Journal of Stress Physiology & Biochemistry, Vol. 9 No. 2 2013, pp. 97-107 ISSN 1997-0838

ORIGINAL ARTICLE

Effects of Water Stress on Rice Production: Bioavailability of Potassium in Soil

Md Sarwar Jahan[1,*], Mohd Nozulaidi Bin Nordin[1], Mond Khairi Bin Che Lah[1], Yusop Mohd Khanif[2]

[1] *Department of Agricultural Sciences, Faculty of Agriculture and Biotechnology, University Sultan Zainal Abidin, 20400 Kuala Terengganu, Malaysia*

[2] *Department of Land Management, Faculty of Agriculture, University Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia*

Tel: +609-668-8526 Fax+609-668-7778

*E-Mail: sarwarjahan@unisza.edu.my

Received November 26, 2012

Water demand in agriculture, municipal, and industrial purposes is increasing rapidly which will pressure on future demand in agriculture. To justify less water use in rice production, we produced rice under different water levels (DWLs) and justified potassium bioavailability. There were five DWLs were employed in this experiment. Besides measuring yield and yield parameters, relative water content (WRC) and chlorophyll content in leaves, soil pH and bioavailability of potassium (K) in soil solution were measured. Yield and yield parameters showed insignificant difference under DWLs. Different water levels did not affect weekly data of chlorophyll content and RWC in leaves. But chlorophyll content and RWC in leaves were significantly higher in week 6 or 9 than week 3. Different water levels did not affect soil pH. Our results suggested that rice can be produced under low water input without affecting yield and yield parameters and K bioavailability in soil.

Key words: bioavailability of potassium, chlorophyll content, low water irrigation, relative water content, rice

ORIGINAL ARTICLE

Effects of Water Stress on Rice Production: Bioavailability of Potassium in Soil

Md Sarwar Jahan[1,*], Mohd Nozulaidi Bin Nordin[1], Mond Khairi Bin Che Lah[1], Yusop Mohd Khanif[2]

[1] *Department of Agricultural Sciences, Faculty of Agriculture and Biotechnology, University Sultan Zainal Abidin, 20400 Kuala Terengganu, Malaysia*

[2] *Department of Land Management, Faculty of Agriculture, University Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia*

Tel: +609-668-8526 Fax+609-668-7778

*E-Mail: sarwarjahan@unisza.edu.my

Received November 26, 2012

Water demand in agriculture, municipal, and industrial purposes is increasing rapidly which will pressure on future demand in agriculture. To justify less water use in rice production, we produced rice under different water levels (DWLs) and justified potassium bioavailability. There were five DWLs were employed in this experiment. Besides measuring yield and yield parameters, relative water content (WRC) and chlorophyll content in leaves, soil pH and bioavailability of potassium (K) in soil solution were measured. Yield and yield parameters showed insignificant difference under DWLs. Different water levels did not affect weekly data of chlorophyll content and RWC in leaves. But chlorophyll content and RWC in leaves were significantly higher in week 6 or 9 than week 3. Different water levels did not affect soil pH. Our results suggested that rice can be produced under low water input without affecting yield and yield parameters and K bioavailability in soil.

Key words: bioavailability of potassium, chlorophyll content, low water irrigation, relative water content, rice

Rice is the staple food in Asia and nearly 90 - 91% of the world's rice is produced and consumed in this region. Rice provides an average of 32% of total calories uptake (Maclean *et al*. 2002; IRRI 2002). In Asia, approximately, irrigated lands cover about 271 million ha for all crops, where rice stands alone for 40 - 46% of the total area (Dawe 2005). About 75% of the global rice volume produced in the irrigated lowlands and 50% of that irrigated rice is produced in Asia (Maclean *et al*. 2002; Guerra *et al*. 1998). In Malaysia, water demand is growing annually is about 4% which was measured about 3.2 billion m^3 (Keizrul and Azuhan 1998). By 2025, fresh water will be less available and irrigated rice will suffer from some degree of water scarcity (Tuong and Bouman 2003; Tuong *et al*. 2005). Water demand for agricultural production is becoming increasingly scarce (Rijsberman 2006). Decreasing water availability for agriculture threatens the productivity of the irrigated rice ecosystem, therefore, new strategy must be sought to save water and sustain rice production (Guerra *et al*. 1998).

