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Effect of water use, growth and ^{15}N recovery under lowland paddy field by different water management

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ABSTRACT

The water and nitrogen (N) play a vital role in rice production aimed at high N use efficiency and water saving irrigation. Water saving management might affect the soil condition (oxidized and reduction) and these soil condition affects the fate of N in paddy soil also. We designed three irrigation regimes, conventional irrigation (Flooding), shallow water depth (SWD), and Non-flooding treatment, for our study. The fate of N and growth of rice were not different among treatments during early growth stage by water management. Root activity of rice during middle growth stage was high in SWD and this fact might be affected above ground biomass and so on during middle growth stage of rice. The recovery efficiency, N uptake and above-ground biomass at heading stage were higher in SWD than other two treatments. Despite water stress under Non-flooding water management at vegetative stage, yield did not differ from Flooding and can save much irrigation water during rice growing period.

INTRODUCTION

Currently, the traditional irrigation technique is getting difficult to be applied due to facing number of problems. The most obvious problem is decreasing trend in the water resources availability especially during dry season. On the other hand, the water demands for domestic and industrial water supply are increasing. As a result, the water availability for agriculture purposes is decreasing and conflicting among the water user and among farmers cannot be avoided.

Nitrogen (N) is normally a key factor in achieving optimum lowland rice grain yields. It is one of the most expensive inputs and if used improperly, can pollute the ground water. Although rice is grown in different ecosystems, 78% of the worlds rice is grown under irrigated or rainfed lowland conditions. Recovery of fertilizer nitrogen by low land rice is usually lower than 50% of N applied (Keisuke et al., 2008). Low recovery of N in annual crops is associated with its loss by volatilization, leaching, surface runoff, denitrification, and plant canopy (Kumada and Asami 1985). Under these situations, increasing rice yield per unit area through use of appropriate N management practices has become an essential component of modern rice production technology.

Recently the term ‘water-saving irrigation techniques has been introduced (Guerra et al., 1998) to denominate irrigation strategies by i) reducing the depth of ponded water, ii) keeping the soil just saturated or iii) alternate wetting /drying, i.e. allowing the soil to dry out to a certain extent before re-applying irrigation water.

The effects of irrigation on N dynamics in rice have not been studied extensively. Some case

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studied have demonstrated that the nitrogen requirement of microorganisms that decompose organic matter in flooded soils is lower than for decomposers in aerated soils which results in lower net N immobilization in flooded soils than in aerobic, well-drained soils (Broadbent, 1979). Direct seeding, keeping soils at saturation, raising beds, swallow water depth with wetting and drying (SWD), mid-season drainage (MSD), alternate wetting and drying systems (AWD), system of rice intensification (SRI) and shallow water depth (SWD), which are water saving and a high yielding method of rice production, has recently become common practice in the world (Lin et al. 2004). SWD improved some manipulation of microclimate by the alternating irrigation and drainage, attained more supply of N to crop, consequently there is more growth rate and higher yield under the same rate of nitrogen. Intermittent irrigation could stimulate roots into deeper soil layers, maintain their activities and presumably promote nitrogen uptake at later stages (Guerra et al., 1998). However, the detailed impact of water-saving irrigation techniques on nutrient cycling (Nitrogen) and rice production is still unknown.

Paddy field is typically submerged and develops a reduced plowed soil layer and oxidized surface soil layer. Nitrogen is normally a key factor in achieving optimum lowland rice grain yields. NH_4-N is changed to NO_3-N at oxidized sites, and NO_3-N moves to reduced areas by diffusion or water flow. Because NO_3-N is an anion and it is easily changed into N_2 gas under in reduced environment, the N is lost from the paddy ecosystem (Patrick and Reddy 1976).

Water-saving practices cans produce more aerobic soil conditions than continuous flooding conditions. Non-flooding irrigation practices could be performed well as keeping oxidative soil condition and should be converted NH_4-N to NO_3-N in paddy field as we hypotheses. Under this situation, N use efficiency should be reduced but the result of this study found different concept and can be expected to save water and reduce CH_4 emission. On the other hand, shallow water depth (SWD) could be performed well as system of rice intensification (SRI). Though shallow water depth (SWD) is a reductive soil condition, it enhanced rice root activity and yield too because SWD could be performed well to kept warm soil temperature entire growth period than conventional practices (flooding). Thus, rice plant uptake much N from both soil and fertilizer sources. SWD also has been proven to be effective in saving water. SWD can be expected to strongly reduced CH_4 emission too. The fate of N fertilizer, rice growth and yield under water-saving management practices is still poorly studied. This experiment, therefore, was conducted to compare the growth and ^{15}N recovery among the water-saving irrigation practices under lowland paddy field using ^{15}N isotope.

MATERIALS AND METHODS

Site and type of experiments

A field experiment was conducted in 2011, 2012 and 2013. A field experiment was conducted at Yamagata University Experimental Farm, Tsuruoka, Japan.

