Impact of Water Saving Irrigation Systems on Water Use, Growth and Yield of Irrigated Lowland Rice

W. M. W. Weerakoon, T. N. N. Priyadarshani, C. H. Piyasiri and L. S. Silva
Rice Research and Development Institute, Batalagoda, Ibbagamuwa, Sri Lanka

Abstract

To meet the growing demand for food and other needs from an increasing population, the rice production in Sri Lanka, which was 3.87 million tonnes in 2008, has to be increased to 4.2 million tonnes by the year 2020. This requirement could be achieved by increasing productivity and/or by increasing the cultivated extent. In 2008, about 77 % and 68 % of the total paddy land extent was cultivated with either partial or full irrigation during the *maha* and *yala* seasons, respectively. A considerable extent of paddy land was either not cultivated or cultivated for other crops due to the scarcity of water in the dry and intermediate zones. Furthermore, with increased competition for water for domestic and industrial needs and climate change, there will be further reductions in the availability of water for rice cultivation. Conserving irrigation water would increase the cultivated extent of land while reducing the probability of late season water-stress in the cultivated rice crop. We studied the impact of different soil water regimes on water use, nutrient uptake, growth and grain yield of 3 – 3½ age lowland rice at the Rice Research and Development Institute, Batalagoda, Ibbagamuwa. There was no significant difference in the grain yield in rice when grown under either saturated or flooded conditions, but the yield decreased significantly with alternate wetting and drying. However, under saturated conditions, the irrigation water requirement was significantly lower than the flooded condition. The lowest irrigation water requirement was recorded with saturated to dry conditions. The irrigation water requirement under flooded conditions, when compared with the saturated condition, increased by 39 % during the *yala* season. During the *maha* season, even though the total irrigation requirement was lower, when compared to saturated conditions, four times more irrigation water was required under flooded conditions. There was a significant increase in plant dry matter production and leaf N (nitrogen) under saturated conditions, when compared with conventional flooded conditions. These findings suggest that when soil water is maintained at a saturated level in lowland rice, a considerable amount of irrigation water could be saved without sacrificing grain yield.

Introduction

Rice is the staple food for over 20 million Sri Lankans and is the livelihood of more than 1.8 million farmers. Sri Lanka produced about 3.9 million tonnes of paddy in 2008 with a national average paddy yield of 4.2 t/ha. With the present population growth rate of 1.1 %, increasing per capita consumption, requirements for seed, and post-harvested wastage in handling, Sri Lanka will need about 20 % more rice in the year 2020. This target could be achieved by increasing the area under rice cultivation and/or increasing productivity per unit area. Out of the island's total rice land extent of 0.71 million ha, about 0.43 million ha was cultivated under irrigated conditions in the year 2007/2008 *maha* season. However, due to the scarcity of water, the extent of rice cultivation under irrigated conditions during the *yala* season decreased to 0.38 million ha. Furthermore, due to the scarcity of water, about 12 % of the area cultivated with rice was also not harvested in 2007. Growing alternate crops in these land classes are difficult due to the presence of excess water during the initial stages. Therefore, most of these lands must be cultivated with rice at the risk of facing moisture stress during the late vegetative and reproductive stage.

It is expected that the future demand for water extracted from major rivers for domestic and industrial needs will increase significantly. With diminishing inputs for thermal power generation, the demand for hydro-power will also increase, thereby diverting less water from the Mahaweli River towards the dry zone. These measures would lead to a decrease in the quantity of water supplied for irrigated agriculture, especially for rice cultivation in the dry zone.

Rice is a major user of the global water supply. About 40-46 % of Asia's total irrigated agricultural lands are utilized for rice cultivation. Studies conducted on irrigation water use suggest that much of the water is being lost due to inefficient water allocation and distribution in the irrigation systems. About 400 – 5,000 liters of water are needed to produce one kg of paddy (Tabbal et al. 1992).

It is reported that over the last 20 years the vulnerability of the northeast monsoon has increased along with an increase in the consecutive dry days in the dry zone. Even though the reduction in annual total rainfall over the island is negligible, increased dry days and less reliability on the monsoon would increase demand for irrigation water, especially in the dry and intermediate zones. With the change in climate, the demand for water from sectors other than agriculture also would increase resulting in a reduction in the availability of water for irrigation. Furthermore, the adverse impacts of climate change on rice will be aggravated with the reduction in the quality and quantity of irrigation water. Hence, there is an urgent need to increase irrigation water use efficiency.