Potassium nutrition affects growth and yield of rice plants. Plants' available K in soil solution exists as exchangeable and nonexchangeable forms which account a small fraction of total K are 1 - 2% and 1 - 10%, respectively. The rest of soil potassium contents exist in potassium-bearing micas and feldspars (Sekhon 1995; Havlin *et al*. 1999). The amount of potassium in the soil solution is not sufficient for rice plant. Potassium functions in phloem loading of sucrose, facilitates photosynthesis and water content in leaves (Karley and White 2010) which maintain turgor pressure of guard cells to cope plants under stress condition. Ishizuka (1965) reported that potassium greatly influences the growth and development of rice plant. Potassium content increased in soil solution is closely related to ferrous ion content in soil (De Datta 1981). Several on-farm water-saving practices have been scientifically developed over time to improve the crop growing conditions (Wang 1992; Mao 1993; Peng *et al*. 1997; Li *et al.* 1999). Jungk (2002) reported that hydrated condition increased K availability in soil may influence plant uptakes.

In Malaysia, rice production is not sufficient and rice is to be imported to meet the country's demand (Ariffin 1998). To date, few attentions have been paid on low water input rice production in relation to bioavailability of K in soil. Therefore, current research was taken to evaluate the effect of DWLs on rice production and bioavailability of K in soil solution.

MATERIALS AND METHODS

Experimental design

Five different water treatments, namely, W1 (continuous flooding at 5 cm), W2 (continuous flooding at 1 cm), W3 (continuous flooding at 5 cm in the first 3 weeks followed by 1 cm), W4 (continuous flooding at 5 cm in the first 6 weeks followed by 1 cm), and W5 (continuous flooding at 5 cm in first 9 weeks followed by 1 cm) were laid out in a completely randomized design with five replications. Rice plants were grown in pots. A pot was filled with the soil leaving 10 cm from the top of the pot to facilitate water treatments. Two holes were made at 1 cm and 5 cm above from the soil level in pot and attached to plastic tube equipments with flow regulators for adjusting required water levels. Silty clay soil of 466 mg/kg of exchangeable K, soil pH of 6.0 and organic matter of 4.12% was used in this study. Proper agronomic practices were maintained according to Chelah *et al*. (2011).

Seeds and fertilizers

Healthy rice seeds of MR 219 were soaked in water for 24 h followed by wet treatment for 2 - 3 days for pre-germination. Sprouted seeds were placed on pots in a row. Fertilizers, urea as N 110 kg ha^{-1} with two splits (2/3 as basal + 1/3 at active tillering), P_2O_5 (60 kg ha^{-1}) as triple super phosphate (TSP) and K_2O (65 kg ha^{-1}) as muriate of potash (MOP) were applied as basal application.

Compound fertilizer (N: P: K= 12: 12: 17) was applied twice at 50 and 71 days after showing (DAS) at the rate of 300 kg/ha, and 200 kg/ha, respectively (MARDI 2001). Yield and yield parameters were determined according to Chelah *et al*. (2011).

Analysis of K content in soil extracts, soil and straw

The soil water samplers (SPS200 SDEC, France) were used to collect soil extract from soil. A porous ceramic cup was fixed at the bottom of an empty PVC tube. All tubes were inserted into the soil. A depression was created inside the tube by suction pump then the soil solution was drawn from soil through the porous ceramic cup into the tube. Potassium content was determined three times in soil were after land preparation (ALP), 51 DAS and after harvest (AH), and two times in straw were 51 DAS and AH by ammonium acetate leaching method (Schollenberger and Simon 1945).

Measurement of chlorophyll content in leaves of rice plants

The SPAD-502 portable chlorophyll meter was used to acquire a rapid estimation of leaf chlorophyll content according to Chelah *et al*. (2011). The measurements were taken on the upper-most collared leaf and five measurements per leaf were taken from each pot. The measurement was done from 11 am to 12 pm to avoid water content on leaf surface.