Treatments

The experiment consisted of three treatments with four replications in 2011, 2013 and three replications in 2012. The three treatments were designated as conventional irrigation (Flooding), Shallow Water Depth (SWD) and Non-flooding. From transplanting to 20 days after transplanting (DAT), a ponded water depth of 0.05-0.06 m was maintained for all the treatments to prevent transplanting shock and cooler temperatures. For the Flooding treatment, ponded water with of 0.05-0.06 m was maintained from 20 DAT to 99 DAT, and the water were drained 20 days before harvesting. For SWD, a ponded water depth of 0.01-0.02 m was maintained from 20 DAT to 99 DAT, and the water was drained 20 days before harvesting. Water depths in the Flooding and SWD plot were monitored at intervals of one or two days using plastic rulers. Irrigation was conducted according to the planned water depths for the Flooding and SWD treatments. Water management of Non-flooding treatment was as follows: On 20 DAT, ponding water of the plots was drained by opening outlets of which height was set at same height as soil surface. The plots were irrigated (splash) again when the soil observed hairline cracks (the soil moisture percentage was about 40%). Outlets of these plots were always open until 57 DAT. After 57 DAT, plots were irrigated again and water depth of 0.01-0.02 m (the outlet of Non-flooding treatment was set at 0.02 m height from soil surface) was maintained until 99 DAT, and the water was drained 20 days before harvesting. The soil moisture content at a soil depth of 0.05 m was measured daily with a DM-18 (Takemura Electric Works. Ltd, Japan). After 57 DAT, a ponded water depth of 0.01-0.02 m was maintained until 99 DAT, and then the water was drained 20 days before harvesting. We also measured the consumption of water for each treatment during 2012 and 2013 without replication, using a flow meter and a water pump. The main plot was 24.6 m long and 14.1 m wide. Each field was further subdivided to create a ^{15}N application plot, which did not receive N basal fertilizer (mini plot, 14.1 x 8.2 m^2). In 2011, 2013 all the water regime plots were arranged in a randomized complete design (RCD), but in 2012, 4 replications could not be employed because of seedling damage, and those plots were arranged in a randomized design with 3 replications.

Manure and fertilizer application

Organic manure (compost) was applied at 10 ton ha^{-1} in 2011 (25 April), 2012 (26 April) and 2013 (30 April) and compound fertilizers (40 kg N ha^{-1}, 40 kg P_2O_5 ha^{-1} and 40 kg K_2O ha^{-1}) were applied as basal fertilizer in 2011 (7 May), 2012 (9 May) and 2013 (10 May). All of the basal fertilizer was incorporated into the soil and puddling was done on 15 May 2011, 20 May, 2012 and 13 May 2013. Ten kilograms of N (as NH_4-N) ha^{-1} was applied as top-dressing at the panicle initiation stage in each year except in 2013. In the year 2013, the plant growth was too vigorous and assumed if it applied the same rate N fertilizer as a top-dressed, there is a great possibility occurring lodging. For minimizing lodging, thus applied half of N compares the general application rate. Wooden boxes (0.6 x 0.3 m) were set at a depth of 0.15 m in the middle of the mini-plot (the zero- N plot) just after transplanting, following the basal N application. To protect the field water inside the wooden boxes, plastic sheets were placed outside the boxes and water was removed from the wooden boxes with a plastic mug. Four grams of N m^{-2} labeled with 3 atom % $(^{15}NH_4)_2SO_4$ was applied to each wooden box and mixed thoroughly by hand with soil. Four hills per wooden box were transplanted. One gram Nm^{-2} labeled with 3 atom % $(^{15}NH_4)_2SO_4$ was applied to each plastic box (0.3 m x 0.15 m plastic box with the averaged tiller number one hill per box) as top-dressing. In the main plot, N was applied as top-dressed after two hills per plot were selected, based on the average number of hills. The Plastic boxes (0.3 x 0.15 m) were set at a depth of 0.15 m, and plastic sheets were placed outside the plastic box. Before the commercial N fertilizer was applied as top-dressing, the boxes were covered with paper bags to prevent the commercial N fertilizer entering into the plastic boxes. After the commercial fertilizer was applied to the main plot, ^{15}N fertilizer was applied inside the plastic boxes.

Seedling age, variety, spacing and transplanting time

Three and a half to four leaf-age seedlings (Oryza sativa L., c.v. Sasanisiki) were transplanted using a 0.3 m × 0.15 m adjusted rice transplanting machine on 18 May 2011, 23 May 2012 and 16 May 2013.

Data collection

Percolation rate

For measuring percolation rate, a PVC pipe was set up into the field and adds water and covered by plastic bag and tight with plastic rope during 25 June to 27 July in 2013 and took the data on the daily basis. For SWD, water level was added up to 2 cm depth while conventional practices added 5 cm depth.

Redox Potential (Eh)

Redox potential was measured at 5 cm soil depth by ORP meter (RM-30P, TOA Electronics Ltd., Japan) with electrode. After insert the electrode, waited while few minutes until the reading value were stable. Eh measurement was done from 4 July to 19 July in 2012 and 6 June to 10 August in 2013.

Plant sample collection

Plant samples were taken from randomly selected areas containing 4 hills × 3 sets i.e., 12 hills from each plot at the maximum tillering (48 DAT) and heading stages (80 DAT) in 2011, the maximum tillering (48 DAT) and heading stages (79 DAT) in 2012 and the maximum tillering (48 DAT), heading stages (78 DAT) and pre-maturing stage (94 DAT) in 2013. The above-ground plant samples collected at the maximum tillering and heading stages were separated into leaves and shoots, and the panicles were also separated. These samples were dried at 80ºC for 2 days.

