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EFFECT OF DIFFERENT IRRIGATION REGIMES ON YIELD AND WATER PRODUCTIVITY OF DIRECT-SEEDED RICE IN THE INTERMEDIATE ZONE OF SRI LANKA

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ABSTRACT

A considerable extent of paddy land in the dry and intermediate zones of Sri Lanka are either not cultivated or cultivated to other crops due to scarcity of water in the Dry and Intermediate Zones. Judicious use of irrigation water would not only allow increasing the cultivated extent but also reduce the probability of late season water stress on the cultivated rice crop. Hence, the impact of different soil water conditions on water use, growth and grain yield of 3-3½ age rice crop at the Rice Research and Development Institute, Batalagoda during 2003 *yala*, 2003/2004 *maha* and 2004 *yala* seasons. There was no significant difference in grain yield in rice when the crop is grown either under saturated soil moisture or flooded conditions however, the yield decreased significantly with depletion of soil moisture below saturation until formation of soil cracks. The lowest irrigation water requirement was recorded with saturated to dry soil condition. Under saturated conditions, the irrigation water requirement was significantly lower ($p<0.05$) than the flooded condition. About 24 % and 72 % of irrigation water could be saved during *yala* and *maha* seasons, respectively, if the field is maintained at saturated soil moisture condition. During *maha* season, even though the total irrigation requirement was lower than the *yala* season, four times more irrigation water was required under flooded condition when compared to saturated soil moisture conditions. There was a significant increase ($p<0.05$) in the plant dry matter production and leaf N level under saturated soil moisture conditions when compared to conventional flooded condition. These results suggest that a considerable volume of irrigation water could be saved in a lowland rice field without sacrificing grain yield, when the soil is maintained at saturated level.

KEY WORDS: Rice, Water productivity, Grain yield, Yield components

INTRODUCTION

Sri Lanka produced about 3.65 million tones of paddy in 2009 with a national average paddy yield of 4.3 t/ha. With the present population growth rate of 1.1 %, increasing per capita consumption, requirements for seed, and wastage in handling, Sri Lanka needs about 20 % more rice by the year 2020. This target could be achieved by increasing the area under rice cultivation and productivity per unit area. Out of the total rice land extent in the island, which is 0.71 million ha, only about 0.461 and 0.268 m ha have been cultivated to rice with supplementary irrigation in 2008/9 *maha* and 2009 *yala* seasons, respectively, which is 73 % in 2008/9 *maha* and 78 % in 2009 *yala* seasons of the cultivated extent during respective seasons. This reduced cultivated extent is mainly due to scarcity of water, and other reasons. Further, about 14 % of the area cultivated to rice was also not harvested in 2009. Growing alternate crops in these land classes are difficult due to excess water during initial stages of the season. Therefore, most of these lands are cultivated to rice at a risk of facing moisture stress during late vegetative and reproductive stage.

About 40-46 % of the Asia's total irrigated agricultural lands are utilized for rice cultivation (Dawe *et al.*, 2005). Therefore, rice is a major user of global fresh water supply. Studies conducted on irrigation water use suggest that much of the water is being lost due to inefficient water allocation and distribution in irrigation systems. About 4000-5000 liters of water is needed to produce one kg of paddy (Tabbal *et al.*, 1992; Bhuiyan *et al.*, 1995).

Maximizing the use of direct rainwater would increase the irrigation water use efficiency (WUE) in rice cultivation in Sri Lanka. Panabokke and Walgama (1974) reported that the total water requirement during *maha* season of a 95–100 day cereal crop could be met totally by rain, if planted in early October. However, farmers in both major and minor irrigation schemes are still reluctant to commence rice cultivation on time (Weerakoon *et al.*, 2006). Nayakakorala (1983) showed that, despite lower yield potentials, the water use efficiency of 3½ month old rice crop was 40 % and 15 % greater than that of a 4½ month old rice crop grown under of flood irrigated conditions in Reddish Brown Earth (RBE) and Low Humic Gley (LHG) soils, respectively. If proper timing and water saving methods are practiced the WUE of short duration rice varieties could be further increased thus bringing an additional area under irrigated rice. It is reported that the predictability of the North East monsoon has decreased along with an increase in consecutive dry days in the dry zone of Sri Lanka over the last 20 years (Premalal, 2008). Increased dry days and less reliability on the monsoon would increase demand for irrigation water, especially for rice cultivation in the dry and intermediate zones.

