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BIOAVAILABILITY OF SOIL NITROGEN IN LOW WATER-INPUT RICE PRODUCTION

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Abstract: The water demand for agriculture, municipal, industrial, and environmental purposes will be increased in the future; less water will be available for rice production. This study was conducted to determine the effects of low water irrigation on rice yield and nitrogen (N) bioavailability in soil. Five different irrigation treatments, namely, W1 (5 cm flooding), W2 (1 cm flooding), W3 (first 3 weeks 5 cm then 1 cm flooding), W4 (first 6 weeks 5 cm then 1 cm flooding), and W5 (first 9 weeks 5 cm then 1 cm flooding) were employed with five replications. SPS200 water sampler was used to collect soil extracts and measured N bioavailability in soil. Low water irrigation did not affect rice yield, yield parameters and N content in soil compared to the traditional irrigation system. Our results suggest that rice production can be implemented under low water irrigation condition without affecting rice yield, yield parameters and N content.

KEYWORDS: rice, low water irrigation, bioavailability of nitrogen, water saving, soil solution

Introduction

Rice is the most important staple food in Asia and nearly 90 - 91% of the world's rice is produced and consumed in this region, providing an average of 32% of total calorie uptake (Maclean *et al*., 2002; IRRI, 2002). Approximately, the world's 271 million ha of irrigated area of all crops is in Asia, where rice accounts for 40 - 46% of the net irrigated area (Dawe, 2005). Rice is the only cereal that can grow in wetland and about 75% of the global rice volume is produced in the irrigated lowlands (Maclean *et al*., 2002). Decreasing water availability for agriculture threatens the productivity of the irrigated rice ecosystem and ways must be sought to save water and increase rice production (Guerra *et al*., 1998).

In Asia, irrigated agriculture accounts for 80 to 90% of the total diverted fresh water used, and more than 50% of this is used for rice cultivation (Guerra *et al*., 1998). In Malaysia, the overall water demand is growing at the rate of 4% annually and the irrigation-water demand is about 13.2 billion m^3 (Keizrul and Azuhan, 1998). Therefore, water for agriculture is becoming increasingly scarce (Rijsberman, 2006). By 2025, 15-20 million ha of irrigated rice will suffer from some degree of water scarcity (Tuong *et al*., 2005). In addition, rice production cannot meet the demand of the increasing population in Malaysia. Rice is to be imported from neighboring countries, especially from Thailand and Vietnam to meet the demand and that value is about MYR 500 million per year (Ariffin, 1998). In 2008, the rice price increased almost double in Malaysia (Omar, 2008). The demand is to produce more rice using low input of water and fulfill the country's needs for saving water resource. Several on-farm water-saving practices have been scientifically developed over time to improve the crop-growing conditions (Li *et al*., 1999). Low water irrigation increases water productivity in rice-based cropping systems through decreasing 50 - 80% of the percolation and seepage water from rice fields (Zhi, 1993) and the loss of fertiliser, especially the nitrogenous fertiliser, can be reduced by using low water-irrigation techniques (Weining, 1993). On the other hand, diseases and insect pests can be cut significantly under the water-saving irrigation. Thus, the quantity of pesticide used and the pesticide pollution in water, soil and rice can be reduced (Yefang, 1993).

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Under water-saving irrigation, the quantity of microbial population in soil e.g. ammonificator, organophosphorus bacteria is greater (Shunzhi, 1993). Therefore, the water-saving irrigation method for rice production should be more widely used because of its potential for saving water, sustaining rice yield, and improving the water and soil environmental conditions in rice-irrigation districts. To date, little attention has been paid on nitrogen bioavailability in soil under water-saving rice cultivation. Therefore the present study was focused on reducing water use in rice cultivation and its effect on N content in soil.

Materials and Methods

Experimental design

Treatments were laid out in a completely randomised design consisting of five different water treatments: W1 (continuous flooding at 5 cm), W2 (continuous flooding at 1 cm), W3 (continuous flooding at 5 cm in the first 3 weeks then 1 cm), W4 (continuous flooding at 5 cm in the first 6 weeks then 1 cm), and W5 (continuous flooding at 5 cm in first 9 weeks then 1 cm) with five replications. Rice plants were grown in a cylindrical concrete culvert measuring 90 cm diameter 90 cm height. The soil of bakau series was of predominantly silty clay with mechanical analysis of 1.2% sand, 44.5% silt and 54.3% clay on average, soil pH of 6.0 and organic matter content of 4.12 %. The soils were filled up to a level of 10 cm from the top of the culvert. Two holes were made at 1 cm and 5 cm above the soil level to the culver wall. Plastic tube equipment was attached to the holes to regulate required water levels. The taxonomic classification of the soil is presented in Table 1.

Seeds, fertilisers and crop care

Healthy rice seeds of Malaysian rice variety MR 219 were planted at the sowing rate of 150 kg ha^{-1}(MARDI, 2001). Fertilisers, 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 dressings. Compound fertiliser (NPK grade= 12:12:17) was applied twice at 50 and 71 days after sowing (DAS) at the rate of 300 kg/ha, and 200 kg/ha, respectively (MARDI, 2001). Crop cares including agronomic practices and pesticides application were done according to (Khairi *et al*., 2011).