Plant N analysis

Plant nitrogen contents were determined by the Kjeldahl method (Kenney and Nelson 1982). The dried plant samples were milled using a Heiko vibrating sample mill (Model TI-100, Heiko Seisakusho Ltd., Japan). Finely grind samples were weighed (Approximately 0.5 gm. sample for shoot and panicles samples and approximately 0.4 gm. for leaf samples). These samples were digested with 10 ml H_2SO_4 to which 1 spoonful of a catalyst mixture of K_2SO_4:$CuSO_4$ (9:1) was added. A final digested volume of 100 ml was prepared, and a 10 ml solution was taken from that volume for distillation. The nitrogen content percentages of the leaf, shoot and panicle samples were measured separately and then added to determine the total nitrogen content percentage in the plants. This percentage was converted into gm. m^{-2} by multiplying it by the respective dry matter weights of leaves, shoots and panicles. ^{15}N plant samples were collected at the maximum tillering (48 DAT in 2011, 2012 and 2013) and heading stages (80, 79 and 78 DAT in 2011, 2012 and 2013) in each years and were analyzed using mass spectrometer (Thermo Scientific Flash 2000 and Con FloIV and Delta V plus, Isotope Ratio MS, Germany).

^{15}N soil analysis

Plastic coring tubes (0.15 m long and 0.05 m in diameter) were used collect soil samples from the centers of 4 hills and 3 different places in each plot at 20, 29 and 48 DAT in 2011 and 24, 36 and 48 DAT in 2012. The amount of exchangeable ammonium N (NH_4-N) was extracted with a 1M KCl solution and evaluated by steam distillation (Bremner and Keeney 1965). The same extracted solution was used to determine the total inorganic N by adding Deverda's alloy apart from magnesium oxide. The nitrate nitrogen content was determined by subtracting the exchangeable ammonium content from the total inorganic nitrogen content.

Active iron (Fe^{2+}) content of the soil

The active or free iron (Fe^{2+}) content of the soil was determined by the Debs method, as modified by Kumada and Asami (1958). Ten grams of fresh soil were measured into a 250 ml plastic bottle mixed with 100 ml of 1 M acetate buffer (pH 2.8), and left to stand for 20 minutes, with occasional shaking at room temperature. After the samples were thoroughly mixed, they were passed through dry filter paper. Depending on field condition, 0.5-1.0 ml of aliquot were transferred into a 20 ml glass tube by pipette and 1 ml of 1,-10-phenanthroline solution were also added. The glass tube was then filled with distilled water. For making calibration curve, 1 ml of 1 M acetate buffer (pH 2.8) solution, 0.1-1 ml of standard iron stock solution were transferred into a 20 ml glass tube by pipette and added 1 ml of 1,-10-phenanthroline solution. Finally the glass tube was filled with distilled water. The resulting absorbance was read at 522 nm and compared with the standard curve. Fe2+ was measured at 14, 24, 36 and 57 DAT in 2012 and 16, 26, 36 and 58 DAT in 2013 respectively.

Number of tillers per hill^{-1} and m^{-2}

Number of tillers per hill was counted from the 20 hills from fixed growth setting place of each plot at 29, 36, 48, 59, 80 and 114 DAT in 2011; 24, 36, 44, 53, 71 and 117 DAT in 2012, and 33, 41, 49, 61, 69 and 81 DAT in 2013, respectively. Mean values were calculated.

Plant height

The plant height was measured from growth checking 20 hills. Measurement was taken at 29, 36, 48, 59, 80 and 114 DAT in 2011; 24, 36, 44, 53, 71 and 117 DAT in 2012, and 33, 41, 49, 61, 69 and 81 DAT in 2013, respectively. Plant height was measured from base of culm to tip of the longest leaf or panicle of the main tiller.

Harvesting time and method

In 2011, all plants were harvested on 16 September, in 2012; all plants were harvested on 18 September and in 2013, were harvested on 19 September. Sixty hills (2.7 m^2) were harvested except in 2013. Fifteen hills (1 m^2) were harvested and repeated three places and 10 hills were selected from among the 60 hills, based on their averages, measurement of the yield components were carried out.

Yield Parameters

Number of spikelets m^2 and panicle^{-1}

Number of spikelets per m^2 and panicle-1were counted from the sample hills used for yield components i.e.10 hills from each plot just before harvesting. All the spikelets from 10 hills were counted by automatic seed counting machine. The total number of spikelets was then divided by total number of panicles from 10 hills to obtain the number of spikelets per panicle.

Filled spikelet percentage

All the spikelets were separated into filled and unfilled spikelets by using $(NH_4)_2SO_4$ solution having specific gravity of 1.06. The unfilled spikelets were again counted and used to calculate unfilled spikelets percentage as per the following formula. Filled spikelets % was calculated as, Filled spikelets percentage = 100-Unfilledspikelets%.

Paddy 1000 grain weight (Test weight)

1000 grains with three replications were counted from the grain obtained after separation. Moisture percentage of the grain was measured by Kent Moisture Meter and adjusted to 14% moisture content.

Grain yield

Grain yield was measured at harvesting stage of crop growth from each plot consisting of 60 hills on both yield components and yield examination basis. Moisture percentage of the grain was measured at least 3 times by Kent moisture meter, and values were averaged.

Statistical analysis

Analyses of variance (ANOVA) and Tukey-Kramer tests were conducted using the STATCEL-2 software. Microsoft Excel was used for correlation analysis and application of and other statistical functions.