The future demand for water extracted from major rivers in Sri Lanka for domestic and industrial needs will increase significantly leading to a decrease in the quantity of water flow in major rivers (Weerakoon and Costa, 2009). Changes in the amount of rainfall in the river catchments would further decrease the water availability in rivers (Premalal, 2009). Therefore, even if the water diverted for agriculture especially from Mahaweli River remains the same over the years, the water available for hydropower generation in the downstream would eventually decrease. Increased population in rice growing districts and urbanization would also increase competition for irrigation water leading to further decrease the water available for rice cultivation (Weerakoon and Costa, 2009). Decreased water availability would not only expose rice crop to terminal droughts, but also force the farmer to cultivate comparatively low yielding ultra short duration varieties in place of 3½ month high yielding rice varieties.

Other than the traditional flood irrigation technique, many methods of irrigation have been proposed to conserve irrigation water for lowland rice cultivation. Greater yields could be obtained without continuous flooded irrigation (Li, 1999, Li and Cui, 1996). Alternate wetting and drying, maintaining soil water content below saturation, and maintaining at saturated conditions are some of the methods that could be adopted in lowland rice cultivation. Thus, a study was conducted to elucidate the effects of different irrigation water management systems imposed at different growth stages of a rice crop on water use, water productivity and grain yield of rice, grown in Red Yellow Podzolic soils in the intermediate zone of Sri Lanka.

MATERIALS AND METHODS

Experiments were conducted at the lowland rice fields at the Rice Research and Development Institute (RRDI), Batalagoda, Ibbagamuwe (07^0 31' N and 80^0 26' E) during 2003 *yala*, 2003/2004, *maha* and 2004 *yala* seasons. Experimental site was located in a middle portion of the rice track, which is in the Red Yellow Podzolic imperfectly drain rice soils. Experimental fields were ploughed twice to a depth of about 15-20 cm and leveled within the field. Four separate equal-sized fields were considered as 4 separate blocks. Within each block, six plots each at the size of 9 m x 9 m were laid out with a 40 cm wide bund around the plot, and with separate water input canals. At the time of leveling of each plot, a basal fertilizer mixture containing 5 kg of N/ha, 35 kg of P_2O_5/ha, 15 kg K_2O/ha and 5 kg $ZnSO_4$/ha were applied. The 3½ month old rice varieties namely, Bg 352, Bg 305 and Bg 358 were cultivated during 2003 *yala*, 2003/2004 *maha* and 2004 *yala* seasons, respectively. Exact quantity of seeds of these varieties (seed rate adjusted according to seed weight) were soaked in water for 24 hrs and incubated for 48 hrs before sowing onto well-prepared seedbeds.

One week after germination, treatments (see text below) were imposed on to rice plants grown in these plots. Even though the treatments were randomly allocated to each plot, to minimize lateral seepage, similar water management treatments were grouped together. To control weeds, Bispyribac Sodium (Nominee®; 100g/litre SC) was applied at 12 days after sowing (DAS) and water was impounded to all plots to a depth of about 10 cm at 3 days after application of the herbicide. Thereafter, the treatments were imposed again and continued until either panicle initiation (PI) or late booting (LB) stage. The treatment combinations were; (1). maintaining standing water to a depth of 10 cm (standing water) throughout the cropping period; until late booting stage, (2). impounding water to a depth of 10cm initially when soil moisture depleted to saturated level (flood to saturate) until late booting stage, (3). impounding water up to soil saturation level when soil starts forming cracks (saturate to dry) until panicle initiation stage, (4). impounding water to a depth of 10 cm when soil moisture reaches saturation level (flood to saturate) until PI stage, (5). impounding water to soil saturation level when soil starts forming cracks (saturate to dry). and (6). maintaining soil at saturated level until LB (saturate).

