Comparison of water use, growth and ^{15}N recovery among Flooding, SWD and Non-flooding water-saving irrigation practices under lowland paddy field

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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. Therefore, we designed three irrigation regimes, conventional irrigation (Flooding), shallow water depth (SWD), and Non-flooding in 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. We found that 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.

Keywords – Water saving irrigation, Shallow water depth, Non-flooding, Recovery efficiency, Xylem exudation

I. INTRODUTION

Modern production agriculture requires efficient, sustainable, and environmentally sound management practices. Rice is important crop for billion people. In 2018, the rice consumption in Asia reached 550 million ton, around 91% of the world rice consumption (FAO, 2019). For producing rice, a tremendous amount of water is used for the rice irrigation under the traditional irrigation technique called as a continuous deep flooding irrigation technique. In this technique, the paddy fields are inundated all the time starting from transplanting until nearly harvesting at certain water depth that varies from 50 mm to 100 mm. Almost 80% of water resources availability is used for irrigation purposes. Nitrogen (N) is normally a key factor in achieving optimum lowland rice grain yields. Recovery of fertilizer nitrogen by low land rice is usually lower than 50% of N applied (Ai *et al*., 2003). Low recovery of N in annual crops is associated with its loss by volatilization, leaching, surface runoff, denitrification, and plant canopy. 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 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 (Mikkelsen, 1987). 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 (Horie *et al.*, 2005). 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). 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.

II. MATERIALS AND METHODS

Site and type of experiments

Field experiments were conducted between April to September 2011, 2012 and 2013 at Takasaka (38º 43′ 18″ N, 139º 49′ 19″ E), which is located 4 km west of the agriculture faculty, experimental farm at Yamagata University, Tsuruoka, Japan. The soil, which is classified as an Aquent (according to the USDA classification system), had the following characteristics: clay loam with a pH of 5.1, cation exchange capacity (CEC) of 28.6 cmol (+) kg^{-1}, total-N content of 2.4 g kg^{-1}, total-C content of 25.7 g kg^{-1}, and available P_2O_5 (according to the Bray No.2 extracting solution method) and exchangeable K_2O of 0.17 and 0.13 g kg^{-1} soil, respectively.

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 (26April) 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 N m^{-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.

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 80°C for 2 days.

Plant N analysis

Plant nitrogen contents were determined by the Kjeldahl method (Kenney and Nelson 1982). ^{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).

Xylem exudation rate measurement

Xylem exudation rates were measured in 2011 (at 42 and 80 DAT), 2012 (at 39 and 79 DAT) and 2013 (at 41 and 78 DAT), according to the method described in San-Oh *et al*. (2004). Samples from two hills per plot that, had an average number of tillers or panicles for each plot, were cut 10 cm from the soil surface, and a plastic bag containing pre-weighed absorbent cotton was attached to the cut end of each stem with rubber bands. After 2 hours, each bag was detached, sealed and weighed, and the exudates weights were calculated by subtracting the weight of the bag and the weight of the absorbent cotton. The xylem exudation rate was expressed in mg $tiller^{-1}h^{-1}$. Three replicates were performed.

Root mass density measurement

To measure root dry weight and root volume, roots were taken from the field using the monolith method at 79 and 78 DAT (heading stage) in 2012 and 2013

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

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.

Yield Parameters

Number of spikelet's m^2 and $panicle^{-1}$

Number of spikelet's per m^2 and $panicle^{-1}$were counted from the sample hills used for yield components i.e.10 hills from each plot just before harvesting.

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.

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.

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.

III. RESULT AND DISUSSION

Water consumption

From beginning of the water management, the total water consumption in Non-flooding and SWD were 529.97 and 608.9 mm respectively, much less than that in Flooding, which was 780.88 mm in 2012 while 1247.9 mm in Non-flooding, 1301.3 mm in SWD and 1443.3 mm observed in Flooding treatment in the year 2013 (Table1). 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 as because much rainfall was fallen during growth period. 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.

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

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 (Fig.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.