RESULTS AND DISCUSSION

Water consumption

Total water consumption was higher in Flooding than SWD and Non-flooding water management in the year 2012 and 2013, respectively (Table 1). The irrigation water use reduced by 51% and 35% in non-flooding and SWD compared to flooding in 2012. Similarly, irrigation water use reduced by 33% and 45% in non-flooding and SWD compared to flooding in 2013. The total water consumption among the treatments in 2013 was more than 2 times higher than 2012 since much rainfall was fallen during growth period.

Table1
Total water consumption in flooding, SWD and Non-flooding water regime during the rice growth period in the year 2012 and 2013 during 20 to 99 DAT.

Treatment	Rainfall (mm)	Irrigation (mm)	Water consumption (mm)
Year		2012	
Flooding	292.5	488.38	780.88
SWD	292.5	316.4 (35%)	608.9
Non-flooding	282.5	237.47(51%)	529.97
Year		2013	
Flooding	1007.0	436.4	1443.3
SWD	1007.0	294.3 (33%)	1301.3
Non-flooding	1007.0	240.9 (45%)	1247.9

Flooding: continuous flooded, SWD: shallow water depth, Non-flooding: kept saturated but not flooded

The total water used for the Flooding treatment was 1.3 times higher than that for the SWD treatment and 2 times higher than that for the Non-flooding treatment in the year 2012 and 2013 during 20 to 99 DAT. This study revealed that the irrigation water use reduced by 48% (on an average 2 years data) and 34% in Non-flooding and SWD water regime compared to Flooding water regime. It has been estimated that a 10% decrease in the water use for irrigated rice could lead to water saving of approximately 150,000 million m^3, almost one-fourth of all the fresh water used world-wide for non-agricultural activities. Several studies have indicated that irrigated rice can be easily cultivated using 8,000 to 10,000 m^3/ha, which is approximately 50% of current use, without affecting yield. The main difficulty with saving water is that the water is not priced properly, especially in schemes where they charge the user by irrigated area and not by volume of water used. Another report mentioned that, The total water use reported for conventional practices is 2 times higher than for modified SRI (system for rice intensification) irrigation in India (Satyanarayana et al., 2007) and 1.4 times higher in Japan (Chapagain and Yamaji 2010) because of the low percolation rate. It is possible that leaching losses increased with the depth of submergence during all growth stages in a paddy field as a consequence of an increased percolation rate (Magdoff and Bouldin 1970). The total water use ratio of this study was similar to that reported in Chapagain and Yamaji (2010); the water management techniques associated with from the SWD and non-flooding treatments decrease water consumption.

Active iron (Fe^{2+})

Two-way ANOVA of active soil iron (Fe^{2+}) content was the same for all the treatments in the early growth stage except for year differences (Table 2). Significance differences in the amount of Fe^{2+} were observed for non-flooding treatment at early mid-tillering, mid-tillering and panicle initiation and are attributable to the water management regime. This result indicated that non-flooding water regime was enough for lower Fe^{2+} content comparing other two water regimes. Fe^{2+} content varied by treatment and year, but their interaction were not significant at the early mid-tillering, mid-tillering and panicle initiation stage in non-flooding water regime than SWD and flooding water regime. Active iron is one of the indicators for judge the soil condition during water management period. This result indicated that the soil condition was oxidized instead of reduced condition. In 2012, Fe^{2+} content of soil in non-flooding water regime was the same for all the treatments in the early, early-mid and mid-tillering stages while in 2013, data showed opposite trend. This opposite trend could be comes from different soil moisture condition in both year. During the water management period in 2012 and 2013 the rainfall pattern was different. However in this experiment Fe^{2+} levels in non-flooding soil condition was significantly lower than SWD and flooding treatments from early mid-tillering to panicle initiation stages might indicate that nitrification occurred largely under our soil moisture conditions.

Table 2

Active iron (Fe^{2+}) of soil in Flooding, SWD and Non-flooding water regime in 2012 and 2013.

Source of variation	Fe^{2+} (g kg^{-1})			
Treatment	Early Tillering	Early Mid-tillering	Mid-tillering	Panicle Initiation
Flooding	6.4	6.5ab	6.9a	6.0a
SWD	6.3	7.2a	8.1a	6.5a
Non-flooding	6.1	5.9b	4.5b	3.4b
Year				
2012	7.4a	8.3a	7.6a	6.9a
2013	5.1b	4.7b	5.3b	3.7b
Significance	*P* value			
Treatment (T)	NS	*	**	*
Year (Y)	**	*	*	*
T x Y	NS	NS	NS	NS

*Significant at $P< 0.05$, ** Significant $P< 0.01$, Means followed by different lower case letter within a column are significantly different at $P< 0.05$ (Tukey-Kramer), NS: not significant, Flooding: continuous flooded, SWD: shallow water depth, Non-flooding: kept saturated but not flooded, Early tillering stage: 14 and 15 DAT in 2012 and 2013, Early Mid-tilleirng: 24 and 25 DAT in 2012 and 2013, Mid-tillering: 36 DAT in 2012 and 2013, Panicle Initiation: 57 and 58 DAT in 2012 and 2013

Redox potential (Eh)

