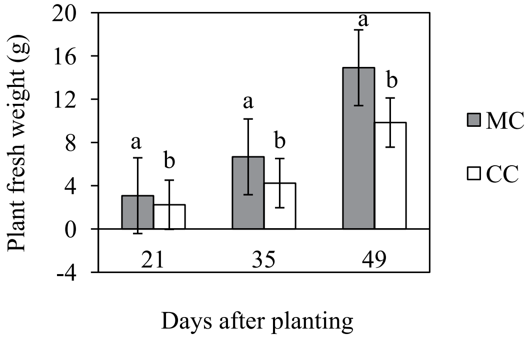



**Figure 8** Mean plant fresh weight of rice under the modified cultivation (MC) technique and the conventional cultivation (CC) technique. Bars in each pair of results with the same lower case letter are not significantly different at $P < 0.05$; error bars indicate ± SE.

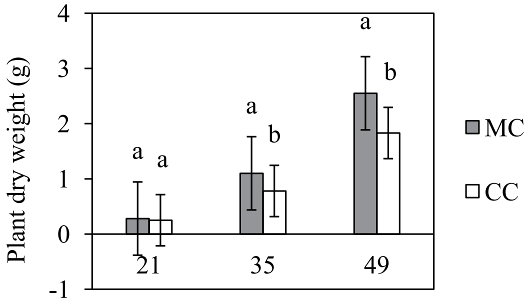
The application of potassium (K) fertilizer and the incorporation of K-abundant rice stubble in the MC technique might support a thicker stem with a higher moisture content resulting in a higher shoot fresh weight. The culm's mechanical strength is increased by K applications, which increase its thickness (Noguchi, 1940) and maintains high turgor pressure in the cells (Kono and Takahashi, 1961). The increased plant fresh weight in the lower plot in the early growing period could be attributed to the availability of more nutrients in the drained water from the upper plot resulting in better plant growth and thereby increasing the plant fresh weight.

**Plant dry weight**

The MC technique produced a higher plant dry weight until 35 and 49 d after planting (Figure 10). Plants in the lower plot accumulated higher dry matter at 21 and 35 d after planting. However, at 49 d after planting, there was no significant difference in dry matter production between the plot levels (Figure 11). The increase in plant dry matter of the MC technique could be attributed to the increase in the LAI of that technique. The increases in plant dry matter in the lower plot at 21 and 35 d after planting were probably due to the increase in the LAI. This is supported by Shieh (1977) who reported a significant, positive correlation coefficient between the LAI and the crop growth rate in the vegetative growth stage.

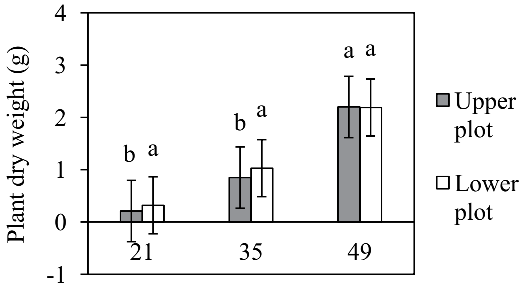
**Net assimilation rate**

The data shown in Figure 12 reveal that the MC technique had a higher NAR than the CC technique at both 35 and 49 d after planting. No significant difference in the NAR was found



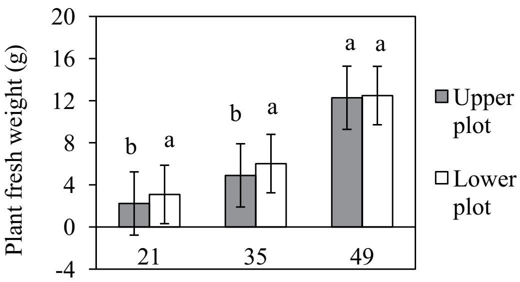

Days after planting

**Figure 10** Mean plant dry weight of rice under the modified cultivation (MC) technique and the conventional cultivation (CC) technique. Bars in each pair of results with the same lower case letter are not significantly different at $P < 0.05$; error bars indicate ± SE.