Measurement of relative water content (RWC) in leaves of rice plants

Fresh healthy and unblemished leaves were collected from each pot. The fresh weight (FW) of the leaves were measured followed by water incubation for 24 h to obtain full turgidity. After 24 h, the samples were blotted dry and the turgid weight (TW) was recorded followed by dry weight after samples were dried at 60°C for 24 h in oven. The RWC was calculated using the following formula.

$$RWC (\%) = (FW – DW) / (TW – DW) X 100$$

Measurement of Soil pH

Soil pH was measured using portable IQ pH meter according to Chelah *et al*. (2011). The pH electrode was calibrated with appropriate buffer solutions before taking data in each time.

Statistical analysis

The data were analyzed for analysis of variance (ANOVA). The means were compared using Duncan’s Multiple Range Test (DMRT) at 5% level using the Statistical Analysis System software version 6.12.

RESULTS

Less water input does not affect rice yield and yield parameters

Whether DWLs affect yield and yield parameters of rice plants, we measured number of tillers, number of panicles, yield, filled and unfilled grains per panicle, and 1000 seeds weight (g). Different water levels did not significantly affect rice yield and yield parameters (Table 1). The rice yield (14% moisture content) obtained was in the range of 68 to 71 g/pot. These results suggest that reducing water input in rice cultivation might not affect yield and yield parameters.

Effect of water stress on bioavailability of potassium (K) in soil

Whether water stress affects potassium in soil, we measured K content in soil extract in every week. Figure 1 showed that K content in soil extract was significantly higher in W2 than W1 in several weeks (Figure 1). It might due to the interaction between K content and water level in soil. This result suggests that less water input increased K availability in soil solution than that of high water input in soil did. Figure 1 also showed that potassium concentrations in soil remained to a higher level for few weeks after flooding then declined rapidly thereafter and reached a consistent low concentration in the following periods. These results were consistent with Slaton (2004).

In soil, the K concentration decreased with increasing plant age but it increased again at ripening stage (Table 2) may due to the effect of fertilizer application and water-potassium interaction in soil. During land preparation, K content in W2 treatment was similar to W1 treatments but it was significantly higher after harvest. This result suggests that less water input also increased K content in soil.

Plants accumulated higher amount of potassium during reproductive stage which was supported by the data of K content in plant (Table 2) which confirmed that plants accumulated higher content of K at ripening stage than that of vegetative stage which was consistent with previous results stated by Ishizuka (1965). This result support to the results stated by e-ifc (2008) that accumulation of higher K at ripening stage contributes to grain filling. Taken together, these results suggest that low water input in rice production might not affect K contents in soil as well in plants.

Effect of water stress on chlorophyll content in rice leaves

We measured chlorophyll content in leaves of rice plants in week 3, 6 and 9 to find out the effect of DWLs on chlorophyll content in rice leaves. In week 3, low water input, 1 cm of flooding water, did not significantly decrease chlorophyll content in rice leaves compared to that of chlorophyll content in leaves of rice plants grown in 5 cm of flooding condition (Figure 2). Similar results were observed in week 6 and 9 (Figure 2). In addition, chlorophyll content in leaves of rice plant gradually increased with increasing plant age regardless of soil water conditions (Figure 2). In this study, we showed that low water input might not affect chlorophyll content in rice leaves.

Effect of water stress on relative water content (RWC) in rice leaves

Relative water content in leaves of rice plants was measured in week 3, 6 and 9 (Figure 3). The RWC in leaves was significantly higher in week 6 and 9 than that of RWC in leaves of plants grown in week 3 but data of RWC in either week showed insignificant difference. This result indicates that DWLs did not affect RWC in leaves and RWC in leaves increased with increasing plant age (Figure 3). Our result also suggests that soil water condition at above saturation level, regardless of water depth, did not affect RWC in leaves. This result was consistent with our previous results stated by Chelah *et al*. (2011) that water condition at saturated levels did not affect RWC in leaves of rice plants.

Soil pH

Soil pH indicates of chemical condition in soil. Soil pH was measured in soil in week 3, 6 and 9 to justify weather DWLs affect soil pH (Figure 4). The pH values were insignificantly different in DWLs and were in the range from 5.1 to 5.6. This result suggests that DWLs might not affect soil pH.