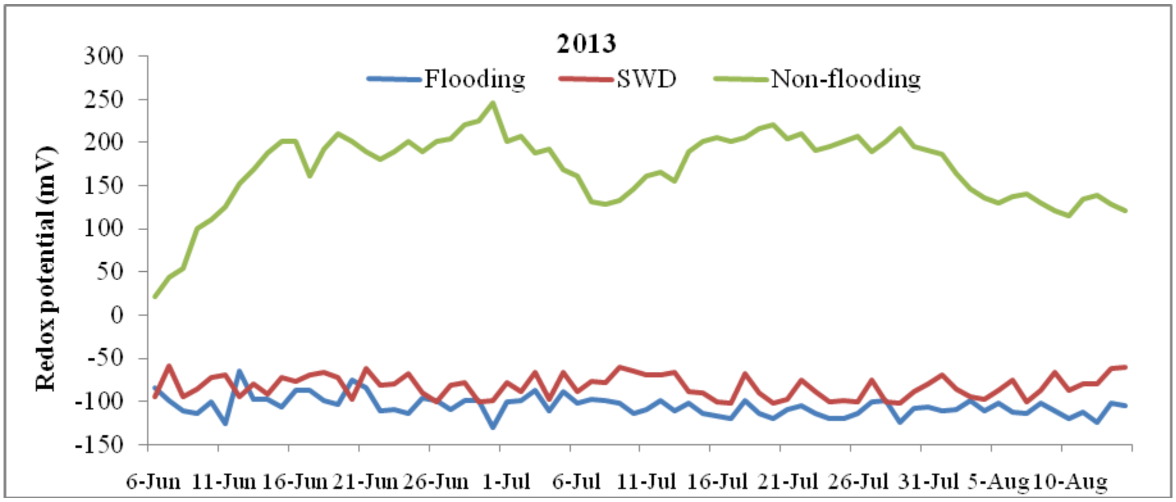

Fig1. Redox Potential (Eh) at 5 cm depth during 4 July to 20 July, 2012 and 6 June to 10 August, 2013

Percolation rate

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) (Fig.2). The percolation rate of the (Flooding) 5 cm water depth was found about 4.4 mm day^{-1} where 1.67 mm day^{-1} observed in SWD (2 cm water depths).

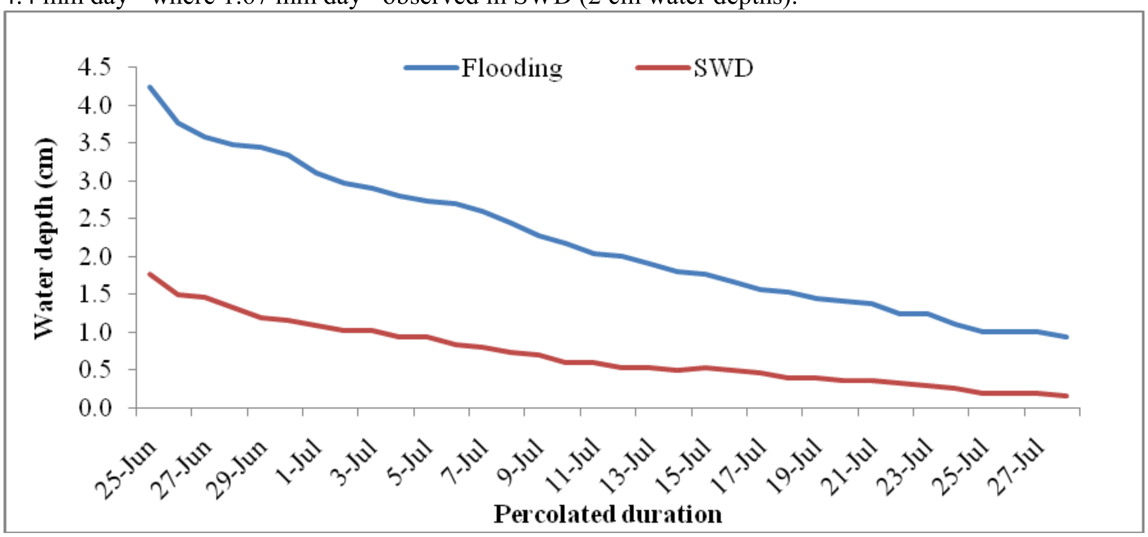

Fig2. Percolation rate at 5 and 2 cm water depth during 25 June to 27 July, 2013

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 (Fig.3). 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.

