INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
13–813/2014/16–4–738–744
http://www.fspublishers.org

Full Length Article

Physiological Response of Local Rice Varieties to Aerobic Condition

Intan Filzah Mahmod[1*], Syed Shahar Barakbah[1], Normaniza Osman[1] and Othman Omar[2]
[1]*Institute of Biological Sciences, Faculty of Science, University of Malaya, 50603 Kuala Lumpur, Malaysia*
[2]*Mardi Station Seberang Perai, 13200 Kepala Batas, Penang, Malaysia*
*For correspond: innzah11@gmail.com

Abstract

Cultivated rice under aerobic condition typically decreases both growth and yield. The experiment was carried out at MARDI Bertam, Seberang Perai to investigate the growth performances of different rice varieties; MRQ74, MR253 (adapted aerobic rice), MR232 (lowland rice). The objective was to assess the effects of different treatments on rice growth in aerobic ecosystem. Rice was cultivated with; soil covered by rice straw mulching (SC), plastic film (PC) and no soil cover (NC) with lowland rice as control. Significantly higher values were obtained for tiller number, panicle number, LAI, above ground biomass, grain weight density and grain yield recorded in SC and response for physiological traits i.e. photosynthesis rate, stomatal conductance and transpiration rate (A, gs, E) was found higher in control. The symptoms of water stress were observed in NC which impaired rice growth and reduced grain yield. Rice responds differently in morphological, physiological and yield component depending on rice varieties and treatments. Results indicated that MRQ74 has superior morphological and physiological characteristics in adaptations to aerobic condition.

Keywords: Rice; Aerobic condition; Growth; Yield; Water stress

Introduction

Water is the most crucial resource for agriculture especially in Asia and becoming increasingly scarce. It was estimated that by 2025, about 15-20 million hectares of irrigated rice will be affected due to water scarcity which threatens the productivity (Belder *et al*., 2004; Adam, 2007; Bouman, 2009). With increase of population and economic growth, the availability of water for agriculture is threatened by competition from domestic and industrial requirements (Singh *et al*., 2008). Furthermore, compared with the world's other major staples, wheat and maize, rice uses around twice as much water; roughly 2,000 L to produce a single kilogram (Adam, 2007).

According to Tao *et al*. (2006) rice is the most unproductive crop in terms of water loss. On average, about 2,500 liters of water need to be supplied (by rainfall and/or irrigation) to a rice field to produce 1 kg of rough rice. These 2,500 liters account for all the outflows of water through evapotranspiration, seepage, and percolation (Bouman, 2009). Atlin (2004) stated that the new upland-adapted varieties (aerobic rice) have improved lodging resistance, as well as highest harvest index and input responsiveness. Aerobic rice can achieve yields of 4–6 tons per hectare and does not require flooded wetland (50 - 70% less water compared to lowland rice) (Qin *et al*., 2010). Generally, irrigated rice tends to become stressed when water is reduced. Thus aerobic rice is the strategy of water saving agriculture.

During recent decades, international and national rice institutes have tested various new techniques for growing rice such as aerobic rice (Bouman *et al*., 2002), alternate wet and dry systems (Bouman, 2007) and rice intensification which partially or totally suppress the need for ponding at the field level (Zeng *et al*., 2002; Peng *et al*., 2005). However, continuously non-flooded rice cultivation leads to less stable productivity and lower grain yields (Kamoshita and Abe, 2007; Sikuku *et al*., 2010; Wei *et al*., 2011). This can be overcome to a certain extent by an alternative way of growing lowland rice using ground covered rice system under non-flooded conditions (Tao *et al*., 2006; Zhang *et al*., 2008). According to Zhang *et al*. (2008), water saving system could prevent soil evaporation and reduce seepage by increasing water use efficiency (WUE). Moreover, this technique improves soil moisture, increases soil temperature and inhibits weed growth (Fan *et al*., 2005). The objectives of this study are to assess the physical and physiological growth responses of soil covered treatment on three varieties of rice.