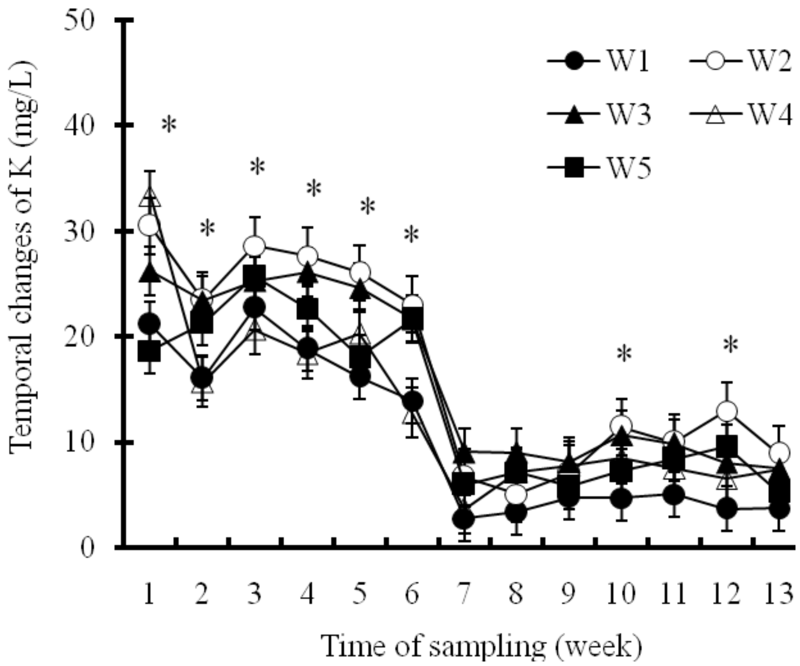

Figure 1: Temporal changes of K content in soil solution. K content gradually decreased with increasing flooding time followed by relatively stable condition. *Means are significantly different in W2 from the control of W1 at P < 0.05

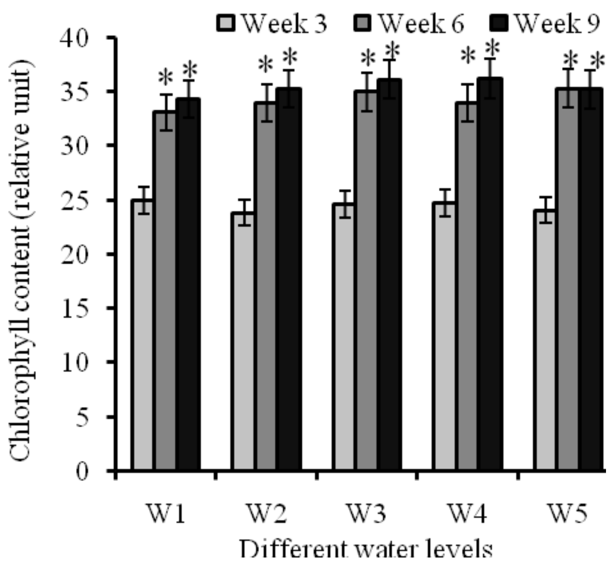

Figure 2: Chlorophyll content in leaves of rice plant grown in different water levels. *Means are significantly different in week 6 and 9 from week 3 at P < 0.05.

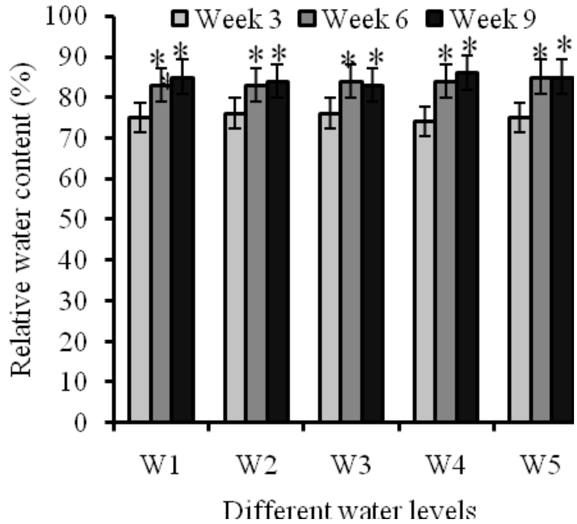

Figure 3: Relative water content in leaves of rice plant grown in different water levels. *Means are significantly different in week 6 and 9 from week 3 at P < 0.05.