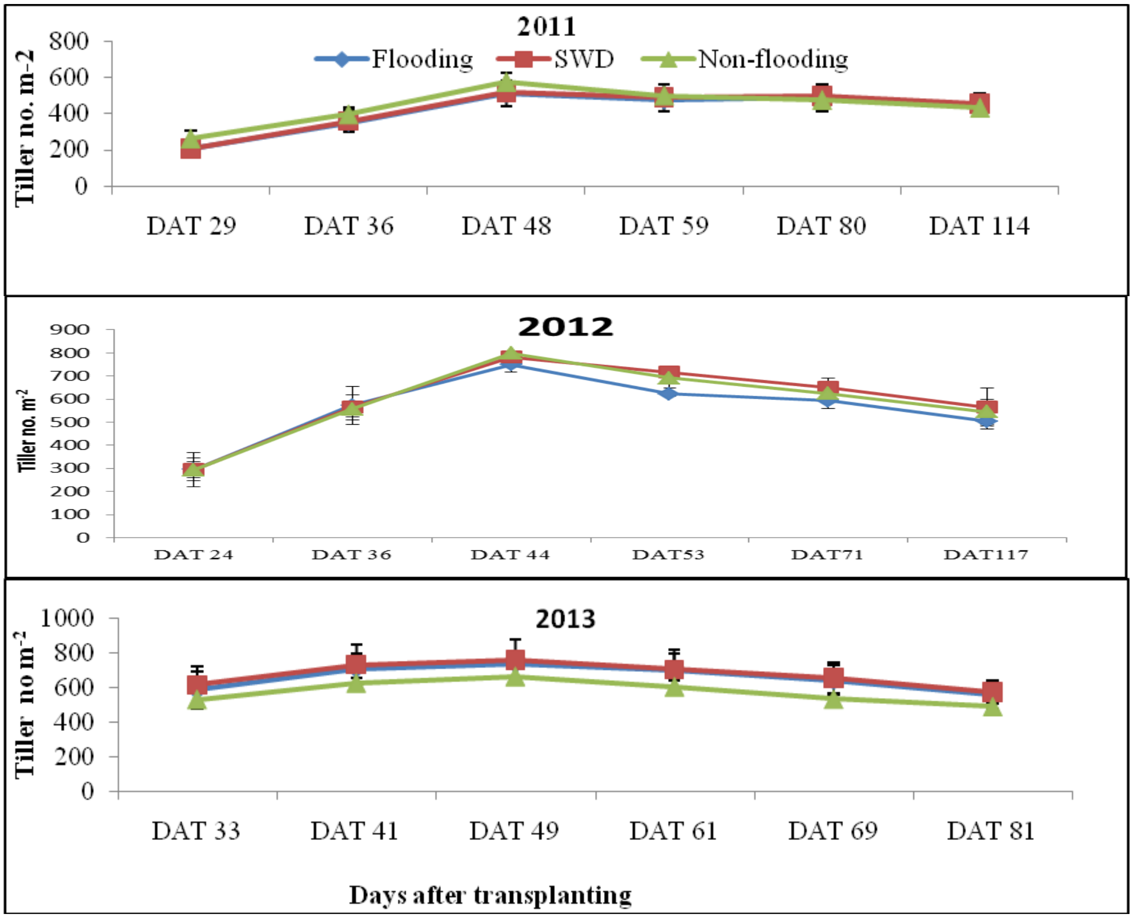

Fig3. Changes in the number of tillers in Flooding, SWD and Non-flooding water regime in 2011, 2012 and 2013

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 (Fig.4). 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.