Materials and Methods

Experimental Design

The experiment was carried out at Malaysian Agriculture Research and Development Institute (MARDI) station, Seberang Perai, Pulau Pinang (5° 32'N, 100° 28'N). The experiment was comprised of four treatments in a complete

To cite this paper: Mahmod, I.F., S.S. Barakbah, N. Osman and O. Omar, 2014. Physiological response of local rice varieties to aerobic condition. *Int. J. Agric. Biol*., 16: 738–744

block design (RCBD) with three replicates and a plot size of 1 m² (1 m × 1 m). The treatments were soil covered by rice straw (SC), soil covered by black plastic film (PC), and uncovered soil (NC). These three treatments were maintained in non-flooded cultivation using adapted aerobic rice varieties (MRQ74, MR253). All three treatments were compared to the normal planting cultivation using lowland variety (MR232) under flooded condition, which served as control.

Seeds were sown in a tray at nursery beds for about 2 weeks before transplanting into the plots. Five seedlings were grown in each of the rows and columns of all plots. The length between each point of seedlings was 15 cm. For PC treatment, black plastic films with 25 perforations (point to transplant seedling) were set up on the top ground of three plots before transplanting. Whilst in SC treatment, mulching rice straw was spread on the ground of three plots just after transplanting and repeated monthly until harvest, during early and maximum tillering. Green fertilizer (N15:P15:K15) was applied in 20 and 40 days after transplanting; while blue fertilizer (N12:P12:K17:MGO2) was applied in 65 and 85 days after transplanting.

Physiological and Agronomic Measurements

For the agronomic determination, tiller number, panicle number and plant height were measured randomly from 1 m^2 areas every two weeks from vegetative stage until harvest. The number of tiller was determined manually at random sample of three hills per plot. LAI was measured at different rice growth stages using Ceptometer (AccuPAR LP-80, Decagon Devices, Inc). Data were taken randomly three times per plot. Chlorophyll content was determined using SPAD-502 chlorophyll meter (Minolta Co., Ltd, Osaka, Japan) then converted to the regression equation into unit μ g mL^{-1} using the equation $y = 1.45x + 1.97$. Photosynthetic rate (A), stomatal conductance (g_s) and transpiration rate (E) were determined using LI-COR (LI-6400XT Portable Photosynthesis System, Lincoln, Nebraska, USA). The measurements were taken randomly on the abaxial surface of three leaves for each treatment at 1500 on 42-56 and 84-98 DAT, corresponding to the stages and growth between tillering and heading. The readings were accomplished within one-hour to minimize errors due to diurnal pattern of photosynthesis. Yield and yield components (panicle number, spikelet per panicle, grain filling percentage, grain weight density, harvest index) were taken after harvest. Grain yield prediction was calculated from the model: Y (t ha^{-1}) = Panicle number per m^2 x spikelets per panicle x fraction of filled spikelet x 1000-grain weight x 10^{-5} (Casanova *et al*., 2002). For aboveground biomass, the shoot samples were harvested by cutting 2 cm above the soil surface at maturity stage and were separated into grain and straw. The samples were washed and oven dried for 72 h at 80ºC to constant weight. Then remaining root mass was washed to remove soil and then oven dried at 80ºC for 72 h and weighed again for root dry weight to determine root-shoot ratio. Harvest Index was calculated: HI = 100 x filled spikelet weight/aboveground biomass (De Datta, 1981).

Data Analysis

Analysis of variance was performed separately for each treatment and each variety (ANOVA). Means were tested by least significant difference at $p = 0.05$ (LSD = 0.05). Pearson's correlation was used in analyzing the relationship between physiological parameters in all rice varieties and treatments.

Results

Effects on Tillering and Plant Height

Straw Cover treatment greatly affected the development and viability of tillers for both adapted rice variety compared to PC and NC treatment (Fig. 1). Among varieties, MRQ74 produced the highest number of tiller followed by MR232 and MR253. In terms of respond on soil cover, MRQ74 had the highest number of tiller in SC followed by PC, NC and control. While for MR253, SC had the highest number of tiller followed by control, PC and NC. MR253 under PC grew rapidly at tillering stage then growth decreased at reproductive stage. In addition, all varieties reached the maximum of tiller number at 70 DAT.

Obviously, there was a significant difference among varieties in plant height with maximum plant height for MR232, whereas there was no significant difference between adapted aerobic rice. Straw cover treatment was not affected for MRQ74 but there is a significant difference of soil moisture on cover treatment for MR253 especially at maturation stage (84-98 DAT). Genotype MR253 under PC and SC had tallest plants compared with NC (Fig. 2). Basically, the height pattern of rice grew rapidly at tillering stage then become constant at maturation stage (70 DAT).