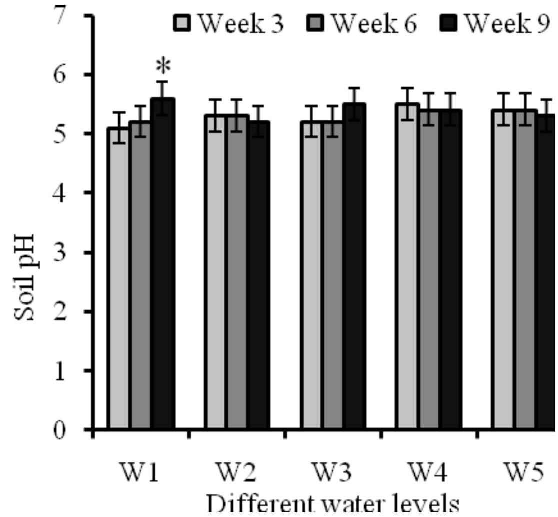

Figure 4: Soil pH in soil in different water levels. *Means are significantly different in week 9 from week 3 at P < 0.05.

Table 1. Effects of different water levels on rice yield and yield components

Treatments	Number of Tillers/pot	Number of Panicles/pot	Unfilled grains /panicle	Filled grains /panicle	1000 seeds weight (g)	Dry straw (g/pot)	Yield (g/pot)
W1	42a	38a	23a	90a	26.2a	92a	71a
W2	41a	37a	26a	87a	26.4a	95a	69a
W3	40a	35a	23a	92a	26.3a	90a	71a
W4	43a	34a	24a	91a	26.2a	92a	68a
W5	42a	35a	22a	92a	26.6a	94a	68a

Means with the same letter are not significantly different in column at P≤0.05 by DMRT

Table 2. Potassium concentration in soil and straw

Treat-ments*	In soil (mg/Kg)			In straw (%)	
	After land preparation	51 DAS	After harvest	51 DAS	After harvest
W1	311b	134b	326b	3.8a	5.9a
W2	299b	223a	554a	4.5a	5.8a
W3	538a	233a	311b	4.2a	6.1a
W4	499ab	163ab	366b	4.2a	5.8a
W5	686a	208ab	472ab	3.9a	6.1a

The means in a column with the same letter are not significantly different at P≤0.05 by DMRT.

DISCUSSION

There are 7 billion people to feed in this planet and another 2 billion are expected to join by 2050. Statistics say that a man drinks 2 to 4 liters of water every day, however most of the water we 'drink' is embedded in the food we eat e.g. producing 1 kilo of wheat 'drinks up' 1,500 liters of water (UN 2012). Unless we increase our capacity to use water wisely in agriculture, we will fail to end hunger and open the door to a range of other ills, including drought, famine and political instability (UN Secretary 2012). Therefore it is necessary to produce more food, rice, of better quality with less water.

Previously done experiments in water-saving system, where soils are exposed to alternate wetting and drying, the aerobic situations occasionally exist under such condition. Dry soil conditions often result in low yields which attributed to nutritional disorders (Singh and Bhattacharyya 1989). In the view of the above point, our study was conducted under different flooding conditions rather than the condition where soil is exposed to a dry condition. The technology based on chemical fertilizers and high-yielding varieties has generally been successfully achieved. Beside their rapid industrial development, it is still have to develop alternative practice that is low water input rice production which might save larger amount of fresh water compared to conventional irrigation system. In this study, we showed that soil water condition maintained at 1 cm flooding level did not affect rice yield (Table 1). We stated in our previous study which showed that maintaining water condition in soil at saturated level throughout the growing period did not affect rice yield (Chelah *et al*. 2011). It is, therefore, suggested that low water input in rice production might not affect rice yield.