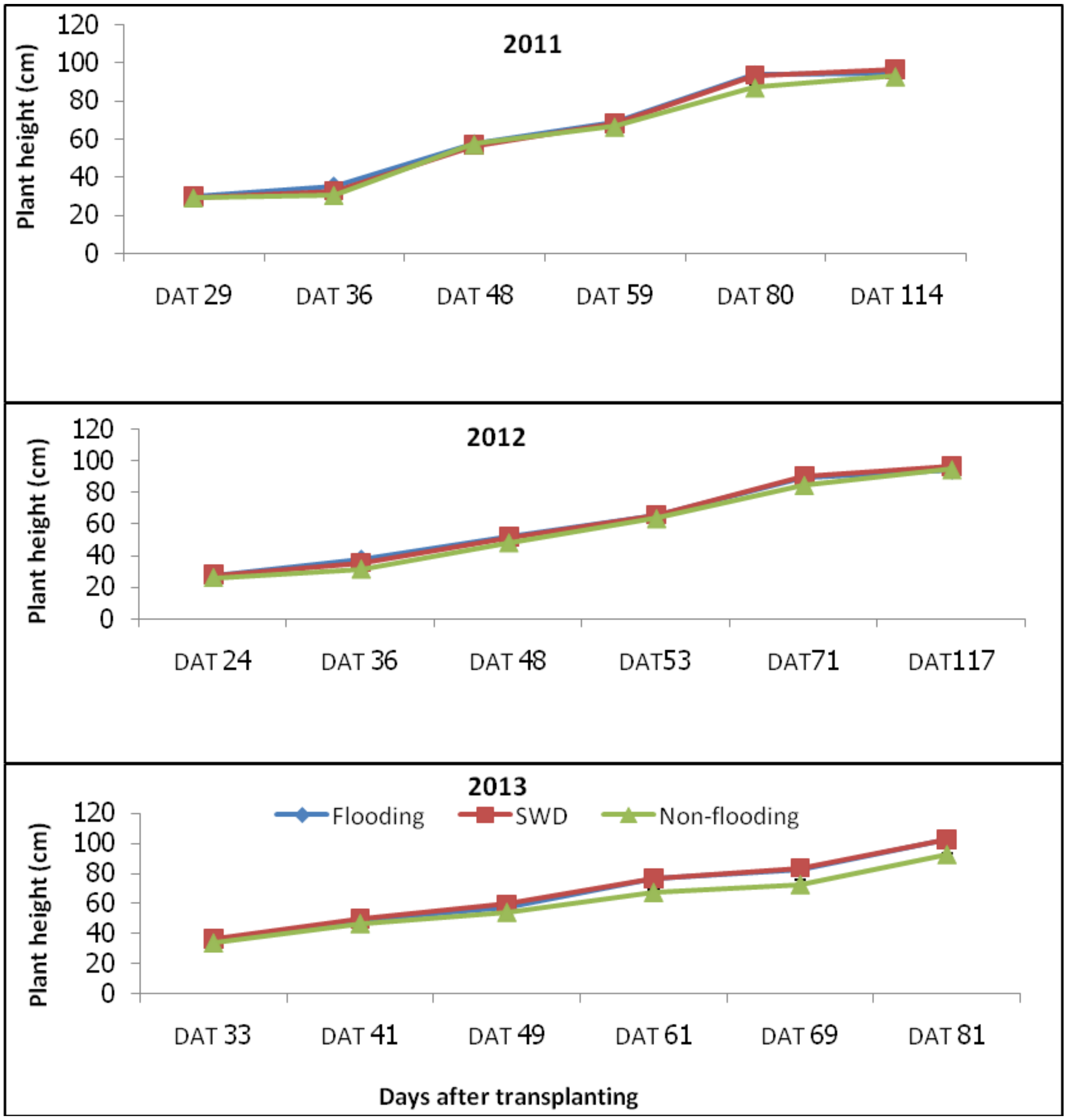

Fig4. Changes in the plant height in Flooding, SWD and Non-flooding water regime in 2011, 2012 and 2013

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 (Table2). 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. On the other hand, in 2013, single ANOVA mentioned that the above-ground biomass was the same for all the treatments in the maximum tillering, heading and pre-maturing stage (Table3) while the higher biomass trend was observed in SWD plots at heading and pre-maturing stage of rice growth.

Xylem exudation rate and root mass density

During the maximum tillering stage (42, 39 and 38 DAT in 2011, 2012, and 2013 respectively), the xylem exudation rate varied by treatment but not by the year (Table4). The xylem exudation rate was significantly higher for the SWD treatment (89.1 mg $tiller^{-1}$ h^{-1}) than for the Non-flooding treatment (50.5 mg $tiller^{-1}$ h^{-1}). At the heading stage, the xylem exudation rate varied by treatment and by year but did not display interaction. Among the treatments, the SWD treatment had higher consistent xylem exudation rate (120.2 mg $tiller^{-1}$ h^{-1}) than the Non-flooding treatment (96.4 mg $tiller^{-1}$ h^{-1}) and the Flooding treatment (93.6 mg $tiller^{-1}$ h^{-1}).

Table2. 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
Unsaturated	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

Table3. Above-ground biomass in rice plant in the year 2013 (ANOVA Table)

Source of variation	Above-ground biomass (g m^{-2})		
Treatment	**Maximum Tillering**	**Heading**	**Pre-maturing**
Flooding	334.8	836.9	1048.9
SWD	338.2	875.7	1129.1
Unsaturated	310.0	812.1	943.8

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, Pre-maturing: 94 DAT respectively

Similarly, root mass density was significantly higher in SWD (0.68 mg cm^{-3} $tiller^{-1}$) than Flooding (0.53 mg cm^{-3} $tiller^{-1}$) and Non-flooding (0.61 mg cm^{-3} $tiller^{-1}$) plots at heading stage in the year 2012 and 2013 (Table5).

