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Effects of Low Water Input on Rice Yield: Fe and Mn Bioavailability in Soil

Jahan, M. S.[1,2]*, Khanif, Y. M.[1], Syed Omar, S. R.[1] and Sinniah, U. R.[3]

[1]*Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia*

[2]*Faculty of Agriculture and Biotechnology, Universiti Sultan Zainal Abidin, 20400 Terengganu, Malaysia*

[3]*Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia*

ABSTRACT

Soil fertility and water condition are the main concerns in rice production. In order to determine the effects of low water input on rice production and soil chemical properties, the Fe and Mn contents, and soil pH in soil were measured during rice cultivation. It was found that rice yield and yield parameters obtained were not significantly different under different water levels. Soil pH was moderately acidic to near neutral. Meanwhile, iron (II) in soil extract slowly increased throughout the rice growing period but it increased markedly after the water was drained off. Manganese availability significantly increased after flooding, but it decreased at a similar trend followed after that, followed by a stable level. In addition, weekly data showed no significant differences in Fe(II) and Mn in the soil extract of the different treatments. These results suggest that low water input does not affect rice production as well as soil pH and Fe(II) and Mn bioavailability in soil.

Keywords: Rice, low water irrigation, plant nutrients, soil pH

INTRODUCTION

Rice is the staple food of Asia with nearly 90% of the world's rice is produced and consumed in this region, providing an average of 32% of the total calorie intakes (Maclean *et al*., 2002). In more specific, out of about 576 million tons rice produced globally per year, 90–91% is produced and consumed in Asia (IRRI, 2002). About 75% of the global rice is produced in the irrigated lowlands (Maclean *et al.*, 2002). Nonetheless, water for agriculture is becoming increasingly scarce (Rijsberman,

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E-mail addresses:
sarwarjahan@unisza.edu.my (Jahan, M. S.),
khanif@agri.upm.edu.my (Khanif, Y. M.),
syedomar@agri.upm.edu.my (Syed Omar, S. R.),
umarani@agri.upm.edu.my (Sinniah, U. R.)
* Corresponding author

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2006). It is predicted that by 2025, 15-20 million ha of irrigated rice will suffer from some degree of water scarcity (Tuong & Bouman, 2003; Tuong *et al.,* 2005). In Malaysia, the overall water demand grows at the rate of 4% annually and is projected to be about 20 billion m^3 by 2020 (Keizrul & Azuhan, 1998). The decreasing water availability for agriculture, especially in rice cultivation has threatened the productivity of the irrigated rice ecosystem and thus, ways must be sought to save water and to increase the productivity of rice (Guerra *et al.,* 1998).

The concentration of water-soluble Fe(II), which is negligible in upland soils, increases in flooded rice soils. Thus, wetland rice suffers iron deficiency less frequently than dryland rice. Electrons (e^-) transferred and hydrogen ions (H^+) consumed through biological activity under reduced soil conditions cause Fe(III) and Mn(III, IV) to be reduced to Fe(II) and Mn(II) forms (Patrick & Turner, 1968). Meanwhile, soil pH is one of the main causes that affects and controls Fe and Mn concentrations in flooded rice soil (Ponnamperuma *et al.,* 1973). To date, the influences of flooding on the physical, chemical and electrochemical properties of soil have been comprehensively researched on and reviewed from time to time (Narteh & Sahrawat, 1999; De Datta, 1981), but less attention has been paid on the effects of low water irrigation on the chemical properties of soil in relation to rice production. Therefore, the current study focused on determining the effects of low water input on rice yield, as well as on Fe and Mn bioavailability in soil solution.

METHODS

In this study, rice (variety MR219) plants were grown in a cylindrical culvert (90 cm in diameter and 90 cm in height) having five different water levels, 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 the first 9 weeks, followed by 1 cm), with five replications. These water levels were maintained by a plastic regulator attached to the culvert wall. Meanwhile, seed rates, fertilizer, agronomic practices were applied according to MARDI (2001). The soil was of silty clay in texture, with 1.2% sand, 44.5% silt and 54.3% clay, a soil pH of 6.0, and an organic matter of 4.12%. The soil also contained 113 mg/kg of Fe and 35 mg/kg of Mn. The soil extracts were collected every week using an SPS200 water sampler (TECNO, 2008), and then analyzed for Fe^{2+} and Mn using an atomic absorption spectrophotometer. A portable Mettler Toledo MP120 pH meter was used to measure the soil pH *in situ* every week. In addition, the electrode of pH meter was calibrated each time before using, while soil pH was measured directly from the soil. The means were compared using Duncan's Multiple Range Test (DMRT) at 5% level using the Statistical Analysis System software version 6.12.