Potassium greatly influences the growth and development of rice plants (Ishizuka 1965). Both soil K pools, exchangeable and solution, reach at low concentrations near the time of panicle differentiation and persist until the flood water is drained out because plants accumulated higher content of K might which affects grain filling (e-ifc 2008). De Datta and Mikkelsen (1985) stated that the concentration of K in flooded soil is greater than in an upland soil. Because flooding enhances the release of exchangeable K into the soil solution by stimulating the reduction of Fe^{3+} to Fe^{2+} and Mn^{4+} to Mn^{2+} which displaces K^+ from CEC sites (Patrick *et al*. 1985). Chlorophyll content in rice leaves indicates the cause of activation of photosynthesis (Kurra-Hotta *et al*. 1987). In our study, soil water condition was maintained above saturated level which did not affect chlorophyll content (Figure 2) in leaves of rice plants indicates proper activation of photosynthesis which may sustain rice yield. We also showed that RWC in rice leaves was not affected by DWLs. Relative water content might depend on rice varieties, nitrogen deficiency, stress condition (Suriya-arunroj *et al*. 2004).

CONCLUSION

We confirmed that rice could be cultivated under low water irrigation condition that is 1 cm flooding without affecting rice yield, yield components, K content in soil and plants. In addition, the low water practice might save larger amount of fresh water compare to that of traditional irrigation system. This study was conducted in pot under controlled environment and further research will be needed to justify nutrients fingerprint in soil in detail and phyto-physiological parameters of rice plants grown in field condition.

ACKNOWLEDGMENTS

We are grateful to the ministry of Malaysia for providing financial support to conduct the research work under the project on Intensification of Research in Priority Areas (IRPA) and Faculty of Agriculture and biotechnology, UniSZA, Terengganu, Malaysia.

REFERENCES

Ariffin, T. (1998) Kegawatan ekonomi dan pengeluaran beras negara: Satu penilaian semula. *Agromedia* 4: 4-9.

Dawe, D. (2005) Increasing water productivity in rice-based systems in Asia—past trends, current problems, and future prospects. *Plant Pro. Sci.* 8: 221-230.

De Datta, S.K. (1981) *Principles and Practices of Rice Production*. New York: John Willey and Sons Inc. New York, USA pp. 1-592.

De Datta, S.K., Mikkelsen, D.S. (1985) Potassium nutrition of rice. *In:*"Potassium in Agriculture" (R.D. Munson, ed.). pp. 665-699. ASA/CSSA/SSSA, Madison, WI.

International Potash Institute (2008) Potassium improves grain filling - a short story in pictures and figures from India, Indonesia and China. *Electronic International Fertilizer Correspondent (e-ifc),* No **16**.

Guerra, L.C., Bhuiyan, S.I., Tuong, T.P., Barker, R. (1998) Producing more rice with less water from irrigated systems. SWIM Paper 5. IWMI/IRRI, Colombo, Sri Lanka p. 24.

Havlin, J., Beaton, J.D., Tisdale, S.L., Nelson, W.L. (1999) Soil fertility and fertilizers: an introduction to nutrient management. Upper Saddle River: Prentice Hall.

International Rice Research Institute (2002) Annual Report for 2002. Los Baños, Philippines.

Ishizuka, Y. (1965) Nutrient uptake at different stages of growth. In: The Mineral Nutrition of the Rice Plant. O. G. Santos, ed. John Hopkins Press. Baltimore, MD pp 199-217.

Jungk, A.O. (2002) Dynamics of nutrient movement at the soil-root interface. In: Y. Waisel, A. Eshel, U.

Karley, A.J., White, P.J. (2010) Potassium. In: Cell

Biology of Metals and Nutrients, R. Hell, and R.R. Mendel (eds). p. 199-224. Plant Cell Monographs **17**.

Keizrul, A., Azuhan, M. (1998) An Overview of Water Resources Utilization and Management in Malaysia. Seminar on "Local Communities and the Environment II". Environment Protection Society Malaysia, Petaling Jaya. pp 24-25.