Physiological Responses

Leaf area index (LAI) showed a typical pattern of rice growth reaching the peak in the middle of growth period and decrement towards the end (Fig. 3). During the growth duration, there was no significant difference of LAI among soil cover treatments. Results indicated that at 84 DAT, LAI for MRQ74 and MR253 were significantly higher compared to MR232. MRQ74 and MR253 reached peak LAI at 84 DAT and MR232 at 70 DAT before decreasing thereafter implying that the highest LAI occurred at the reproductive stage.

Total chlorophyll showed an increasing value through the entire rice growth in all varieties. The chlorophyll content of MRQ74 was highest compared amongst varieties. The rapid increase of the total chlorophyll was observed in the early growth stage (28-42 DAT). However, chlorophyll

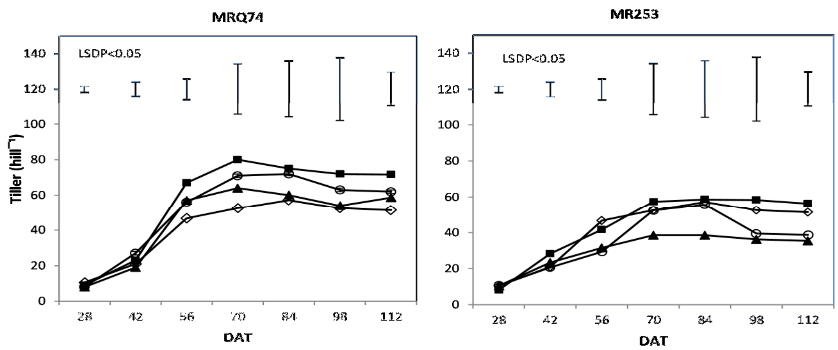

Fig. 1: Tiller number for each variety during the entire growth in every treatment; (O) PC, (■) SC, (▲) NC, (◊) Control. Each point represents the mean of three replicates and the vertical bars represent LSD at 0.05

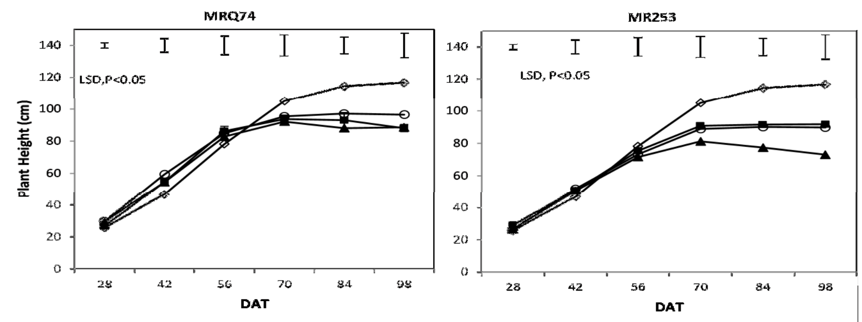

Fig. 2: Plant height for each variety during the entire growth in every treatment; (O) PC, (■) SC, (▲) NC, (◊) Control. Each point represents the mean of three replicates and the vertical bars represent LSD at 0.05

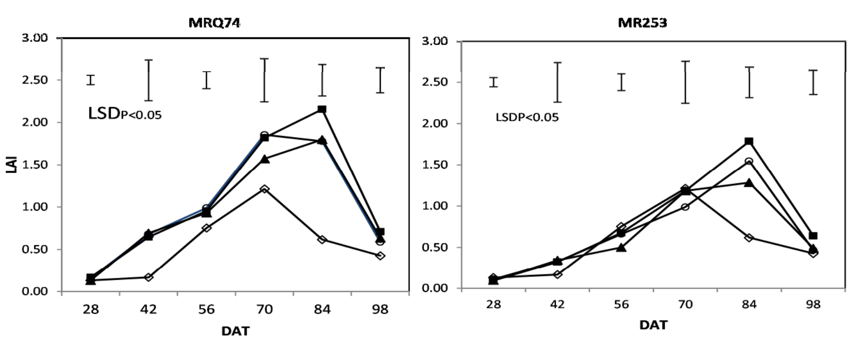

Fig. 3: Chlorophyll content for each variety during the entire growth in every treatment; (O) PC, (■) SC, (▲) NC, (◊) Control. Each point represents the mean of three replicates and the vertical bars represent LSD at 0.05

content was not affected by the treatments. Maximum total chlorophyll was reached at the 84 DAT before constant (Fig. 4).