Days after planting

**Figure 11** Mean plant dry weight of rice in the upper plot and lower plot. Bars in each pair of results with the same lower case letter are not significantly different at $P < 0.05$; error bars indicate ± SE.




Days after planting

**Figure 9** Mean plant fresh weight of rice in the upper plot and lower plot. Bars in each pair of results with the same lower case letter are not significantly different at $P < 0.05$; error bars indicate ± SE.

between plot levels (Figure 13). The increases in the LAI and plant dry matter under the MC technique were possibly due to the increase in the NAR under the MC technique. Closer spacing in the broadcasting method of the CC technique resulted in mutual shading among leaves in the canopy, leading to a lower incidence of solar radiation for photosynthesis which might result in a decreased NAR.

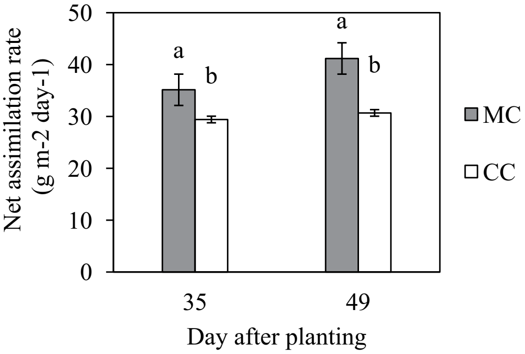



**Figure 12** Mean net assimilation rate of rice under the modified cultivation (MC) technique and the conventional cultivation (CC) technique. Bars in each pair of results with the same lower case letter are not significantly different at $P < 0.05$; error bars indicate ± SE.

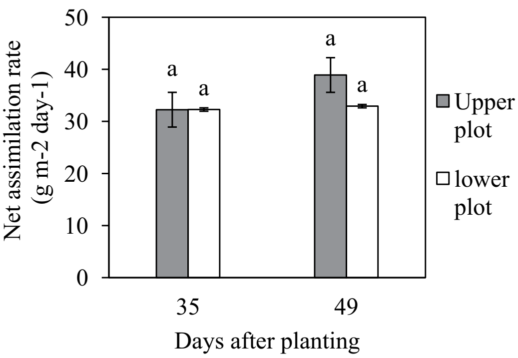



**Figure 13** Mean net assimilation rate of rice in the upper plot and lower plot. Bars in each pair of results with the same lower case letter are not significantly different at $P < 0.05$; error bars indicate ± SE.

**Grain yield**

Compared with the CC technique, a significantly higher grain yield was recorded under the MC technique (Figure 14). The upper and lower plots produced similar grain yields (Figure 15).

Production of a higher LAI resulting in greater dry matter production and a higher NAR might have been the reason for the higher grain yield. Thakur and Patel (1998) reported that the LAI, dry matter production and the NAR

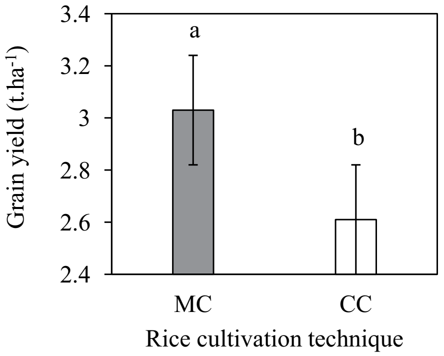



**Figure 14** Mean grain yield of rice under the modified cultivation (MC) technique and the conventional cultivation (CC) technique. Bars in each pair of results with the same lower case letter are not significantly different at $P < 0.05$; error bars indicate ± SE.

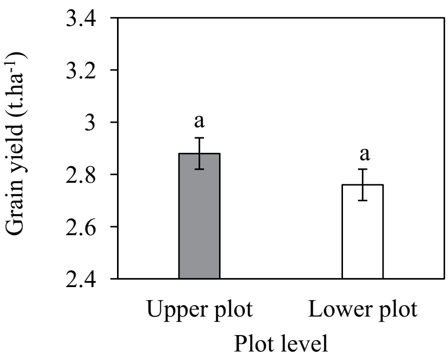



**Figure 15** Mean grain yield of rice in the upper plot and lower plot. Bars in each pair of results with the same lower case letter are not significantly different at $P < 0.05$; error bars indicate ± SE.

are ultimately reflected in a higher grain yield. The higher grain yield recorded under the MC technique might have been due to the production of a significantly higher number of filled grains resulting in a larger HI (Ye *et al*., 2013).