From 4 July to 20 July, Eh of Flooding and SWD water regime was ranged from -58 to -107 and -47 to -103 mV, respectively while Non-flooding water regime ranged from 122 to 209 mV in the year 2012. From 6 June to 10 August, redox potential of Flooding and SWD water regime was ranged from -55 to -130 mV, while Non-flooding water regime ranged from 125 to 230 mV in the year 2013 (Figure 1). In the year 2012, Eh was measured during drainage period partially but in the 2013, Eh was measured from beginning to after finished the drainage period. Even the drainage was finished and re-irrigate again the soil condition was not changed rapidly. Furthermore, rainfall also not effect directly to redox potential value. This result mentioned that, Non-flooding water regime enhanced redox potential and kept positive value even after water management finished. Once soil condition was changed means reductive to oxidative condition observed the redox potential also changed under certain period. During this soil condition, N use efficiency of paddy field should be decreased.

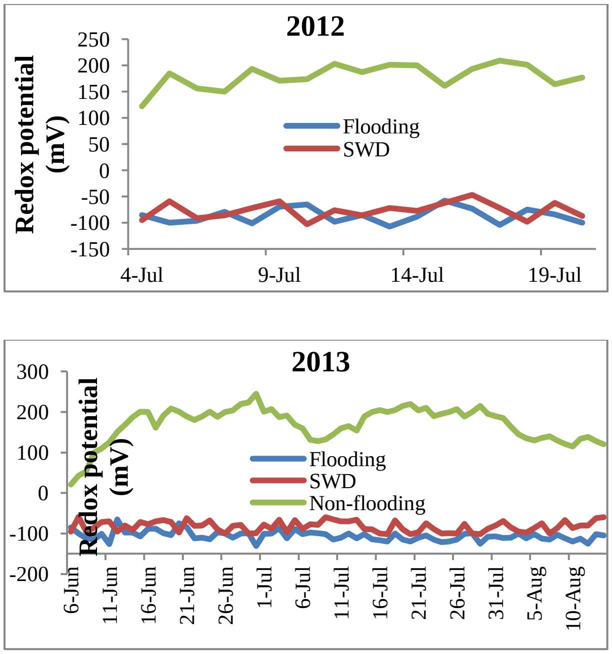

Figure 1
Redox Potential (Eh) at 5 cm depth during 4 July to 20 July, 2012 and 6 June to 10 August, 2013.

It is reported that non-flooding soil conditions influenced redox potential comparing other water regimes (Figure 1). Water management was expected to enhance aerobic soil conditions and increase the redox potential. Active ferrous iron first appeared in the soil when the redox potential fell below 100 mV and increased in concentration with further decreases in the redox potential (Gotoh and Patrick 1972). According to the result, non-flooding soil conditions could be converting Fe^{2+} to Fe^{3+} among the treatment. Patrick and Jugsujinda (1992) reported the results of a study in which Fe^{2+} was changed to Fe^{3+} and NH$_4$-N was transferred to NO$_3$-N from reduced to oxidized conditions when the redox potential rose above 200 mV, and the concentrations increased further as the redox potential increased. In contrast, our result indicates that redox potential obtained in between 123 to 219 during the drainage period. This redox potential value was not stable and not rose above 200 mV continuously. Thus we expect nitrification might not occur largely under our soil moisture condition of if nitrification happened it was taken by rice plat soon. Therefore, N loss did not occurred under Non-flooding soil condition.

Percolation rate

Percolation is the vertical flow of water to below the root zone. The percolation rate was higher for fields with deep ground water tables (5 cm depth) than for field with shallow ground water tables (2 cm depth) (Figure 2). The percolation rate of 5 cm water depth was found about 4.4 mm day-1 in flooding where 1.67 mm day^{-1} observed in SWD (2 cm water depths).

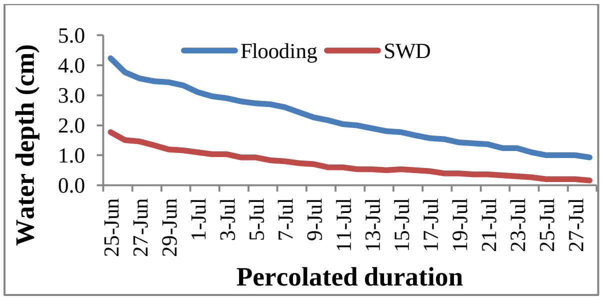

Figure 2
Percolation rate at 5 and 2 cm water depth during 25 June to 27 July, 2013.

The percolation rate of rice fields are affected by a variety of soil factors (Wickham and Singh 1978): structure, texture, bulk density, mineralogy, organic matter content etc. The percolation rate is further influenced by the water regime in and around the field. Large depth of ponded water favor high percolation rates (Sanchez, 1973; Wickham and Singh 1978). In a field survey in the Philippines, Kampen (1970) found that percolation rates were higher for fields with deep ground water tables (>2 cm depth) than for fields with shallow groundwater tables (0.5-2 cm depth) which is similar to this study.