Chelah, M.K.B., Nordin, M.N.B., Musliania, M.I., Khanif, Y.M., Jahan, M.S. (2011) Composting Increases BRIS Soil Health and Sustains Rice Production on BRIS Soil. *SicenceAsia* **37**: 291-295.

Kurra-Hotta, M., Satoh, K., Katoh, S. (1987) Relationship between photosynthesis and chlorophyll content during leaf senescence of rice seedlings. *Plant Cell Physiol*. **28**: 1321–1329.

Li, Y.H., Dong, B., Yu, F. (1999) Improving irrigation management of paddy fields for sustainable increases in water productivity. In: Musy A, Pereira LS, Fritsch M, editors. Emerging technologies for sustainable land use and water management. Proceedings - 2nd Inter-Regional Conference on Environment-Water, September 1- 3, 1999, Lausanne, Switzerland - Lausanne (Switzerland): Presses Polytechniques et Universitaires Romandes. xv 71p.

Maclean, J.L., Dawe, D.C., Hardy, B., Hettel, G.P. (2002) Rice Almanac, third ed. IRRI, Los Baños, Philippines, p 253.

Mao, Z. (1993) Principle and technique of water-saving irrigation for rice. China: Wuhan University of Hydraulic and Electrical Engineering.

http://www.fao.org/docrep/W4367E/w4367e0h.htm, accessed on 01-2-2012.

MARDI. (2001) Padi Variety MR219. Pusat penyelidikan tanaman makanan dan industri MARDI. 50779 Kuala Lumpur.

Patrick, W.H., MIkkelsen, Jr D.S., Wells, B.R. (1985) Plant nutrient behavior in a flooded soil. P. 197-228.. *In* O.P. Engelstad (ed.) Fertilizer technology and use. 3rd ed. Soil Sciecne Society of America, Madison, WI.

Peng, S.Z., Yu, S.E., Zhang, H.S. (1997) Water saving irrigation techniques for paddy. Beijing, China Water and Hydro Publ. 155 p.

Rijsberman, F.R. (2006) Water scarcity: Fact or fiction? Agricultural Water Management, pp 5-22.

Schollenberger, C.J., Simon, R.H. (1945) Determination of exchange capacity and exchangeable bases in soil-ammonium acetate method. *Soil Sci.* **39(1-6)**: 13-23.

Sekhon, G.S. (1995) Characterization of K availability in paddy soils – present status and future requirements. pp 115-133. *In* Potassium in Asia – Balanced Fertilization to Increase and Sustain Agricultural Production, IPI, Basel, Switzerland.

Singh, K.N., Bhattacharyya, H.C. (1989) Direct seeded rice. Oxford and I.B.H. Publication, New Delhi 31.

Slaton, N.A., Dunn, D., Pugh, B. (2004) Potassium Nutrition of Flood-Irrigated Rice Better Crops. Vol. **88**

Suriya-arunroj, D., Supapoj, N., Toojindab, T., Vanavichitb, A. (2004) Relative leaf water content as an efficient method for evaluating rice cultivars for tolerance to salt stress. *ScienceAsia* **30**: 411-415.

Tuong, T.P., Bouman, B.A.M. (2003) "Rice Production in Water Scarce Environments." In J.W. Kijne, R. Barker, and D. Molden, eds., Water Productivity in Agriculture: Limits and Opportunities for Improvement. Wallingford, UK: CABI Publishing.

Tuong, T.P., Bouman, B.A.M., Mortimer, M. (2005) "More Rice, Less Water—Integrated Approaches for Increasing Water Productivity in Irrigated Rice-Based Systems in Asia." *Plant Prod. Sci.* **8**: 231–41.

UN. (2012) UN world water day. http://www.unwater.org/worldwaterday/. Accessed on 25 March 2012.

UN Secretary. (2012) Secretary-General's Message on World Water Day, New York. http://www.un.org/sg/statements/index.asp?nid=5938. Accessed on 25 March 2012.

Wang, G.T. (1992) High-yield and water-saving irrigation method: deep-thin-alternate dry and wet. *Irrigation and Drainage Small and Hydropower Station* **8**: 18-19.