RESULT AND DISCUSSION

The Effects of Low Water Irrigation on Rice Yield

The results indicated that low water input did not affect rice yield as well as yield parameters (Table 1). Rice yield containing 14% moisture was in the range of 0.98 to 1.10 kg/m^2, and this is consistent with the finding by MARDI (2001). Bouman and Tuong (2001) stated that water savings under saturated soil conditions were on average (23%) with the yield reductions of only 6%. Soil water condition at the saturated level reduced rice yield about 5% and saved about 35% of the total fresh water as compared to the flooded conditions (Tabbal *et al.,* 2002). Recently, Khairi *et al. (*2011) found that rice could be grown on saturated soil condition without affecting rice yield. As compared to the above results, the findings of the current work suggested that continuously maintaining the water level at 1 cm did not affect yield (Table 1) and it was possible to save >30% of fresh water used in continuous 5 cm flooding condition (data not shown). These results suggest that rice can be cultivated under 1 cm flooding condition without affecting rice yield.

Soil pH

Weekly *in situ* soil pH data showed that the different flooding levels showed no significant effect on the soil pH during rice cultivation (see Fig.1). In other words, soil pH remained in the range of 5.4 to 6.6 throughout the rice growing period. Meanwhile, soil pH at lower acidic to neutral conditions makes available most of the plant nutrients for plant uptakes (Jensen, 2010). Application of fertilizer temporarily increased soil acidity for a short period before it decreases soil acidity by the following week (Fig.1). Flooding may initially decrease soil pH due to CO_2 that is formed in aerobic respiration by bacteria

TABLE 1
The effects of different water levels on rice yield and yield components

Treatments	Tiller number /pot	Panicle number /pot	Unfilled grain /panicle	Filled grain /panicle	1000 seeds weight (g)	Dry straw (kg/m^2)	Dry filled grain (kg/m^2)
W1	384a	361a	22a	93a	27.6a	1.3a	1.01a
W2	381a	365a	25a	90a	27.3a	1.3a	0.98a
W3	377a	345a	24a	91a	27.7a	1.2a	1.01a
W4	390a	359a	22a	94a	27.4a	1.2a	0.99a
W5	388a	352a	21a	95a	27.5a	1.2a	1.01a

Means with the same letter are not significantly different in the column at P≤0.05 by DMRT and increase after the first few weeks to 6.7 - 7.2 (Ponnamperuma, 1972). The subsequent increase in pH over time is due to the consumption of H^+ ions because of Fe (III) reduction (Kirk, 2004). This result indicates that low water input may not affect soil pH in soil.

Effect of low water input on bioavailability of Fe and Mn

After submergence, hydrated Fe^{3+} oxide is reduced to Fe^{2+} (Ponnamporuma, 1977). Fig.2a shows that Fe^{2+} concentration gradually increased in the soil solution

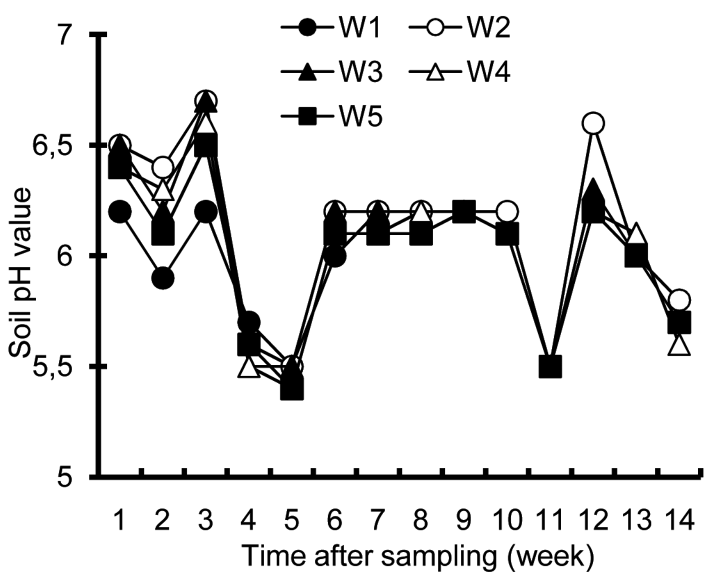

Fig.1: The effects of different flooding levels on *in-situ* soil pH.
A) Soil pH values are more or less similar in all the treatments with time.

TABLE 2
The effects of different water levels on iron and manganese in soil and straw

Treatments	In Straw				In Soil					
	Fe (%)		Mn (mg/kg)		Fe (mg/kg)			Mn (mg/kg)		
	51 DAS	AH	51 DAS	ALP	ALP	51 DAS	AH	ALP	51 DAS	AH
W1	0.115a	0.125b	755a	668a	102a	274a	271ab	271ab	38a	25a
W2	0.12a	0.123b	640a	690a	114a	270a	267ab	267ab	40a	28a
W3	0.113a	0.138ab	711a	740a	128a	279a	275a	275a	38a	26a
W4	0.11a	0.163a	757a	651a	123a	284a	259ab	259ab	38a	27a
W5	0.115a	0.143ab	766a	673a	98a	288a	245b	245b	38a	27a