Water is lost through evaporation from free water surface, transpiration from the crop, seepage and percolation of the soil, bund leakages and runoff from the field. Seepage and percolation vary with the soil environment, which could be partially controlled through proper management. In the dry zone of Sri Lanka, seepage and percolation losses vary between 7-10 mm per day in the 'reddish brown earth (RBE)' soils, while it is lower in the 'low humic gley (LHG)' soils. The total irrigation water requirement for the rice crop grown in RBE and LHG soils are around 1,057 mm and 948 mm, respectively. This suggests that with the conventional system of water management, a significant quantity of water is required for a lowland rice crop. Percolation of water is increased with a large depth of water (Sanchez 1973; Wickham and Singh 1978).

Other than the traditional flood irrigation system, many methods of irrigation have been proposed to conserve irrigation water in lowland rice cultivation. Systems such as alternate wetting and drying, maintaining soil water below saturation and maintaining saturated conditions are some such methods. This study was designed to compare different irrigation systems used in Sri Lanka based on water use, water productivity and grain yield of rice.

Materials and Methods

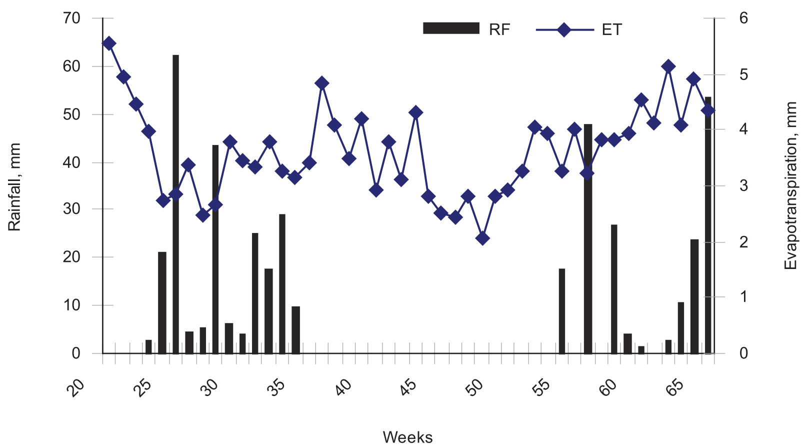
Experiments were conducted at the lowland rice fields at the Rice Research and Development Institute (RRDI), Batalagoda, Ibbagamuwa (07^0 31' N and 80^0 26' E) during the *yala* season of 2003 and *maha* seasons of 2003/2004. The experimental site was located in the middle portion of the rice track in the well-drained lowland soil category, and the experiment plots were prepared under lowland conditions. Fields were ploughed twice to a depth of about 15-20 cm and leveled to maintain uniformity within the field. Four separate fields were considered as four separate blocks. Within each block, six 9 m x 9 m plots with a 40 cm wide bund around the plot were prepared. At the time of leveling of each plot, a basal fertilizer mixture containing 5 kg/ha of N (nitrogen), 35 kg/ha of P_2O_5, 15 kg/ha of K_2O and 2 kg/ha of $ZnSO_4$ were applied to rice varieties, Bg 352 with a 3 ½–month maturity age, Bg 305 with 3-month maturity age, and Bg 358 with 3 ½–month maturity age were used during the *yala* 2003, *maha* 2003/2004 and *yala* 2004 cultivation seasons, respectively. Rice seeds were soaked in water for 24 hrs and incubated for 48 hrs and then were sown onto these well-prepared seed-beds. One week after germination, treatments were employed on to rice plants grown in these plots. Even though the treatments were randomly allocated to each plot, to minimize lateral seepage, similar treatments of water management were grouped together. To control weeds at 12 days after sowing, Nominee (Bispyribac Sodium, 100g/1SC) was applied and water to all plots was impounded to a depth of about 10 cm at 3 days after the application of weedicides. Thereafter, the treatments were employed again and continued until either panicle initiation (PI) or the late booting (LB) stage. Treatment combinations were: maintaining 10 cm water layer (standing water) throughout the cropping period; irrigate to a water depth of 10 cm when soil moisture reaches saturation level and continued until the late booting (LB) stage (flood to saturate^{-1}); irrigate to soil saturation level when soil started to form cracks and continued until the LB stage (saturate to dry^1); irrigate to a water depth of 10 cm when soil moisture reached saturation level and continued until PI stage (flood to saturate^{-2}); irrigate to soil saturation level when soil starts forming cracks and continued until the PI stage (saturate to dry^2); maintain soil at saturated level until LB (saturate throughout). At the end of the respective treatment period, plots were filled with water to a depth of 10 cm and continued until physiological maturity. Nitrogen fertilizer in the form of urea was applied to the treatment at 21, 35, 49 and at the late booting stage at the rate of 20, 30, 30 and 15 kg/ha, respectively. Thirty kg of K_2O in the form of ‘muriate of potash’ was applied at 49 days. Insecticides recommended by the Department of Agriculture (DOA) were applied to control leaf folder and the paddy bug. There was no disease incidence during the experimental period.