Exchangeable $^{15}NH_4$-N in soil

The trend of exchangeable NH_4-N in soil was similar to $^{15}NH_4$-N in soil during the rice growing periods. Exchangeable $^{15}NH_4$-N was the same for all the treatments in early tillering, mid-tillering stage except maximum tillering stage (Figure.3) indicating that the amount of NH_4-N was not affected by differences in the water management treatments until maximum tillering stage, due to the reduced conditions of the soil. Under reduced conditions, NH_4-N is stable in soil, so loss of N also reduced. In 2012, the $^{15}NH_4$-N content was significantly higher for the SWD (12.1 mg kg^{-1} dry soil) treatment than for the Non-flooding (5.0 mg kg^{-1} dry soil) and Flooding (5.0 mg kg^{-1} dry soil) treatments, but the amount of $^{15}NH_4$-N contents at this stage were negligible.

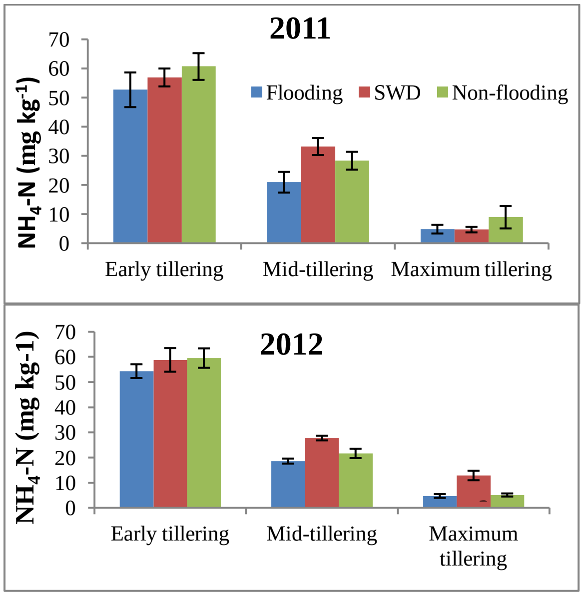

Figure 3
Amount of NH_4-N in Flooding, SWD and Non-flooding water regime during early to middle growth stages of rice in 2011 and 2012. Vertical bar represents standard error, NS: non-significant, (Tukey-Kramer test, P>0.05), Flooding: continuous flooded, SWD: shallow water depth, Non-flooding: kept saturated but not flooded.

Tiller number and plant height

The tiller numbers m^{-2} at the maximum tillering stage were 614, 632 and 670 for the Flooding, SWD and Non-flooding plots, respectively, with 502, 532 and 528 at the heading stage in 2011 and 2012 (Figure 4). But in the 2013, the trend of tiller numbers m^{-2} whole growing period in Non-flooding plots was lower than SWD and Flooding plots though statistically had no significant differences. The trend of lower tiller number m^{-2} could be comes from lower N uptake or lower N absorption capacity under Non-flooding plots due to N loss possibility.

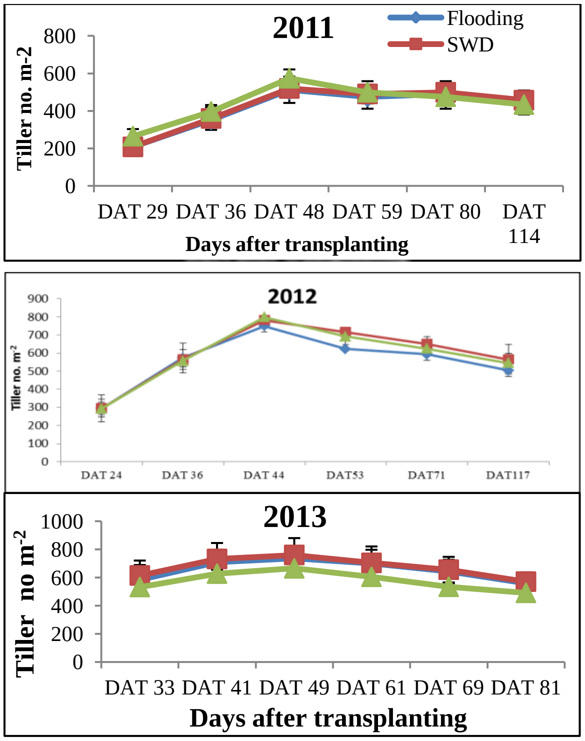

Figure 4
Changes in the number of tillers in Flooding, SWD and Non-flooding water regime in 2011, 2012 and 2013.

At the maximum tillering stage, the average rice plant heights were 54.8, 55.1 and 53.4 cm for the Flooding, SWD and Non-flooding treatments, respectively, and the average heights increased to 92, 92 and 86 cm, respectively, at the heading stage in 2011 and 2012 (Figure 5). The height was increased up to 106 cm at ripening stage. The trend of plant height was quite different in 2013 due to vigorous growth and Non-flooding plots showed shorter plant height at PI (69 DAT) and heading stage (78 DAT) and found significance difference than SWD and Flooding plots. The average plant height in 2013 was 5-10 cm higher in SWD and Flooding plots than other two years.