Photosynthetic rate of plants showed significant difference among PC, SC, NC and control (Tables 1 and 2). At heading stage, the photosynthesis rate was significantly high compared to tillering stage for all treatments and varieties except NC. Variety MR232 had the highest photosynthetic rate at tillering stage. However, at heading stage there was a significantly high photosynthesis rate in PC for MRQ74. In general, both MRQ74 and MR253 exhibited a similar trend of stomatal conductance and transpiration rate from tillering to heading stages. At tillering stage, the control plants lost the most water by high

Table 1: Photosynthetic rate (A), stomatal conductance (g_s), transpiration rate (E) and water use efficiency (WUE) in every treatment and variety at tillering stage

Variety	Treatment	A (µmol m^{-2} s^{-1})	Gs (mmol m^{-2} s^{-1})	E (mmol m^{-2} s^{-1})	WUE
MRQ74	PC	65.23 ab	0.04 a	2.28 a	28.60 b
	SC	70.86 ab	0.14 b	7.31 b	9.69 a
	NC	59.50 a	0.08 ab	4.62 ab	12.88 ab
MR253	PC	77.88 ab	0.07 ab	3.68 ab	21.18 ab
	SC	99.77 cd	0.28 c	14.11 c	7.07 a
	NC	83.1 bc	0.23 c	11.70 c	7.10 a
MR232	Control	119.33 d	0.50 d	21.69 d	5.50 a

Different letters in each column difference at $p \leq 0.05$ by Duncan's New Multiple Range Test (DMRT)

Table 2: Photosynthetic rate (A), stomatal conductance (g_s), transpiration rate (E) and water use efficiency (WUE) in every treatment and variety at heading stage

Variety	Treatment	A (µmol m^{-2} s^{-1})	Gs (mmol m^{-2} s^{-1})	E (mmol m^{-2} s^{-1})	WUE
MRQ74	PC	196.64 e	0.53 c	18.83 d	10.45 d
	SC	145.69 d	0.28 ab	12.70 ab	11.00 e
	NC	71.31 a	0.23 a	11.46 a	6.22 a
MR253	PC	112.29 c	0.28 ab	12.06 ab	9.31 c
	SC	109.22 bc	0.33 b	14.70 ab	7.43 b
	NC	86.39 ab	0.27 ab	13.07 abc	6.61 a
MR232	Control	147.77 d	0.33 b	15.62 c	9.46 c

Different letters in each column show significant difference at $p \leq 0.05$ by Duncan's New Multiple Range Test (DMRT)

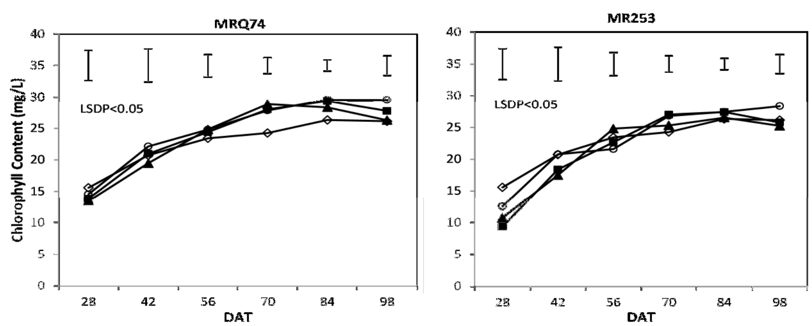

Fig. 4: Chlorophyll content for each variety during the entire growth in every treatment; (O) PC, (■) SC, (▲) NC, (◊) Control. Each point represents the mean of three replicates and the vertical bars represent LSD at 0.05

transpiration rate and stomatal conductance followed by SC, NC and PC for both MRQ74 and MR253. It was different at heading stage and MRQ74 achieved significantly higher transpiration rate and stomatal conductance in PC treatment followed by control, SC and NC while in MR253, SC and control were higher than PC and NC.

Results indicated that non-flooded rice has high WUE compared to flooded rice. At tillering stage, the highest WUE was found in PC and the lowest was in the control (Table 1 and 2). It responds differently at heading stage whereby WUE in PC was still the highest and the lowest for NC.