The amount of water applied to each plot in each block was measured using a calibrated partial flume. The partial flume water height was then converted to the amount of water applied using the calibration curve. Weekly rainfall and average pan evaporation data were collected from the meteorology station located about 100 m from the experimental site. Plant samples were collected from all plots using a 50 cm x 50 cm quadrant at physiological maturity. Plants were separated into component plant parts and weighed after oven drying for 72 hrs at 80°C. At maturity, plants from the rest of the field were harvested, leaving a 50 cm border around the plot. The final harvest was cleaned and filled and grains were sun-dried, and the final yield was adjusted to 12 % seed moisture content. Data were analyzed using the normal ANOVA procedure for an experiment arranged in the randomized complete block design using SAS statistical package.

Results and Discussion

Figure 1 suggests that average daily pan evapotranspiration in the experimental site was about 3.5 mm and 4.0 mm during *yala* 2003 and *maha* 2003/2004 seasons, respectively. In general, there was sufficient water received during the latter part of the *yala* crop, and the total number of irrigations given for different stages of treatments was greater during the *yala* season than the *maha* season (Table 1). In general, 10 irrigations were made during the *yala* crop to maintain standing water to a depth of 10 cm, while only 5 irrigations were needed during the *maha* season. The average number of irrigations and the amount of water applied were lowest, with the treatment, where water was applied in small quantities to maintain the field between soil saturation and crack formation until late booting (Table 1). Furthermore, the difference in the amount of water applied between saturated soil culture and saturate to dry was not statistically significant.

Figure 1. Weekly total rainfall and average weekly evapotranspiration at the experimental-site during the experimental period.



In the saturated soil culture, soil was kept close to saturation throughout, thereby reducing the hydraulic head and keeping seepage and percolation at a very lower level. Therefore, the amount applied per water issue was relatively lower. However, the number of water issues did not decrease significantly when compared with the flooded system of irrigation. It was reported that with saturated soil culture, water input decreased by an average of 23 % from the

Table 1. The number of irrigation issues and the amount of irrigation water applied (m^3/ha) to each treatment from seedling establishment during 2003 *yala* and 2003/2004 *maha* seasons.

Treatment	Number of irrigations		Amount of water applied (m^3/ha)	
	Yala	*Maha*	*Yala*	*Maha*
Standing water throughout	10	5	4,426 ^{b}	2,047 ^{a}
Flood to saturate $^{-1}$	11	4	5,427 ^{a}	1,610 ^{a}
Saturate to dry $^{-1}$	5	3	2,872 ^{c}	523 ^{ac}
Flood to saturate^{2}	9	4	5,551 ^{a}	1,738 ^{a}
Saturate to dry^{2}	10	3	5,042 ^{ab}	829 ^{b}
Saturate throughout	9	3	3,363 ^{c}	558 ^{bc}

Note: [1] – treatment employed up to LB, [2] – treatment employed only up to PI

continuous flooded condition (Bouman and Tuong 2001). In the saturate to dry treatment, it was expected that a much lower amount of water is necessary, but the heavy percolation through the cracks formed have increased the amount of water applied. This was particularly true when treatment was employed only up to the PI stage and, thereafter flooded the field. However, the lowest amount of water applied was recorded with the ‘saturate to dry’ treatment employed up to the late booting stage. This suggests that alternate wetting and drying could save a considerable amount of irrigation water. The amount of water applied, and the number of water issues, is significantly lower during the *maha* season than that of the *yala* season. This was due to higher rainfall coupled with the 3-month maturity aged rice variety used in this study during the *maha* season. The results of many field experiments suggest that the total water input could decrease by 15 – 30 % without any significant impact on the grain yield (Cabangon et al. 2004; Belder et al. 2004). This experiment shows that about 24 – 35 % and 70 % irrigation water could be saved during the *yala* and *maha* seasons, respectively, if the field is either maintained at saturated condition or saturate to dry situation. Even though the total amount of water applied is greater during the *yala* season, the difference between water saving irrigation treatment remained the same, suggesting that a significant amount of irrigation water could be saved irrespective of the season, if the field is maintained at saturated or saturated to dry condition.