The higher grain yield under the MC technique might have also been due to efficient nutrient utilization as the result of increased organic matter by stubble incorporation. Tanaka (1978) stated that organic matter supplies nitrogen (N) to rice plants throughout the growing period and this continuous N supply favors a high yield by preventing excessive vegetative growth and lodging. The incorporation of cereal straw along with inorganic fertilizer application resulted in a high rate of N mineralization and a subsequent high rice grain yield (Singh and Singh, 1995). Huang *et al.* (2013) also found that the rice yield was not adversely affected by crop residue retention with reduced rates of inorganic N, phosphorus (P) and K fertilizers compared with full rates of inorganic fertilization alone. Crop residue retention can significantly increase the rice yield and substitute for some inorganic fertilizer (Huang *et al.*, 2013). Yang and Zhang (2006) and Xue *et al.* (2013) also stated that midseason drainage and alternate wetting and drying can inhibit the formation of unproductive tillers, improve root activity and enhance grain filling, thus increasing the rice yield. Lodging under the CC technique possibly inhibited the translocation of assimilates for grain filling resulting in a higher percentage of unfilled grain and a subsequent lower grain yield.

**Panicle length**

There was a longer panicle length under the MC technique than in the CC technique. This parameter was not significantly affected by plot level (Table 4).

**Number of spikelets per panicle**

The differences in the number of spikelets per panicle between the two cultivation techniques were not significant. Similarly, the number of spikelets per panicle was not significantly affected by plot level (Table 4).

**Table 4** Different cultivation techniques and different plot levels on yield components of lowland rice.

| | Panicle length (cm) | Number of spikelets per panicle | Filled grain percentage (%) | 1,000 grains weight (g) |
|---|---|---|---|---|
| Rice cultivation technique (Factor A) | | | | |
| MC technique | 26.83$^{a}$ | 92.68$^{a}$ | 83.10$^{a}$ | 25.36$^{a}$ |
| CC technique | 23.54$^{b}$ | 97.14$^{a}$ | 68.17$^{b}$ | 25.32$^{a}$ |
| *F* test | * | ns | ** | ns |
| Coefficient of variation (%) | 17.17 | 10.52 | 4.70 | 4.57 |
| Plot level (Factor B) | | | | |
| Upper plot | 24.04$^{a}$ | 94.44$^{a}$ | 76.31$^{a}$ | 25.78$^{a}$ |
| Lower plot | 26.33$^{a}$ | 95.37$^{a}$ | 74.96$^{a}$ | 24.89$^{b}$ |
| *F* test | ns | ns | ns | * |
| Coefficient of variation (%) | 17.17 | 10.52 | 4.70 | 4.57 |

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

**Filled grain percent**

A higher filled grain percentage was recorded under the MC technique compared to the CC technique whereas grain filling was not affected by plot level (Table 4).

Xu *et al.* (2010) reported that residue retention could accelerate grain filling, which may be ascribed to a better nutrient supply in the late rice-growing period. Closer spacing resulted in taller plants under the CC technique which might have been more susceptible to lodging (Yoshida, 1981). Premature lodging may have decreased the translocation efficiency and grain filling and increased sterility (Murata and Matsushima, 1975) as well as reducing the grain yield (San-oh *et al.*, 2001). Potassium is known to play an important role in the lignification of vascular bundles that contributes to the higher susceptibility to lodging of K-deficient plants (Fageria *et al.*, 2003). The lack of K fertilizer and the stubble burning under the CC technique might have caused decreased K availability and subsequently increased the susceptibility to lodging.

**Thousand grain weight**

The results indicated that 1,000 grain weight was not significantly different between the two cultivation techniques, whereas the upper plot produced larger grains compared to the lower plot (Table 4).

**Harvest index**

A significantly higher HI was recorded under the MC technique compared to the CC technique (Figure 16). The harvest index was not significantly different between the upper plot and lower plot (Figure 17).