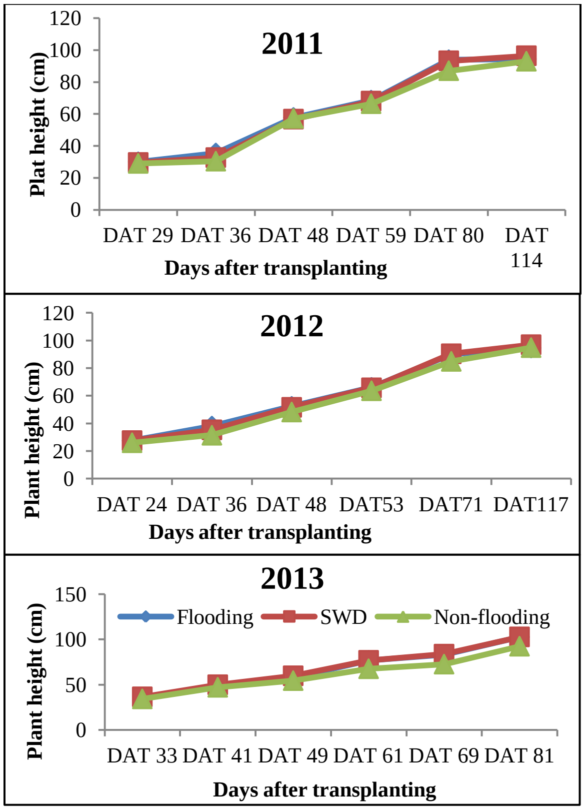

Figure 5
Changes in the plant height in Flooding, SWD and Non-flooding water regime in 2011, 2012 and 2013.

Above-ground biomass

The above-ground biomass varied by year, but the treatment and the treatment x year interactions were not significant at the maximum tillering stage. At the heading stage (80 DAT in 2011, 79 DAT in 2012 and 78 DAT in 2013), the biomass varied by treatment and year but the treatment x year interactions were not significant (Table 3). The above-ground biomass (923.5 g m^{-2}) in the SWD plots was significantly higher than those in the Flooding (831.8 g m^{-2}) and Non-flooding (852.1 g m^{-2}) plots. There were no significant differences in the above-ground biomass between the Flooding and Non-flooding plots.

Table 3
Above-ground biomass in rice plant in the year, 2011, 2012 and 2013 (2-way ANOVA).

Source of variation	Above-ground biomass (g m^{-2})	
Treatment	Maximum Tillering	Heading
Flooding	256.4	831.8b
SWD	274.6	923.5a
Non-flooding	253.3	852.1b
Year		
2011	184.8c	896.8a
2012	275.5b	868.9ab
2013	327.6a	841.6b
Significance	P value	
Treatment (T)	NS	**
Year (Y)	**	*
T x Y	NS	NS

*Significant at *P*< 0.05, ** Significant *P*< 0.01, Means followed by different lower case letter within a column are significantly different at *P*< 0.05 (Tukey-Kramer), NS: not significant, Flooding: continuous flooded, SWD: shallow water depth, Non-flooding: kept saturated but not flooded, Maximum tillering stage: 48 DAT in 2011, 2012 and 2013, Heading stage: 80, 79 and 78 DAT in 2011, 2012 and 2013 respectively

N uptake

The N uptake did not vary by treatment, by year or by treatment x year interaction at the maximum tillering stage, but it did vary by treatment at the heading stage (Table 4). The N uptake was lowest in the Non-flooding (8.1 gm-2) and flooding (8.6 gm^{-2}) plots and highest in SWD (10.9 gm^{-2}) plots at the heading stage, and there were statistically significant differences between the SWD, Flooding and Non-flooding treatments.

Table 4
N uptake of rice plant in the year 2011, 2012 and 2013 (2-way ANOVA).

Source of variation	N uptake (g m^{-2})	
Treatment	Maximum Tillering	Heading
Flooding	5.6b	8.6b
SWD	6.8a	10.9a
Non-flooding	5.6b	8.1b
Year		
2011	5.2b	9.3b
2012	7.4a	10.8a
2013	5.8b	7.9c
Significance	P value	
Treatment (T)	*	*
Year (Y)	*	*
T x Y	NS	NS

*Significant at $P < 0.05$, Means followed by different lower case letter within a column are significantly different at $P < 0.05$(Tukey-Kramer), NS: not significant, Flooding: continuous flooded, SWD: shallow water depth, Non-flooding: kept saturated but not flooded, Maximum tillering stage: 48 DAT in 2011,2012 and 2013, Heading stage: 80, 79 and 78 DAT in 2011, 2012 and 2013 respectively

It is important to remain leaves alive during later growth stages for better yield. To increase carbohydrates production, higher leaf N concentration is considered to be desirable because of its positive correlation with photosynthetic rate (Osaki et al., 2001). Photosynthetic rates depend on leaf N concentration (Peng et al., 1995) and play a crucial role in biomass production and yield formation.

The mechanisms for increased nutrient uptake as well as N uptake with rising soil temperature are not well understood. Root respiration is known to increase with rising soil temperature (Atkin et al. 2000), in part due to higher availability of carbohydrates from enhanced photosynthesis, providing more energy for active transport. Decreased root hydraulic conductance at low root zone temperature was attributed, in part, to decreased capacity to replenish respiratory substrates in plant (Wan et al**.**, 2001). However, the correlation between the rise in nutrient uptake and root respiration breaks down at higher temperatures, indicating that other energy-demanding processes are also changing (BassiriRad 2000). Formation of carbonic acid as a result of increased respiration (auto- and heterotrophic) can decrease rhizosphere and soil pH, which is widely known to affect the availability and uptake of essential ions, especially macro and micronutrients. Our results also agree the above discussion and might be one of the reasons for higher N uptake and recovery efficiency in SWD than Flooding and Non-flooding treatments.