Yield Components

Compared with rice under continuous flooding, the grain yield showed reduction under non-flooded condition. However, only the grain yield of MRQ74 under SC treatment was comparable to the control (Table 3). The grain yield under NC reduced by 38% and 50% compared to PC and SC. There was an obvious significant difference amongst varieties rather than treatments in number of spikelet, grain weight density and grain yield except for number of panicles. However, percentage of filled grain was insignificant among treatments and varieties (Table 3).

Above ground biomass and harvest index of MRQ74 showed a significant difference amongst treatments but not in MR253 (Table 4). Soil cover treatment did not affect MR253 in producing dry matter. Root-shoot ratio showed no significant difference for all varieties and treatments. Harvest index was found high in MRQ74 under SC and low in MR253 under NC.

Discussion

The growth patterns were similar between tiller number and

Table 3: Grain Yield and its component under different soil cover treatment

Variety	Treatment	Panicle Number/Hill	Spikelet/Panicle	Filled Grain (%)	1000-Grain Weight (g)	Grain Yield (t/ha)
MRQ74	PC	45.00 b	52.00 ab	48.83 a	17.80 bc	5.39 ab
	SC	58.00 b	43.00 a	53.13 a	19.61 c	7.39 b
	NC	32.00 a	37.00 a	67.61 a	17.96 bc	3.40 ab
MR253	PC	30.00 a	85.00 bc	35.99 a	11.89 a	2.84 ab
	SC	52.00 b	55.00 ab	36.97 a	11.63 a	3.11 ab
	NC	25.00 a	36.00 a	49.23 a	15.26 ab	1.66 a
MR232	CONTROL	22.00 a	106.00 c	64.61 a	19.90 c	7.06 b

Table 4: Effects of soil cover treatment on RWC aboveground biomass, harvest Index (HI) and root-shoot ratio

Variety	Treatment	Tiller Number/Hill	Aboveground Biomass	Harvest Index (%)	Root-Shoot Ratio
MRQ74	PC	62.00 de	69.22 bc	29.96 abc	0.74 b
	SC	59.00 cde	81.24 c	43.74 c	0.66 ab
	NC	44.00 abc	43.62 ab	20.82 ab	0.66 ab
MR253	PC	72.00 e	55.71 ab	20.48 ab	0.45 ab
	SC	39.00 ab	55.09 ab	32.37 abc	0.79 b
	NC	35.00 a	31.3 a	13.61 a	0.30 a
MR232	CONTROL	51.00 bcd	67.57 bc	41.71 bc	0.60 ab

*Within a column for each parameter, means followed by different letters are significantly different at 0.05 probability level according to least significant difference (LSD) test

plant height. Rice grain yields are highly dependent upon the number of panicle-bearing tillers produced per plant (Hasamuzzaman *et al*., 2009). All varieties grew rapidly at tillering stage then slow growth at reproduction stage until harvest. According to Kamoshita and Abe (2007), tiller number subsequently increase the both source and sink capacity. Furthermore, different varieties respond differently to soil cover treatment. The possible reason may be attributed to the soil temperatures which resulted in decreased tiller number in MR253 under PC at reproduction stage (Tao *et al*., 2006; Zhang *et al*., 2008).

Plant height varied between control and adapted aerobic variety is due to the difference of variety. The reduction in plant height of adapted aerobic rice showed that aerobic varieties are tolerant to drought condition (Sikuku *et al*., 2010). Moreover, soil cover treatments in MR253 grow differently in plant height. According to Zubaer *et al*. (2007), it might be due to inhibition of cell division or cell enlargement due to water stress dependent upon turgor.

The increase in LAI over time is due to the formation and subsequent expansion of new leaves closely correlated with tiller formation (Tao *et al*., 2006). Qin *et al.* (2010) reported that straw mulching can increase LAI compared to treatment without straw mulching. Even though LAI among treatments was not significant still showed a sequence growth where SC is the highest followed by PC and NC in both adapted rice varieties respectively. Sritharan and Vijayalakshmi (2012) mentioned that LAI was directly related to grain yield. Therefore, maintenance of high LAI at reproduction stage is desirable for producing high yield in stressed plants.