However, the dry condition in treatments of flooded to dry or saturate to dry could create a hidden water stress, which could affect both growth and yield of rice. It was indeed true that there was a reduction in all growth parameters when the field was subjected to a dry situation (Table 2).

There was a significant increase of the total biomass in treatments where there is no moisture stress to the rice plant. Maintaining rice plants at a saturated condition throughout the growing period has resulted in a significant increase of the total biomass (Table 2). In all treatments where flood water was maintained to a certain depth, there was a significant reduction in the plant growth when compared with the saturated soil culture. Furthermore, it was observed that the leaf greenness or SPAD value (measured during the late booting stage using SPAD 502, Minolta Co. of Japan) was 42.1 in the saturated treatment, while it was 41.6 in the flooded treatment. SPAD values in all other treatments ranged between 36.9 and 40.4.

Table 2. Total plant dry weight, root dry weight and number of panicles per square meter, spikelet number and filled grain number per panicle, 1,000 grain weight and Harvest Index (HI) of rice plants at physiological maturity stage during 2003/2004 *maha* season.

Treatment	Total dry weight, kg/m^2	Root weight g/m^2	Panicle number $/m^2$	Spiklets /panicle	Grains /panicle	1,000 grain weight, g	HI
Standing water throughout	1,340 b	109.0 b	493 b	68 a	57 a	22.5 a	0.50 a
Flood to saturate $^{-1}$	1,397 b	124.5 a	538 a	64 a	54 a	21.9 a	0.49 a
Saturate to dry $^{-1}$	1,322 b	118.0ab	533 a	59 ab	50 b	22.6 a	0.48 a
Flood to saturate^2	1,291 b	114.9ab	467 b	65 a	56 a	22.2 a	0.50 a
Saturate to dry^2	1,229 c	105.3 b	527 a	58 b	51 b	21.5 a	0.49 a
Saturate throughout	1,418 a	124.6 a	515 a	67 a	57 a	22.5 a	0.49 a

Even though there was no leaf N stress when the SPAD reading was around 40, increase in total biomass and leaf N status suggest that there was an increased uptake of N in the saturated soil condition than the flooded and flooded to dry systems, which could be due to reduced leaching losses. Nitrate leaching losses increase with heavy irrigation regimes in coarse textures soils (Aulakh and Singh 1997; Singh and Sekhon 1976). Furthermore, increased root dry weight also suggests that the ability of the rice plant to take up nutrients had increased with saturated soil culture. With the increase in nutrient uptake, there could be an increase in tillering as there are enough photosynthates produced for developing tiller. However, standing water could suppress tillering. Better canopy status during both vegetative and reproductive stages have contributed to increase the spikelet number and filled grain number per panicle in the non-stressed treatments (Table 2). There was no change in seed weight as that is controlled mostly by the genetic potential of the variety.

Grain yield did not differ among treatments without soil drying in *yala* 2003 and *maha* 2003/04 and *yala* 2004 (Table 3). However, there was a significant decrease in grain yield with soil drying treatments when compared with the flooded or saturated treatments. Furthermore, it did not differ among treatments where the stress was relieved at PI or at LB. This suggests that there will be a significant impact on grain yield with alternate wetting and drying of soil. In contrast many researchers have observed no differences or increases in grain yield with alternate wetting and drying (Wei Zhang and Song 1989). However, Bouman and Tuong (2001) suggest that there is a reduction in the grain yield in alternate wetting and drying when compared with rice grown with standing water. With the reduction in the amount of water used and the increased grain yield in the saturated soil culture treatment, the irrigation water productivity has significantly increased with saturated soil culture than with that of flooded rice culture. Even though the irrigation water productivity in the saturate to dry treatment was not different to that of saturated treatment, the average grain yield was significantly lower in the saturate to dry system. Irrigation water productivity was significantly greater in the *maha* season when compared with the dry *yala* season. This is because the grain yield increased while the amount of irrigation water applied, decreased. This was possible as there was sufficient rainwater to keep the soil under saturation.

Table 3. Grain yield (t/ha) and irrigation water productivity (g grain kg^{-1} water) of rice grown under different soil water regimes during 2003 *yala*, 2003/2004 *maha* and 2004 *yala** seasons.