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 all treatments at 21, 35, 49 DAS and at late booting stage at the rate of 20, 30, 30 and 15 kg N/ha. Thirty kg of K_2O in the form of Muriate of Potash was applied at 49 days after sowing. Insecticides recommended by the Department of Agriculture were applied to control leaf folder and paddy bug. There was no disease incidence recorded during the cropping period.

The volume of water applied to each plot within a block was measured using a calibrated Partial Flume. The water height of the Partial Flume was then converted to the volume 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. The leaf greenness or SPAD value was measured during late booting using SPAD 502, Minolta co, Japan. Plant samples were collected from all plots at the physiological maturity using a 50 cm x 50 cm quadrant. 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 fields were harvested leaving a 50 cm boarder around the plot. The final harvest was cleaned, filled grains were sundried and final yield was adjusted to 12 % seed moisture content. Data were analyzed using the ANOVA procedure for an experiment arranged in a randomized complete block design using SAS statistical software package

RESULTS AND DISCUSSION

The total rainfall received during the cropping period in 2003 *yala*, 2003/2004 *maha* and 2004 *yala* seasons were 230 mm, 114 mm, and 247 mm respectively. The rainfall during *maha* season was lower than the two *yala* seasons but evapotranspiration (ET) was also low at early growth of the rice plant during the same season, leading to a lower demand for water. The Bg 352 and Bg 358 cultivated in the *yala* seasons recorded an average of 103 days to mature while Bg 305 cultivated in the 2003/2004 *maha* season took 93 days to mature. Therefore, based on the requirement of the crop, the irrigation water demand in *maha* season was lower than that of *yala* season (Figure 1).

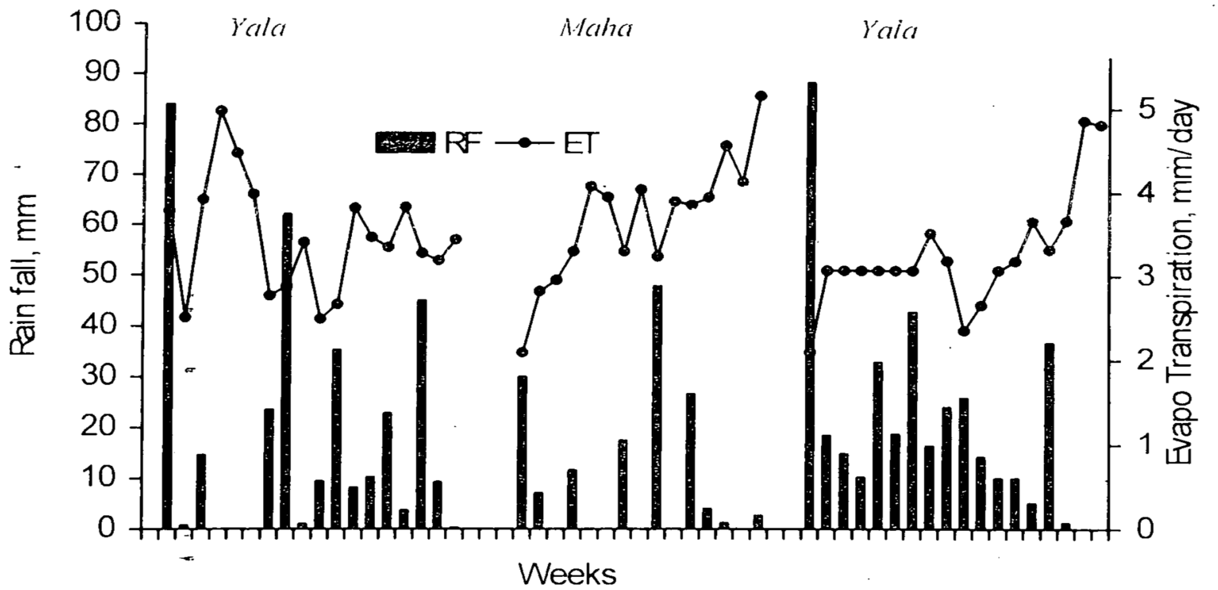

Figure 1. Weekly total rainfall and average weekly evapotranspiration at the experimental site during 2003 *yala*, 2003/2004 *maha* and 2004 *yala* seasons.