Numerous reports (Deivanai *et al.*, 2010; Rajiv *et al.*, 2010; Anjum *et al.*, 2011) claimed that chlorophyll content decrease under water stress. Apparently, the results showed that chlorophyll content of rice plant under non-flooded condition was higher than flooded condition. It follows that chlorophyll content is one of the physiological attributes related to aerobic rice improvement to form a high yielding character (Parthasarathi *et al*., 2012). Anjum *et al*. (2011) revealed that chlorophyll content has a positive relationship with photosynthesis rate.

According to Cha-Um *et al.* (2010), the low photosynthetic rate is a response to water stress and it showed that non-flooded rice responded to aerobic treatment by having low photosynthesis rate especially in NC treatment. The highest photosynthetic rate at heading stage was found in MRQ74 under PC speculatively in response to high carbon demands at this stage. Based on results, PC treatment helps MRQ74 in minimizing water loses from transpiration process especially at tillering stage. Stomatal conductance was always found higher under flooding condition (control) because abundant water availability to root, which influenced it to produce chemical signal to the shoot to affect stomatal opening (Zulkarnain *et al*., 2009).

Generally, water use efficiency in rice subjected to water deficit declined significantly. There are reports that soil cover treatment significantly increased WUE (Fan *et al*., 2005; Liu *et al*., 2005; Zhang *et al*., 2008). The high value of WUE in PC speculatively was attained by high photosynthesis and reduction of transpiration rate. The results suggest that contrary to the various report (Deng *et al*., 2000; Yang *et al*., 2008; Zhang *et al*., 2008) the reduction in transpiration rate, would not necessarily lead to reduced photosynthetic rate. In some cases, such as in PC when evapotranspirative demand was high during midday, transpiration rate decreased more than photosynthesis rate. Soil cover treatment enhances the WUE thus effectively reduce water deficit in aerobic cultivation. The tiller

Table 5: Relationship between physiological parameters in all rice varieties and treatments by using Pearson's correlation

Parameters	Tiller Number	Plant Height	LAI	Chl	A	gs	E	WUE
Tiller number	–	0.748**	0.669**	0.709**	0.551**	0.393**	0.354*	-0.130
Plant height	–	–	0.671**	0.799**	0.614**	0.407**	0.370*	-0.187
LAI	–			0.778**	0.355*	0.233	0.166	-0.111
Chl	–	–	–	–	0.507**	0.355*	0.288	-0.047
A	–	–	–	–	–	0.814**	0.732**	-0.196
Gs	–	–	–	–	–	–	0.976**	–0.423**
E	–	–	–	–	–	–	–	–0.496**
WUE	–	–	–	–	–	–	–	–

*$p = 0.05$, **$p = 0.01$

number, plant height, A, g_s, Chl and LAI were positively correlated at $p \leq 0.01$ to one another, but WUE was negatively correlated (Table 5).

Basically, grain yield was attributed to number of panicle, number of spikelet, percentage of filled grain and grain weight density (Tao *et al*., 2006; Zhang *et al*., 2008; Zulkarnain *et al*., 2009; Wei *et al*., 2011; Sritharan and Vijayalakshmi, 2012). Under flooded situation, spikelet per panicle, percentage of filled grain and grain weight density were high even though the panicle number was low. For non-flooded rice, the greater grain yield especially in SC was attributed to the high panicle number per hill and specifically for MRQ74, where the grain weight density was also the highest. The grain yield of NC reduced due to low panicle number, spikelet number and grain weight density. Rice is vulnerable to water stress even to mild water stress, which leads to the reduction of grain yield in aerobic rice. Nevertheless, the results suggest that to sustain cultivation of rice under non-flooded situation (aerobic condition), it is necessary to adopt soil cover treatment for promising yield.

Different varieties responded differently in development of dry matter. The number of panicle, spikelet number and grain weight density directly contributed to the aboveground biomass (Kamoshita and Abe, 2007; Wei *et al*., 2011; Xie *et al*., 2011). In addition, high root-shoot ratio exhibits a drought resistance in plants (Zulkarnain *et al*., 2009; Sritharan and Vijayalakhsimi, 2012). Reduced root growth might give negative impacts on plant growth thereby reduce sink activity besides reducing the availability of water and minerals (Kamoshita and Abe, 2007; Zulkarnain *et al*., 2009; Sikuku *et al*., 2010). Under this situation the R:S ratio was not bearing with other parameters.