Rice yield is mainly governed by the sink size and can be increased by increasing the sink size. However, when the sink size is large enough, the grain yield is limited by the percentage of ripened grains to some extent (Matsushima et al., 1958). In this experiment, significant difference in yield was observed among the treatments and SWD had the greater influenced of the yield than other two treatments due to the high fertilizer N efficiency of SWD can be deduced the following results: First was the increase in spikelet number and subsequently the spikelet per unit area is a good indicator of increase potential for grain yield with increase in spikelet numbers (Wada et al., 1986). Such effect could greatly give bigger advantage in SWD due to greater panicle number per m2, spikelet per unit area and filled% being developed by the rice plant. Second was the increase N availability and recovery at critical growth stages. Generally, bigger N demand by rice fall at mid-tillering, PI and flowering stage. Such N demand is understandably rational from the viewpoint of rice nutrition and production to attain increase production of productive tiller and spikelet's per unit area, and higher filled spikelet's. Despite, the N uptake or recovery efficiency results of this showed different concept and N uptake of recovery efficiency of Non-flooding treatments did not decrease as the general concept. Thus, N loss might not be occurred under Non-flooding soil condition. However, that the higher N recovery efficiency of SWD than Non-flooding and Flooding water-saving practices can be attributed to the higher N uptake and higher root physiological activity due to the higher soil temperature during entire growth period. It is suggested from this study that controlled irrigation (SWD) and prolonged drainage (Non-flooding) conserve water and maintain or increase root physiological activity and yield too.

Yield and yield components

The brown rice yield varied by treatment (Table 5). Among the treatments and in 3 years, the yield obtained with SWD (6,228 kg ha^{-1}) was significantly higher (at the 1% level) than the yields obtained with the Flooding (5,512 kg ha-1) and Non-flooding (5,396 kg ha^{-1}) treatments. The number of spikelets per m^2 varied by treatment, but the year and treatment x year interaction were not significant. Among the treatments and for 3 years, the SWD treatment yielded a significantly higher spikelet number (37,000) than the Non-flooding (32,000) and Flooding (34,000) treatments. The spikelet numbers per panicle varied by year, but the treatment and treatment x year interaction were not significant. The percentage of filled spikelets varied by treatment and year, but the treatment x year interaction was not significant. The differences in spikelet filling (%) was observed in Non-flooding (85) and SWD (83) than Flooding (78) plot and the differences in 1000-grain weight between the treatments were negligible. Conversely, the panicle number per m^2 varied by treatment and by year, but the treatment x year interaction was not significant. Among the treatments for 3 years, the SWD treatment had the highest panicle number per m^2 (509) and the Non-flooding treatment had the lowest (442), with that for the Flooding treatment being between the two (460). The results of the present study are in agreement with the report of Bhuiyan and Tuong (1995) who observed a standing depth of water throughout the season is not needed for high rice yields. A similar result was obtained by Sato and Uphoff (2008) with the use of intermittent irrigation in SRI management. Similarly, Hatta (1967), Tabbal et al. (1992), and Singh et al. (1996) reported that maintaining a very thin water layer, at saturated soil condition, or alternate wetting and drying can reduce water applied to the field by about 40-70 percent compared with the traditional practice of continuous shallow submergence, without a significant yield loss. Keisuke et al. (2008) and Davids (1998) also reported a reduced irrigation water requirement for non-flooded rice by 20–50 percent than for flooded rice, with the difference strongly dependent on soil type, rainfall, and water management practices (Davids 1998).

Table 5
Yield and yield components of rice in the year 2011, 2012 and 2013.

Source of variation	Panicle number	Spikelet number	Spikelet number	Filled spikelet	1000-grain weight	Yield
Treatment	(m^{-2})	(Panicle^{-1})	(10^3 m^{-2})	(%)	(g)	(Kg ha^{-1})
Flooding	460b	75	34b	78b	20.7	5512b
SWD	509a	76	37a	83ab	21.1	6228a
Non-flooding	442b	73	32b	85a	20.9	5396b
Year						
2011	432b	81a	34	79b	21.1a	5578b
2012	510a	72b	36	88a	20.4b	6402a
2013	468b	71b	34	79b	21.3a	5419b
Significance	*P* value					
Treatment (T)	**	NS	*	*	NS	**
Year (Y)	**	**	NS	**	**	**
T x Y	NS	NS	NS	NS	NS	NS

*Significant at $P < 0.05$, ** Significant $P < 0.01$, Means followed by different lower case letter within a column are significantly different at $P < 0.05$ (Tukey-Kramer), NS: not significant, Flooding: continuous flooded, SWD: shallow water depth, Non-flooding: kept saturated but not flooded

CONCLUSION

This study showed that higher N recovery efficiency was observed at maximum tillering stage than at heading stage regardless of treatments while recovery efficiency of basal N had significantly higher in SWD than Flooding at heading stage. Furthermore, NH_4-N was not significant among the treatments at mid and maximum tillering stage. SWD had the highest biomass while Flooding and Non-flooding irrigation regimes accumulated the less and were significant among the irrigation regimes at heading stage. Total N uptake was highest in SWD and lowest in Flooding irrigation regime at heading stage. Therefore, the brown rice yield of SWD was significantly higher than Flooding and Non-flooding. In addition, this research suggests that water can be saved more by Non-flooding water saving practice though Flooding and Non-flooding had the similar yield. Further studies on the interaction of water and N characteristics in paddy field should be pursued.

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