The total numbers of irrigation water supply (number of irrigations) given for different treatments were greater during *yala* season than that of *maha* season (Table 1). To maintain standing water in the field to a depth of 10 cm, about 10 irrigations were required during the 2003 *yala* season while only 5 were required during 2003/2004 *maha* season. This could be due to the lower evaporative demand and the shorter duration of the variety used during the *maha* season. The lowest number of irrigations was required to maintain saturate to dry soil condition until PI stage during the *yala* season. However, during *maha* season, the total number of irrigations to maintain the saturate to dry condition and throughout the saturate condition was only 3 (Table 1). The numbers of irrigations for different treatments did not reflect the total water applied to different treatments as the lowest quantity of water was required to maintain the soil between saturate and dry condition (Table 1).

Water is lost through evaporation from free water surface, transpiration from the crop surface, seepage and percolation (S&P) from the soil, bund leakages and runoff from the field. In the saturated soil culture, keeping the soil close to saturation throughout reduces the hydraulic head, thus having S&P at a very low level. The water loss through S&P increases with increase in depth of water (Sanchez, 1973; Wickham and Singh, 1978). Therefore, under saturated conditions, the quantity of water required per water issue was relatively low, however, the number of water issues did not decrease significantly when compared with flood irrigation. Bouman and Tuong (2001) reported that with saturated soil culture, the water input decreased by an average of 23 % from the continuous flooded condition.

Table 1. Number of irrigation issues and the volume of irrigation water applied (m^3/ha) to each treatment from seedling establishment until late booting during 2003 *yala* season and 2003/2004 *maha* season

Treatment	*Number of irrigations*		*Volume of water applied (m^3/ha)*	
	2003 *yala*	2003/2004 *maha*	2003 *Yala*	2003/2004 *maha*
Standing water	10	5	4426 b	2047 a
Flood to saturate[a]	11	4	5427 a	1610 a
Saturate to dry[a]	5	3	2872 c	523 bc
Flood to saturate[b]	9	4	5551 a	1738 a
Saturate to dry[b]	10	3	5042 ab	829 b
Saturate	9	3	3363 c	558 bc

Means followed by the same letter are not significantly different at p=0.05.

The results revealed that even greater volume of water could be saved as the water required to maintain the saturated condition was 24 % and 72 % lower than that required for flood irrigation in *yala* and *maha* seasons, respectively (Table 1). In the saturate to dry treatment, a lower water requirement was expected but, the heavy percolation through the cracks formed has increased the volume of water applied in this study. This was particularly true when treatments were imposed only up to PI stage and flooded thereafter. However, the lowest volume of water applied was recorded with the "saturate to dry" treatment imposed up to LB, suggesting that alternate wetting and drying could save a considerable volume of irrigation water. Results of many field experiments suggest that the total water input could decrease by 15-30 % without any significant impact on grain yield (Cabangon *et al.*, 2004; Belder *et al.*, 2004). Tabbal *et al.* (2002) reported that saturated soil culture reduces water input by 30-60 % compared with the conventional system with a yield reduction of 4-9 %. Even though the total voleme of water applied is greater during *yala*, the magnitude of difference between water saving irrigation treatment remained the same in the present study suggesting that, irrespective of the season, a significant volume of irrigation water could be saved if field is maintained at saturated or saturated to dry condition.

However, the dry condition in treatments of saturate to dry at both growth stages could create a hidden water stress, which may affect the growth and yield of rice. This was evident as there was a reduction in growth when field was subjected to dry situation (Figure 2).