Zulkarnain *et al*. (2009) stated that shorter plants and less tillers would have attributed to the lower grain yield and similar with MR253. Grain yield was comparable among treatment. Results suggested that it is not necessary to flood rice to obtain high grain yield as maintaining a soil cover treatment throughout the growing season resulted in similar rice yield between flooded and non-flooded. The most severe effect of water stress was NC based on the dropping of values in every physical growth and physiological parameters.

In conclusion, the soil cover system has the potential to reduce water input in rice cultivation. Between PC and SC, it responds differently in morphology, physiology and yield component. The results proved that SC would increase the tillering, LAI, panicle number, aboveground biomass, grain weight, grain yield and HI. Plastic film cover helps in enhancing the photosynthesis, which increase the carbon sink by producing high spikelet number. Moreover, PC possibly reduces the water loss by reducing the transpiration rate and stomatal conductance thus with highest WUE. MRQ74 was well adapted to aerobic condition. The soil cover system would be a better practice if implemented in the suitable area (soil and environment condition) using the specific rice variety. Further investigation are needed on the effect of soil cover system to the soil water and mineral content thus couple with physiology, growth and yield will developed a better management practice in cultivating rice under aerobic condition.

Acknowledgements

This research was supported by Posgraduate Research Fund Grant (PPP) Project, No. PS 272/2008C. Special thank to Dr. Syed Shahar and Dr. Normaniza for his supervision during the whole project. Thank also to MARDI for providing seeds and field research.

References

Adam, B., 2007. High and dry. *Rice Today*, 6: 28–30

Atlin, G. N., M. Laza, M. Amante and H.R. Lafitte, 2004. Agronomic performance of tropical aerobic, irrigated, and traditional upland rice varieties in three hydrological at IRRI. *Proceedings of 4th International Crop Science Congress*, 26 Sep-1 Oct 2004, Brisbane, Australia

Anjum, S.A., X.Y. Xie, L.C. Wang, M.F. Saleem, C. Man and W. Lei, 2011. Morphological, physiological and biochemical responses of plants to drought stress. *Afr. J. Agric. Res*., 6: 2026–2032

Belder, P., B.A.M. Bouman, R. Cabangon, L. Guoan, E.J.P. Quilang, J.H.J. Spiertz and T.P. Tuong, 2004. Effect of water saving irrigation on rice yield and water use in typical lowland conditions in Asia. *Agric. Water Manage*., 65: 193–210

Bouman, B.A.M., X.G. Yang, H.Q. Wang, Z.M. Wang, J.F. Zhao, C.G. Wang and B. Chen, 2002. Aerobic Rice (Han Dao): a new way growing rice in water short areas. *Proceedings of the 12th International Soil Conservation Organization Conference, 26-31 May*, pp: 175–181. Tsinghua University Press, Beijing, China

Bouman, B.A.M., 2007. The aerobic rice reality. *Rice Today*, 6: 38

Bouman, B.A.M., 2009. How much water does rice use. *Rice Today*, 8: 29

Casanova, D., J. Goudriaan, M.M. Catala Forner and J.C.M. Withagen, 2002. Rice yield prediction from yield components and limiting factors. *Eur. J. Agron*., 17: 41–61

Cha-Um, S., S. Yooyongwech and K. Supaibulwatana, 2010. Water deficit stress in the reproductive stage of four indica rice (*Oryza sativa* L.) genotypes. *Pak. J. Bot*., 42: 3387–3398

De Datta, 1981. *Principles and Practices of Rice Production*. The International Rice Research Institute, Philippines. John Wiley & Sons, Inc. New York, USA

Deivanai, S., S. Sheela Devi and P. Sharmila Rengeswari, 2010. Physiochemical traits as potential indicators for determining drought tolerance during active tillering stage in rice (*Oryza sativa* L.). *Pertanika J. Trop. Agric. Sci*., 33: 61–70

Deng, X.P., L. Shan, Y.Q. Ma and S. Inanaga, 2000. Diurnal oscillation in the intercellular CO_2 concentration of spring wheat under the semiarid conditions. *Photosynthetica*, 38: 187–192

Fan, M.S., X.J. Liu, R.F. Jiang, F.S. Zhang, S.H. Lu, X. Zheng and Z.P. Christie, 2005. Crop yields, internal nutrient efficiency and changes in soil properties in rice-wheat rotations under non-flooded mulching cultivation. *Plant Soil*, 277: 265–276

Kamoshita, A. and J. Abe, 2007. Growth of rice plants (*Oryza sativa* L.) under non-flooded water-saving paddy fields. *Agric. J*., 2: 375–383