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

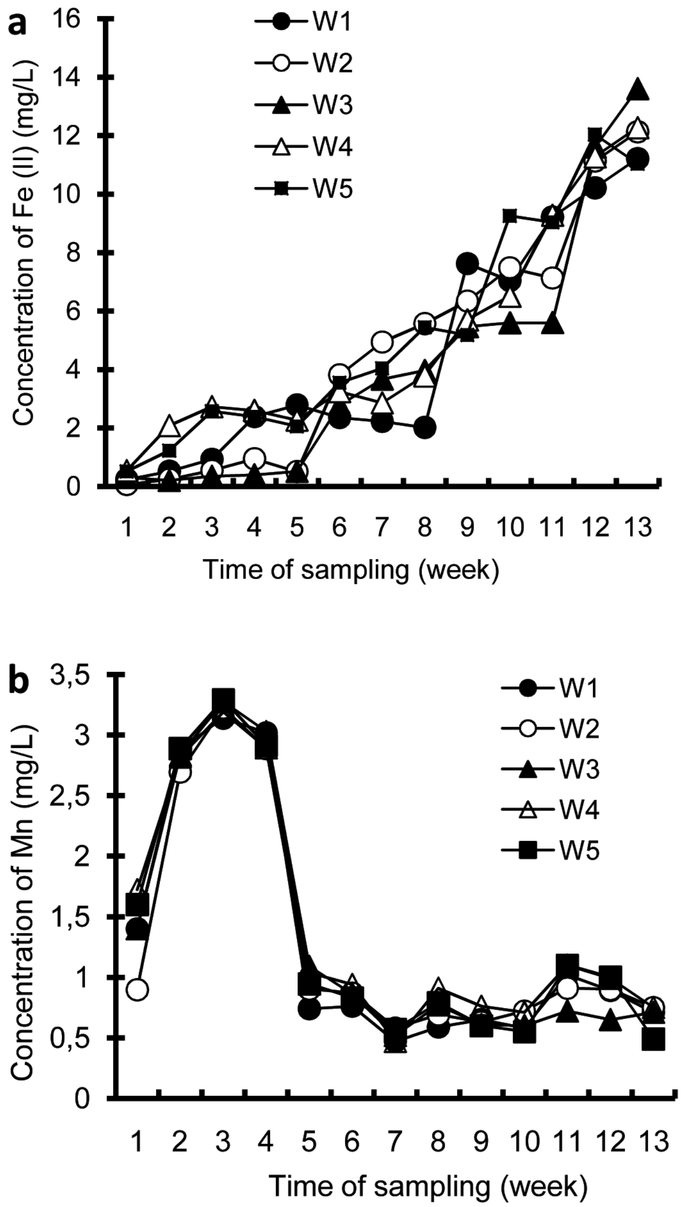

Fig.2: The temporal changes of the iron and manganese concentrations in the soil extract
a) Fe^{2+} concentrations increased slowly with time but increased markedly after water was drained out. Weekly data showed no differences; (b) Mn concentrations increased markedly after flooding but it then decreased again to a stable level.

with increasing time until the ripening stage. This result is consistent with the previous results that the duration of submergence influences iron content in soil as high as 300 mg/L after 4 weeks submergence (Yoshida, 1981). Ponnamperuma *et al.* (1973) also stated that Fe^{2+} concentration increased gradually in the soil with pH 6 but increased markedly after flooding in soil with pH 5.5. This result indicates that soil pH may affect the Fe^{2+} concentration in flooded soil. In this experiment, the Fe^{2+} concentration in the soil extract did not increase markedly after flooding the soil but it gradually increased throughout the rice growing period (Fig.2a). This result suggests that flooding increases Fe^{2+} concentration in soil. In addition, iron content in soil was found to be higher at 51 days after sowing (DAS) and after harvest (AF) than that of after land preparation (ALP), as shown in Table 2. This result also suggests that flooding increases Fe^{2+}concentration in soil with time. Plants accumulate higher content of iron at the reproductive stage than that of the vegetative stage (Table 2). The results of the current study indicate that low water input (i.e. flooding at continuous 1 cm) may not affect the availability of the Fe^{2+} content in the soil solution as compared to the traditional flooding at continuous 5 cm.

In the soil extract, the Mn concentration increased markedly after submergence, followed by an equally rapid decline to a stable level throughout the growing period (Fig.2b). This result is consistent with the previous result of Jugsujinda and Patrick (1977), Redman and Patrick (1965) and Cho and Ponnamperuma (1971). This may due to the effects of flooding and poor aeration that increase the availability of manganese (Chen *et al.,* 2005). Fig.2b also shows that different water inputs did not affect Mn content in the weekly data. In soil, Mn concentration increased further after flooding than that of after ripening and the plants also accumulated higher content of Mn at the vegetative stage than the ripening stage (Table 2). The current study showed that no deficiency of Mn was found in soil and this could be due to the effect of soil pH which was above 5.5, and this finding is consistent with that of Bolan *et al.* (2003). The finding of this study also suggests that low water irrigation did not affect availability of Mn in soil.

CONCLUSION

In conclusion, the above results confirmed that flooding at continuous 1 cm did not affect rice yield and yield components, soil pH and Fe and Mn bioavailability. The authors recently stated that maintaining saturated condition throughout the growing period did not show effect on rice yield. Therefore, low water input rice production could be implemented to save fresh water to be used for other sectors and to increase the country's rice production. Nonetheless, further research is needed to justify the field research with low water input and to cope with plants under soil and environmental stress conditions.

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