Yield measurement

At maturity, the numbers of tillers and panicles, grain and straw yield were recorded. The panicles were separated from the straws and oven-dried at 60°C and the weights were recorded. Filled grains were separated by using salt solution with specific gravity of 1.0 (Khairi *et al*., 2011) then washed, oven-dried, weighed and counted for filled grain per panicle, unfilled grain per panicle and weight of 1000-grains.

N in soil and plant

The SPS200 (SDEC, France) water sampler was used to collect soil extract from soil. A porous ceramic cup was fixed at one end of a PVC tube. All tubes were inserted into the soil at 5 cm depth. Upon creating a vacuum inside the tube, the soil solution was drawn from the soil through the porous ceramic cup and tube. Just after collection, the soil extracts were treated with 5 mg/L phenyl mercuric acetate to stop urease activity followed by analysis of NH_4^+ (Technicon, 1977). Auto analyser was used to measure N content in soil solution, soil and plant. Soil samples were taken from five spots in each culvert at 0 to 10 cm depth. Composite sample was used to determine soil N. In soil, N contents were analysed after land preparation (ALP), 51 DAS and after harvest (AH) and in straw, at 51 DAS and AH. Total N in soil was analysed by sulphuric-salicylic acid digestion method (Bremner and Mulvaney, 1982) and straw samples were digested with H_2SO_4 and H_2O_2 (Thomas *et al.,* 1976).

Statistical analysis

The data were analysed 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 (SAS Cor.).

Results

Plant yield

The numbers of tillers and panicles, yield (kg/m^2), straw (kg/m^2), unfilled grains/panicle, filled grains/panicle, and 1000 seeds weight were measured for treatments effect. Different irrigation treatments did not affect rice yield and yield parameters (Table 2). The tiller and panicle numbers per square metre were in the range of 674 to 695 and 636 to 665, respectively. The straw weight was in the range of 1.315 to 1.446 Kg/m^2. The filled grains per panicle and 1000 seeds weight found were in the range of 89 to 101, and 27.2 to 27.8 g, respectively. The rice yield (14 % moisture content) obtained was in the range of 1.187 to 1.239 Kg/m^2. These results suggest that low water irrigation did not affect rice yield and yield parameters.

Ammonium (NH_4^+) in soil

Weekly data showed that different irrigation levels did not affect NH_4^+ content in soil solution but the NH_4^+ concentration increased after flooding within a couple of weeks then decreased thereafter (Figure 1) due to mineralisation process (Godshalk and Wetzel, 1978). In addition, N contents in soil solution found were different from one weekly data to another weekly data (Figure 1). These results indicate that N uptake by plant increases with increasing plant age. In soil, the total N found was insignificantly different among treatments (Table 3). This result also suggests that different water levels did not affect N content in soil (Table 3). On the other hand, plants accumulated higher content of N at 51 DAS than that of AH (Table 3) suggesting that plants need higher content of N at the vegetative stage than that of reproductive stage. Taken together, low water irrigation might not affect N bioavailability in soil solution as well as uptakes by plants.

Crop care

To determine whether different water treatments affect weed and insect populations, weed and insect populations throughout the rice-growing periods were carefully monitored. Weeds were picked out by hand twice at 25 and 51 DAS. The

Table 1: The taxonomic classification of soil.

Soil series	Location	Soil taxonomy (Source: Soil Survey Staff, 1999)	Parent material
Bakau	Tanjung Karang	Typic Tropaquept, very fine clayey, mixed, acid, isohyperthermic, pale	Marine Alluvium

Table 2: Effects of different water levels on rice yield and yield components.

Treatments	Tiller number/m	Panicle number/m	Unfilled grains/panicle	Filled grains/panicle	1000 seeds weight (g)	Straw (kg/m^2)	Yield (kg/m^2)
W1	691a	657a	20a	93a	27.7a	1.428a	1.239a
W2	695a	665a	26a	92a	27.2a	1.446a	1.187a
W3	682a	647a	24a	89a	27.8a	1.344a	1.223a
W4	679a	641a	19a	93a	27.4a	1.315a	1.227a
W5	674a	636a	23a	101a	27.2a	1.348a	1.224a

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

Table 3: Nitrogen concentration in soil and straw.

Treatments*	Soil			Straw	
	ALP N (%)	51 DAS N (%)	AH N (%)	51 DAS N (%)	AH N (%)
W1	0.34a	0.32a	0.34ab	3.4a	2.4a
W2	0.31a	0.36a	0.36a	3.2a	2.2a
W3	0.32a	0.34a	0.34ab	3.2a	2.4a
W4	0.32a	0.31a	0.33b	3.6a	2.2a
W5	0.33a	0.30a	0.34ab	3.2a	2.2a

* Data were analysed based on sampling date but not between/among sampling dates. Means with the same letter are not significantly different in column at P≤0.05 by DMRT