Table4. Xylem exudation rate of rice plant in the year 2011, 2012 and 2013

Source of variation	Xylem exudation rate (mg $tiller^{-1}h^{-1}$)	
Treatment	Tillering	Heading
Flooding	64.4b	93.6b
SWD	89.1a	120.2a
Non-flooding	50.5b	96.4b
Year		
2011	74.8	126.5a
2012	60.1	81.6b
2013	67.1	96.6b
Significance	*P* value	
Treatment (T)	*	**
Year (Y)	NS	**
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, Tillering stage: 42, 39 and 40 DAT in 2011, 2012 and 2013, Heading stage: 80, 79 and 78 DAT in 2011, 2012 and 2013 respectively, each treatment 2 hills plot^{-1} x 3 replication: 6 hills

Table5. Root mass density of rice plant in the year 2012 and 2013 (2-way ANOVA)

Source of variation	**Root mass density (mg cm^{-3} tiller^{-1})**
Treatment	**Heading stage**
Flooding	0.53b
SWD	0.68a
Non-flooding	0.61c
Year	
2012	0.63
2013	0.59
Significance	P value
Treatment (T)	**
Year (Y)	NS
T x Y	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, Tillering stage: 42, 39 and 40 DAT in 2011, 2012 and 2013, Heading stage: 80, 79 and 78 DAT in 2011, 2012 and 2013 respectively, each treatment 2 hills plot^{-1} x 3 replication: 6 hills

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 (Table6). 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.

Similarly in the year 2013, N uptake by rice plant was the same for all the treatments in the maximum tillering stage. But at the heading stage, N uptake by rice plant was quite opposite trend observed in Non-flooding plots compare to SWD and Flooding plots (Table7). Similar lower trend was observed in Non-flooding plots at pre-maturing stage. Probably this result supported the lower plant height during growth stage.

Table6. 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
Unsaturated	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

Yield and yield components

The brown rice yield varied by treatment (Table7). 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).

Table7. 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

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).

Percolation is the vertical flow of water to below the root zone. The percolation rate rice fields are affected by a variety of soil factors: structure, texture, bulk density, mineralogy, organic matter content etc. Soil structure is a changed by the physical action of puddling. In heavy-textured, montmorillonitic clay, sodium cations and a high bulk density are favorable for effective puddling to reduce percolation rates. The percolation rate is further influenced by the water regime in and around the field. Large depth of ponded water favor high percolation rates (Wickham and Singh 1978). In a field survey in the Philippines, 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 our study and we found similar percolation rate under shallow water depth.

Bhuiyan and Tuong (1995) concluded that a standing depth of water throughout the season is not needed for high rice yields. They added that about 40-45 percent of the water normally used in irrigating the rice crop in the dry season was saved by applying water in small quantities only to keep the soil saturated throughout the growing season, without sacrificing rice yields. A similar result was obtained by Sato and Uphoff (2008) with the use of intermittent irrigation in SRI management. Similarly, 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).

Our results indicate 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.

Our study reported that Non-flooding soil conditions influenced redox potential comparing other water regimes (Fig.4). Water management was expected to enhance aerobic soil conditions and increase the redox potential. Active or 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, 1974).

An enhanced xylem exudation rate and root mass density, which is affected by physiological activity in the root and root biomass (Yamaguchi *et al*. 1996) during the entire growth period, especially during the heading stage, is an important phenomenon in shallow water management practices for rice plants (Table5). Mishra *et al*. (2006) revealed and argued that this practice could be a major reason for the enhanced root activity in rice plants under shallow water management. Another report argued that one potential mechanism for enhanced root growth in warmer soils is the source-sink relationship between above-ground and below-ground plant parts. Elevated soil temperatures are known to increase the rate of photosynthesis (Schwarz *et al*. 1997).

In addition, the recovery efficiency for top-dressed N was significantly higher for the SWD treatments (Table9), indicating a higher N absorption ability for rice roots in photosynthetic efficiency of the lower rice leaves by keeping the xylem exudation rate of the roots high during the middle and later growth stages (Table5). Root mass density of rice root in our results also supports the above logic (Table6).

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 m^2, 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.

In this study therefore, we conclude 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.

IV.CONCLUSION

This study showed that 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. 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.

REFERENCES

[1] Ai, K., Rao, D.L.N. and Moraghan, J.T. "A comparison of the isotope and differences methods for determining nitrogen fertilizer efficiency", J. Plant and Soil. 105, 55-67, 2003.