The greater HI under the MC technique was probably due to the higher filled grain percentage of that technique and the higher percentage of empty grain might have contributed to the lower HI under the CC technique. Ye *et al.* (2013) also recorded that the production of a significantly higher number of filled grain results in a larger HI.

## CONCLUSION

Compared with the CC technique, the MC technique produced a significantly higher grain yield and yield components such as the filled grain percentage, LAI, plant dry weight, NAR and HI. The effects of the upper plot and lower plot on yield and most yield

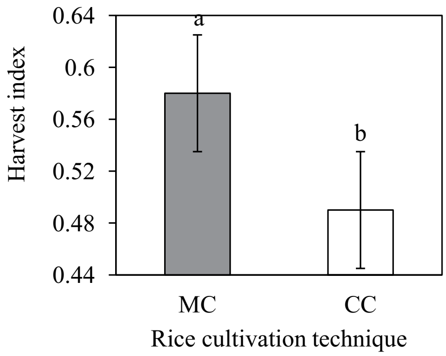



**Figure 16** Mean harvest index of rice under the modified cultivation (MC) technique and the conventional cultivation (CC) technique. Bars in each pair of results with the same lower case letter are not significantly different at $P < 0.05$; error bars indicate ± SE.

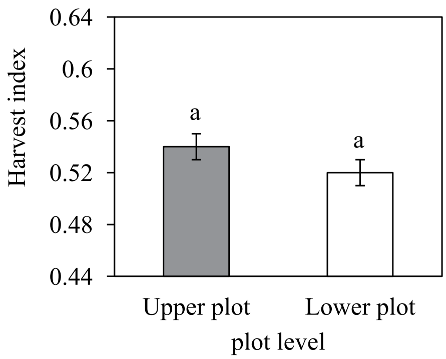



**Figure 17** Mean harvest index of rice in the upper plot and lower plot. Bars in each pair of results with the same lower case letter are not significantly different at $P < 0.05$; error bars indicate ± SE.

components and plant growth parameters were not statistically different. The modified cultivation technique might lead to economic sustainability through reducing fertilizer and seed costs and increasing the profit from a higher rice grain yield; to environmental sustainability through reducing the use of agrochemical fertilizers and environmental pollution by stubble burning; and to social sustainability by avoiding the risks from agrochemicals and dust from stubble burning.

Overall, the results suggested that farmers should follow the MC technique to achieve higher productivity of lowland rice with improvements to soil properties such as soil pH, CEC and organic matter and to achieve economically, environmentally and socially sustainable lowland rice production in acid sulfate soil over the long term.

## ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Thailand International Development Cooperation Agency (TICA) for financial support of this study.

## LITERATURE CITED

Ali, R.I., N. Iqbal, M.U. Saleem and M. Akhtar. 2012. Effect of different planting methods on economic yield and grain quality of rice. **Int. J. Agric. Appl. Sci.** 4: 28–34.

Awan, T.H., R.I. Ali, Z. Manzoor, M. Ahmad and M. Akhtar. 2011. Effect of different nitrogen levels and row spacing on the performance of newly evolved medium grain rice variety, ksk-133. **J. Anim. Plant Sci.** 21: 231–234.

Chauhan, B.S., G. Mahajan, V. Sardana, J. Timsina and M.L. Jat. 2012. Productivity and sustainability of the rice-wheat cropping system in the Indo-Gangetic Plains of the Indian subcontinent: Problems, opportunities, and strategies. **Adv. Agron.** 117: 315–369.

DeveÃvre, O.C. and R.W. Horwath. 2000. Decomposition of rice straw and microbial carbon use efficiency under different soil temperatures and moistures. **Soil Biol. Biochem.** 32: 1773–1785.

Fageria, N.K., N.A. Slaton and V.C. Baligar. 2003. Nutrient management for improving lowland rice productivity and sustainability. **Adv. Agron.** 80: 63–152.

Hasanuzzaman, M., M.L. Rahman, T.S. Roy, J.U. Ahmed and A.S.M. Zobaer. 2009. Plant characters, yield components and yield of late transplanted Aman Rice as affected by plant spacing and number of seedling per hill. **Adv. Biol. Res.** 3: 201–207.