Hasamuzzaman, M., M. Fujita, M.N Islam, K.U. Ahamed and K. Nahar, 2009. Performance of four irrigated rice varieties under different levels of salinity stress. *Int. J. Integ. Biol*., 6: 85

Liu, X.J., Y.W. Ai, F.S. Zhang, S.H. Lu, X.Z. Zeng and M.S. Fan, 2005. Crop production, nitrogen recovery and water use efficiency in rice–wheat rotations as affected by non-flooded mulching cultivation (NFMC). *Nutr. Cycl. Agroecosyst*., 71: 289–299

Parthasarathi, T., K. Vanitha, P. Lakshamanakumar and D. Kalaiyarasi, 2012. Aerobic rice-mitigating water stress for the future climate change. *Int. J. Agron. Plant Prod*., 3: 241–254

Peng, S., B.A.M. Bouman, R.M. Visperas, A. Castaneda, L. Nie and H.K. Park, 2005. *Comparison between Aerobic and Flooded Rice in the Tropics: Agronomic Performance in an Eight-season Experiment*, pp: 252–259. International Rice Research Institute, Manila, Philippines

Qin, J., X. Wang, F. Hu and H. Li, 2010. Growth and physiological performance responses to drought stress under non-flooded rice cultivation with straw mulching. *Plant Soil Environ*., 56: 51–59

Rajiv, S., P. Thivendran and S. Deivanai, 2010. Genetic divergence of rice on some morphological and physiochemical responses to drought stress. *Pertanika J. Trop. Agric. Sci*., 33: 315–328

Sikuku, P. A., G.W. Netondo, J.C. Onyango and D.M. Musyimi, 2010. Effects of water deficit on physiology and morphology on three varieties of nerica rainfed rice (*Oryza sativa* L.). *ARPN J. Agric. Biol. Sci*., 5: 23–28

Singh, S., J.K. Ladha, R.K. Gupta, L. Bhushan and A.N. Rao, 2008. Weed management in aerobic rice systems under varying establishment methods. *Crop Prot.,* 27: 660–671

Sritharan, N. and C. Vijayalakshmi, 2012. Physiological basis of rice genotypes under aerobic condition. *Plant Arch.,* 12: 209–214

Tao, H., H. Brueck, K. Dittert, C. Kreye, S. Lin and B. Sattelmacher, 2006. Growth and yield formation of rice (*Oryza sativa* L.) in the water-saving ground cover rice production system (GCRPS). *Field Crop Res*., 95: 1–12

Wei, F., H. Tao, S. Lin, B.A.M. Bouman, L. Zhang, P. Wang and K. Dittert, 2011. Rate and duration of grain filling of aerobic rice HD297 and their influence on grain yield under different growing conditions. *Sci. Asia*, 37: 98–104

Xie, X.J., S.H.H. Li, X.Y. Zhao, B.B. Li and D.F. Xu, 2011. Effect of photosynthetic characteristic and dry matter accumulation of rice under high temperature at heading stage. *Afr. J. Agric. Res.,* 6: 1931–1940

Yang, F., Z.W. Liang, Z.C. Wang and Y. Chen, 2008. Relationship between diurnal changes of net photosynthesis rate and influencing factors in rice under saline sodic stress. *Rice Sci*., 15: 119–124

Zeng, L., S.M. Lesch and C.M. Grieve, 2002. Rice growth and yield respond to changes in water depth and salinity stress. *Agric Water Manage.,* 59: 67–75

Zhang, Z., S. Zhang, J. Yang and J. Zhang, 2008. Yield, grain quality and water use efficiency of rice under non-flooded mulching cultivation. *Field Crop Res*., 108: 71–81

Zubaer, M.A., A.K.M.M.B. Chowdhury, M.Z. Islam, T. Ahmed and M.A. Hasan, 2007. Effects of water stress on growth an yield attributes of Aman rice genotypes. *Int. J. Sustain. Crop Prod*., 2: 25–30

Zulkarnain, W.M., M.R. Ismail, M. Ashrafuzzaman, H.M. Saud and I.C. Haroun, 2009. Rice growth and yield under rain shelter house as influenced by different water regimes. *Int. J. Agric. Biol*., 11: 566–570

(Received 14 June 2013; Accepted 11 September 2013)