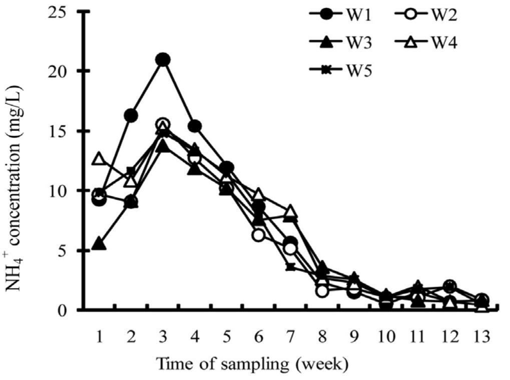

Figure 1: Temporal changes of NH_4^+ concentration in soil solution.

weed populations were insignificantly different. During growing period, different species of insets were observed from time to time e.g rice stem borer (whiteheads, deadhearts symptoms), green leaf hopper, brown plant hopper and rice leaf roller. The infection was very low and physical practices were done to cure from infection of insects, except brown plant hopper which was controlled by the application of Confidor 222 SL. Rice plants were attracted by rice stem borer only in W1 treatment (continuous 5 cm flooding) at reproductive stage and plants with dead panicle were removed from the culvert to prevent further infection. Experimental plot was covered with iron mesh and no bird or rat was found inside the experimental plot.

Discussion

Rice yield

Agricultural development in Asia for several decades has focused on increasing the supply of staple foods, particularly rice, in order to eliminate food shortages. The technologies based on chemical fertilisers and high-yielding varieties have generally been successful in achieving this objective. Alternative practice in order to conserve water in rice production in response to the scarcity in agriculture e.g. low water-input rice production should be addressed. A new irrigation practice that might save a significant amount of fresh water from traditional irrigated rice system was introduced. Our results demonstrated that low water irrigation did not affect rice yield or yield parameters and the average rice yield was consistent with MARDI (2001) reported at 10.70 t/ha. Weed growth is greatly influenced by cultivation method and is a major constraint to direct seeding, as rice and weeds emerge together (Kim *et al*., 1992). Planting rate has an important role in weed control. Thai farmers normally apply seed in very dense stands to help the rice compete with weeds. In dry-seeded rice, a higher seed rate of 125-162.50 kg/ha was found very effective in suppressing weeds (Supatanakul and Vongsaroj, 1977). For wet-seeded rice, a rate of 100 kg/ha was found to be suitable (Kanchanomai, 1981). These results give support to our study where seed rate was used at 150 kg/ha to reduce weed populations to reduce competition with rice plants. In addition, rice plants were attacked by different insects e.g. rice stem borer, green leaf hopper, brown plant hopper and rice leaf roller at different stages of rice plant and proper agronomic practices and insecticide were used to reduce insect populations. Note that the insect populations were desirably lowered and no insecticide was applied except for brown plant hopper.

N bioavailability

When a soil is flooded, the nitrogen incorporated is changed to the ammonium form (NH_4^+), which is stable under flooded condition and increased N availability (Godshalk and Wetzel, 1978). In flooded soils, however, the nutrient availability is quite different from non-flooded soil. Any nitrate present during flooding is quickly denitrified (Ponnamperuma, 1972) and NH_4-N is the main nitrogen source upon which the crop is feeding (Godshalk and Wetzel, 1978). Buresh and De Detta (1990) suggested that flooding created the disappearance of NO_3^- which remained in the soil as either NH_4^+ or organic N. Since conversion of NO_3^- to NH_4^+ was negligible, either denitrification or leaching appeared to be the major loss of mechanism. The N content initially increased in soil solution after flooding then decreased with increases of plant age and time (Figure 1). The application of 2nd split of urea and compound fertiliser did not show effect on NH_4^+ concentrations in soil extract and could be due to plant uptakes. The amount of available N accumulation generally increases with plant age and decreases at ripening stage (Yoshida, 1981). Urea hydrolysed and was lost very quickly from the soil, compound fertiliser released nutrients slowly in the soil and plant uptakes higher amount of N during vegetative stage. These could be reasons as to why application of fertiliser did not increase N content in soil solution. Results confirmed that low water irrigation did not affect N bioavailability in soil and the sufficient level of NH_4-N was retained in soil solution for plant use. In summary, previously-done experiments in water-saving system, where soils are exposed to alternate wetting and drying, resulted in aerobic situations occasionally existing under such condition. Dry soil conditions often result in low yields which are attributed to nutritional disorders (Singh and Bhattacharyya, 1989). In the view of the above point, a study was conducted under low water-irrigation condition that gave similar rice yield, yield components and N bioavailability to high water-level irrigation and therefore a lot of fresh water can be saved by using the current practice. Previous results stated that alternative drying and flooding can save about 40% of total water used in traditional system (Bhagat *et al*., 1999). In addition, our recent study stated that saturated condition of soil did not show effect on rice yield (Khairi *et al*., 2011). It is suggested that farmers can practice 1 cm of water irrigation without affecting cost and yield. Farmers can maintain water level from 1 cm flooding to field saturation. After first application of water at 1 cm flooding, subsequent irrigation will be applied before soil water condition goes below to saturated level. Further research needs to be done at field condition for justifying detailed agronomic management practices and evaluation of physiological and environmental parameters.

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