Huang, S., Y. Zeng, J. Wu, Q. Shi and X. Pan. 2013. Effect of crop residue retention on rice yield in China: A meta-analysis. **Field Crop Res.** 154: 188–194.

Javaid, T., I.U. Awan, M.S. Baloch, I.H. Shah, M.A. Nadim, E.A. Khan, A.A. Khakwani and M.R. Abuzar. 2012. Effect of planting methods on the growth and yield of coarse rice. **J. Anim. Plant Sci.** 22: 358–362.

Kono, M. and J. Takahashi. 1961. Studies on the relationship between breaking strength and osmotic pressure of paddy stem. **J. Sci. Soil Manure. Japan.** 32: 380–385.

Murata, Y. and S. Matsushima. 1975. Rice, pp.73–79. *In* L.T. Evans (ed.), **Crop Physiology.** Cambridge University Press. Cambridge, UK.

Naklang, K., S. Fukai and K. Nathabut. 1996. Growth of rice cultivars by direct seeding and transplanting under upland and lowland conditions. **Field Crop Res.** 48: 115–123.

Noguchi, Y. 1940. Influence of potassium nutrition on culm structure of the rice plant. **Proc. Crop Sci. SOC. Jpn.** 11:499–510. *Cited* S. Yoshida. 1981. Fundamentals of Rice Crop Science. The International Rice Research Institute. Los Baños, the Philippines.

San-oh, Y., T. Ookawa, N. Aizawa and T. Hirasawa. 2001. Varietal differences in growth, lodging and related characters of rice plants broadcasted in submerged paddy field at different densities. **Japan. J. Crop Sci.** 70: 515–524.

Shamshuddin, J., A.A. Elisa, M.A.R.S. Shazana, C.I. Fauziah, Q.A. Panhwar and U.A. Naher. 2014. Properties and management of acid sulfate soils in southeast asia for sustainable cultivation of rice, oil palm, and cocoa. **Adv. Agron.** 124: 91–136.

Shieh Yhu-Jang. 1977. Effect of planting density on community photosynthesis and yielding components of rice plants. **Bot. Bull. Acad. Sinica.** 18: 153–168.

Singh H. and K.P. Singh. 1995. Effect of plant residue and fertilizer on grain yield of dryland rice under reduced tillage cultivation. **Soil Till. Res.** 34: 115–125.

Thakur D.S. and S.R. Patel. 1998. Growth and sink potential of rice as influenced by the split application of potassium with FYM in inceptisols of eastern central India. **J. Potassium Res.** 14: 73–77.

Tanaka, A. 1978. Role of organic matter, pp. 605–620. *In* **Soils and Rice.** International Rice Research Institute. Los Baños, the Philippines.

Tsujimoto, Y., T. Horie, H. Randriamihary, T. Shiraiwa and K. Hommaa. 2009. Soil management: The key factors for higher productivity in the fields utilizing the system of rice intensification (SRI) in the central highland of Madagascar. **Agr. Syst.** 100: 61–71.

Xu, Y, L. Nie, R.J. Buresh, J. Huang, K. Cui, B. Xu, W. Gong and S. Peng. 2010. Agronomic performance of late-season rice under different tillage, straw, and nitrogen management. **Field Crop Res.** 115: 79–84.

Xue, Y., H. Duan, L. Liu, Z. Wang, J. Yang and J. Zhang. 2013. An improved crop management increases grain yield and nitrogen and water use efficiency in rice. **Crop Sci.** 53: 271–284.

Yang, J. and J. Zhang. 2006. Grain filling of cereals under soil drying. **New Phytol.** 16: 223–236.

Ye, Y., X. Liang, Y. Chen, J. Liu, J. Gu, R. Guo and L. Li. 2013. Alternate wetting and drying irrigation and controlled-release nitrogen fertilizer in late-season rice. Effects on dry matter accumulation, yield, water and nitrogen use. **Field Crop Res.** 144: 212–224.

Yoshida, S. 1981. **Fundamentals of Rice Crop Science.** The International Rice Research Institute. Los Baños, the Philippines. 269 pp.