Treatment	Grain yield, t / ha			Irrigation water productivity, g grain kg^{-1} water	
	2003 *Yala*	2003/4 *Maha*	2004* *Yala*	2003 *Yala*	2003/4 *Maha*
Standing water throughout	4.74 a	5.77 a	5.29 a	1.077 abc	2.829 b
Flood to saturate $^{-1}$	4.90 a	5.75 a	4.95 ab	0.933 bc	3.577 b
Saturate to dry $^{-1}$	4.19 b	5.08 b	4.65 b	1.507 a	10.590 a
Flood to saturate^{2}	4.89 a	5.25 ab	5.03 ab	0.895 bc	3.090 b
Saturate to dry^{2}	4.04 b	4.28 c	4.56 b	0.806 c	5.459 b
Saturate throughout	4.54 a	5.46 ab	5.46 a	1.455 a	12.650 a

Note: * Water productivity not measured

In general, maintaining saturated soil culture in lowland rice paddies could save irrigation water requirement while maintaining the same or even a greater level of grain yield when compared to the flooded system. The water saving, especially during the *yala* season, could be used for the cultivation of an additional area under rice in the dry and intermediate zone of Sri Lanka. These results also suggest that a successful *maha* rice crop could be raised with over 50 % less irrigation water than what is used at present, if saturated soil culture is maintained. However, the irrigation infrastructure has to be modified to meet these requirements.

Conclusions

There is a considerable scope to reduce the irrigation water applied to lowland rice culture during both *yala* and *maha* seasons in the intermediate zone of Sri Lanka. Saturated soil culture significantly decreased irrigation water use while maintaining the same level of yield. Irrigation water productivity was highest with both saturated soil culture and saturate to dry soil culture. ISn the direct seeded rice culture in Sri Lanka, even though maintaining saturated soil culture is difficult with the present irrigation schedule, maintaining saturated soil conditions in the seed bed without imposing a water stress to the plant could save a significant quantity of irrigation water, which could be used to increase the cultivated extent of rice land in Sri Lanka.

References

Aulakh, M. S.; Singh, B. J. 1997. Nitrogen Losses and Fertilizer N Use Efficiency in Irrigated Porous Soils. *Nutrient Cycling in Agro-ecosystems* 47:197-212.

Belder, P.; Bouman, B. A. M.; Spiertz, J. H. J.; Cabangon, R.; Guoan, L.; Quilang, E. J. P.; Li, Y.; Tuond, T. P. 2004. Effect of Water and Nitrogen Management on Water Use and Yield of Irrigated Rice. *Agric. Water Manage*. 65:193-210.

Bouman, B. A. M.; Toung, T. P. 2001. Field Water Management to Save Water and Increase Its Productivity in Irrigated Rice. *Agric. Water Manage.* 49:11-30.

Cabangon, R. J.; Tuong, T. P.; Castillo, E. G.; Bao, L. X.; Lu, G.; Wang, G. H.; Cui, L.; Mouman, B. A. M.; Li, Y.; Chongde, C.; Jianzhang, W. 2004. Effects of Irrigation Methods and N Fertilizer Management on Rice Yield, Water Productivity and Nutrient Use Efficiencies in Tropical Lowland Rice Conditions in China. *Rice Field Water Environ.* 2:195-206.

Dowe, D. 2005. Increasing Water Productivity in Rice-based Systems in Asia - Past Trends, Current Problems and Future Prospects. *Plant Prod. Sci.* 8:221-230.

Sanchez, P. A. 1973. Puddling Tropical Rice Soils. 2. Effects of Water Losses. *Soil Sci.* 115 (4): 303-308.

Singh, B. J.; Sekhon, G. S. 1976. Some Measures of Reducing Leaching Losses of Nitrate Beyond Potential Rooting Zone 1. Proper Co-ordination of Nitrogen Splitting with Water Management. *Plant Soil* 44:193-200.

Tabbal, D. F.; Lampayan, R. M.; Bhuiyan, S. I. 1992. Water Efficient Irrigation Techniques for Rice. In *Soil and Water Engineering for Paddy Field Management*. Proceedings of the Intl. Workshop on Soil and Water Engineering for Paddy Field Management, January 28-30, 1992, AIT, Bangkok. pp. 146-159.

Wei, Z.; Si-tu, S. 1989. Irrigation Model of Water Saving - High Yield at Lowland Paddy Field. In *International Commission on Irrigation and Drainage*. Seventh Afro-Asian Regional Conference, October 15-25, 1989, Tokyo, Japan. Vol 1-C: 480-496.

Wickham, T. H.; Singh, V. P. 1978. Water Movement through Wet Soils. In *Soils and Rice*. Los Banos, Philippines: International Rice Research Institute (IRRI). pp. 337-357.