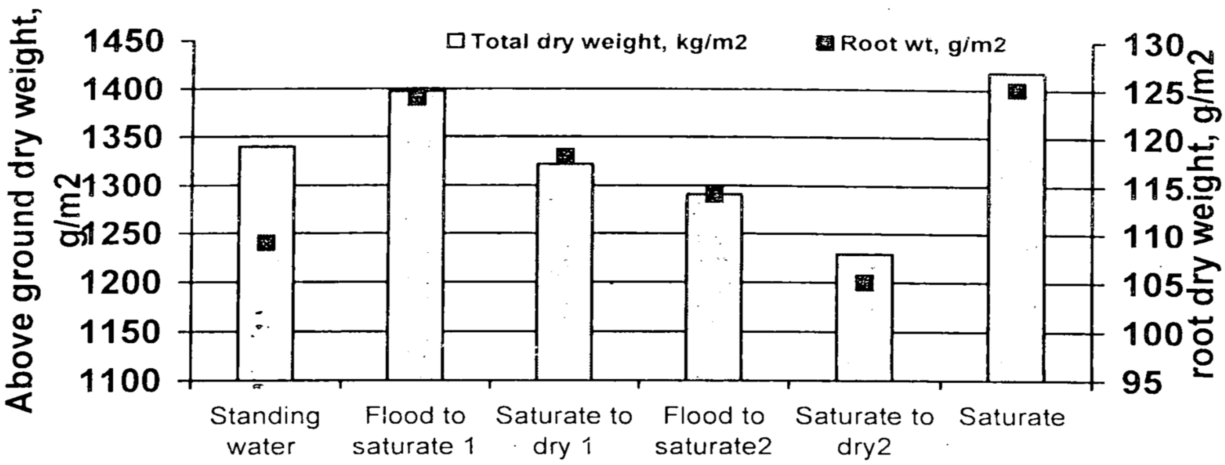

Figure 2. Change in total above ground dry weight and root dry weight (g/m^2) of rice grown under different irrigation regimes during 2003/2004 *maha* season.

Maintaining rice plants at saturated condition through the growing period significantly increased the total biomass and root dry weight of rice (Figure 2). In all the treatments where floodwater was maintained to a certain depth, there was a significant reduction in plant growth when compared with saturated soil culture. Further, the leaf greenness or SPAD value was 42.1$\pm$0.3 in the saturated treatment while it was 41.6$\pm$0.4 in the flooded treatment. The SPAD reading in all other treatments ranged between 36.9 and 40.4. Even though there was no leaf N stress when SPAD reading is around 40, the increased total biomass and leaf N status suggest that there was an increased uptake of N in the saturated soil culture than the flooded and flooded to dry systems. This could be due to the increased nitrate leaching losses with heavy irrigation regimes in coarse textured soils as reported by Aulakh and Singh (1997) and Singh and Sekhon (1976). The increased root dry weight under saturated condition suggests that the ability of rice plant to take up nutrients would have also increased with the saturated soil culture.

With the increase in nutrient uptake, there could be an increase in tillering due to adequate photosynthates produced for the developing tiller. Saturated conditions or no standing water also creates a favorable environment for tillering. The reason for the reduction in tiller number with flood irrigation could be due to the reduction in assimilates supply as well as suppression of tillering. Further, better individual plant status under the non-stressed conditions has contributed to increase the number of spikelet and number of filled grain per panicle than the stressed treatments (Table 2). There was no change in the seed weight as this character is mostly genetically controlled.