[2] Bhuiyan, S. I. and Tuong, T.P. "Water use in rice production: Issues, research opportunities and policy implications. Paper presented at the Inter-Center Water Management Workshop, 29-30". Colombo, Sri Lanka: International Irrigation Management Institute. Geneva. World Health Organization, 1995.

[3] Chapagain, T. and Yamaji, E. "Impacts of alternate wetting and drying irrigation on rice growth and resorces-use efficiency". In Yamaji., E., hapagain, T. (eds.), proceedings of an International workshop on water-saving irrigation for rice, China. 23-25, 2010.

[4] Davids, W.J. "Root signals and the regulation of growth and development of plants in drying soil". Annu. Rev. Plant Physiol. Plant Mol. Biol. 42, 55-76, 1998.

[5] FAO (Food and Agriculture Organization) "Prospects for food, nutrition, agriculture, and major commodity groups". World agriculture: toward 2030-2050, Interim report. Global Perspective Studies Unit. Rome: FAO, 2019.

[6] Gotoh S, Patrick WH, "Transformation of iron in a waterlogged soil as affected by redox potential and pH". Soil Sci. Soc. Am. Proc., 38, 66-71, 1974.

[7] Guerra, L.C., Bhuiyan, S.I., Tuong, T.P. and Barker, R. "Producing more rice with less water from irrigated system". SWIM Paper 5. IWMI/IRRI, Colombo, 2008.

[8] Horie T, Ohnishi M, Angus JF, Lewin LG, Tsukaguchi T and Matano T. "Physiological characteristics of high-yielding rice inferred from cross-location experiments". Field Crops Research, 52:55-67, 2005.

[9] Keisuke, S., Scagel, C.F., Cheng, L., Fuchigami, L.H., Rygiewicz, P.T. "Soil temperature and plant growth stage influence nitrogen uptake and amino acid concentration of apple during early spring growth". Tree Physiol. 21, 541-547, 2008.

[10] Lin, X.Q., Zhang, Y.P. and Zhu, D.F. "Rice root growth and nutrient uptake as influenced by organic manure in continuously and alternately flooded paddy soils". Agric. Water Manage., 70, 67-81, 2004.

[11] Magdoff, F.R. and Bouldin, D.R. "Nitrogen fixation in submerged soil and sand-energy material media and the aerobic-anaerobic interface". Plant and Soil. 33, 49-61, 1970.

[12] Mikkelsen, D.S. "Availability of ammoniacal nitrogen to lowland rice as influenced by fertilizer placement". Agron. J. 49, 296-300, 1987.

[13] Mishra HS, Rathore TR, Dant RC, "Effect of intermittent irrigation on groundwater table contribution, irrigation requirement and yield of rice in mollisols of the Tarai Region". Agricultural water Management.,18, 231-241, 2006.

[14] Patrick, W.H. Jr, and Reddy, K.R. "Nitrification-denitrification reactions in flooded soils and water bottoms: dependence on oxygen supply and ammonium diffusion". J. Environ. Qual. 5, 469-472, 1976.

[15] Satyanarayana, A., Thiyagarajan, T.M., Uphoff, N. "Opportunities for water saving with higher yield from the system of rice intensification". Irrig. Sci. 25, 99-115, 2007.

[16] Schwarz, P.A., Fahey. T.J. and Dawson, T.E. "Seasonal air and soil temperature effects on photosynthesis in red spruce (*picea rubens*) sapling". Tree physiol. 17, 187-194, 1997.

[17] Sing, S., Sing, J.S. and Kashyap, A.K. "Methane consumption by soils of dryland rice agriculture: influence of verities and N-fertilization". Chemosphere. 38, 175-189, 1996.

[18] Tabbal, D.F., Lanpayan, R.M. and Bhuiyan, S.I. "Water-efficient irrigation technique for rice. In ed. V.V.N Murty and K. Koga, Soil and Water Engineering for Paddy Field Management". Asian Institute of Technology, Bangkok, 1992.

[19] Wada, G., Shoji, S and Mae, T. "Relationship between nitrogen absorption and growth and yield of rice plants". JARQ. 20, 135-145, 1986.

[20] Yamaguchi, T., Tsuno, Y., Nakano, J. and Mano, R. "Analysis of factors concerning bleeding rate from the basal part of stem in rice plants". Jpn. J. Crop Sci. 64 : 703-708, 1996.