Table 2. Number of panicles per square meter, spikelet number per panicle, filled grain number per panicle, 1000 grain weight and Harvest Index (HI) in 2003/2004 *maha* season, grain yield (t/ha) of rice grown under different soil water regimes during 2003 *yala*, 2003/2004 *maha* and 2004 *yala* seasons

Treatment	*Panicle no/m²*	*Spikelet /panicle*	*Grain /panicle*	*1000 Grain wt. g*	*HI*	*Grain yield t/ha* 2003 *yala*	2003/04 *maha*	2004 *yala*
Standing water	493 b	68 a	57 a	22.5 a	0.50 a	4.74 a	5.77 a	5.29 a
Flood to saturate[a]	538 a	64 a	54 a	21.9 a	0.49 a	4.90 a	5.75 a	4.95 ab
Saturate to dry[a]	533 a	59 ab	50 b	22.6 a	0.48 a	4.19 b	5.08 b	4.65 b
Flood to saturate[b]	467 b	65 a	56 a	22.2 a	0.50 a	4.89 a	5.25 ab	5.03 ab
Saturate to dry[b]	527 a	58 b	51 b	21.5 a	0.49 a	4.04 b	4.28 c	4.56 b
Saturate	515 a	67 a	57 a	22.5 a	0.49 a	4.54 a	5.46 ab	5.46 a

Means followed by the same letter are not significant at p=0.05. The yield components reported are for the 2003/2004 *maha* season

There was a significant decrease in the grain yield with decrease in soil moisture in all seasons, suggesting that depleting soil moisture below saturation has a significantly negative impact on grain yield. In contrast researchers have observed no difference or increase 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 grain yield in alternate wetting and drying when compared with rice grown under standing water. The differences in grain yield in response to soil drying could be due to differences in the magnitude of soil moisture depletion in different experiments.

With the reduction in the volume of water used and increased grain yield in the saturated soil culture treatment, the irrigation water productivity has significantly increased than that of flooded rice culture (Table 3). Even though the irrigation water productivity in the saturate to dry treatment was not significantly different ($p>0.05$) to that of the saturated treatment, the average grain yield was significantly lower ($p<0.05$) in the saturate to dry condition. The irrigation water productivity was greater in the *maha* season when compared with the *yala* season. This is mainly due to that the grain yield was higher in *maha* season than the *yala* seasons while the volume of irrigation water applied decreased, as there was sufficient rain to keep the soil under saturation. Further, the duration of the crop grown in 2003/04 *maha* was also low, resulting in a decrease in water use during that season.

In general, maintaining saturated soil culture in lowland rice paddies could save a considerable volume of irrigation water while maintaining the same level or even greater grain yield. The saving of water with this condition could be a significant volume as the change in weather patterns could increase irrigation water required for flooded condition.

Table 3. Water productivity of rice grown under different soil water conditions during 2003 *yala* season 2003/2004 *maha* season

Treatment	*Irrigation Water productivity (g grain kg⁻¹ water)*	
	2003 *yala* *	2003/4 *maha* *
Standing water	1.077 abc	2.829 b
Flood to saturate[a]	0.933 bc	3.577 b
Saturate to dry[a]	1.507 a	10.590 a
Flood to saturate[b]	0.895 bc	3.090 b
Saturate to dry[b]	0.806 c	5.459 b
Saturate	1.455 a	12.650 a

* Mean followed by the same letter are not significantly different at p=0.05.

When planted at the correct time, rainwater could easily maintain the field at saturated condition, but additional water is required for maintaining a continuous water level. Further water saving specially during *maha* season could be used for the cultivation of additional area under rice or other crops during *yala* season in both dry and intermediate zone of Sri Lanka. Farmers can cultivate medium duration (3½ month) rice varieties in both *yala* and *maha* seasons instead of cultivating ultra short varieties, which has a lower yield potential.

CONCLUSIONS

Water is becoming a scarce resource especially for lowland rice cultivation. Therefore, a considerable volume of irrigation water applied to lowland rice culture in both *yala* and *maha* seasons must be reduced. Irrigation water productivity was the highest with saturated soil culture and saturate to dry soil culture. Drying of soil below saturation until cracks are formed would reduce yield. In the direct-seeded rice culture in Sri Lanka, maintaining saturated soil culture without imposing water stress to the rice plant could save about 24 % and 72 % irrigation water during *maha* and *yala* seasons, respectively, without affecting the final yield. This saved volume of water could be used to provide irrigation to additional extents of rice cultivation in the country.

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