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DEVELOPMENT OF EFFICIENT WATER MANAGEMENT STRATEGIES FOR RICE IN THE *YALA* SEASON ON NON CALCIC BROWN SOILS OF THE AMPARA DISTRICT OF SRI LANKA- A FIELD STUDY

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ABSTRACT

The principal objective of this study was to evaluate alternative water-saving irrigation regimes for rice cultivation in the yala season on Non-Calcic Brown soils in the Ampara district with a view of reducing total water input while ensuring minimum or zero yield reductions. The field experiments were conducted at Ampara during the yala seasons of 2006 and 2007. Seven water-saving irrigation treatments were imposed as following: Standing water (SW) throughout (T1); SW during vegetative (VEG) and reproductive (REP) stages and saturated soil conditions (SAT) during grain-filling, GF, (T2); SW during VEG followed by SAT during the rest (T3); SW during VEG followed by SAT during REP and allowing to dry down to crack formation (CF) during GF (T4); SAT throughout (T5); SAT during VEG and REP followed by CF during GF (T6) and SAT during VEG and CF during the rest (T7). The two yala seasons differed in their weather patterns, with 2006 being a typically dry yala season with very little mid-seasonal rainfall while 2007 being a relatively wet yala season with mid-seasonal rainfall during all three phenological stages of the crop. In 2006, vegetative growth of the rice crops, measured in terms of leaf area index (LAI) and total dry weight (TDW) decreased with decreasing water availability across the seven experimental treatments. In contrast, in 2007, the different treatments did not have significant effects on vegetative growth. In both seasons, water-saving irrigation regimes showed significant reductions in final grain yield ranging from 27 – 49% in 2006 and 18 – 68% in 2007. The lowest yield reduction was shown in T3 in 2006 and in T2 in 2007. Grain yields of all water-saving irrigation regimes and yield of the control treatment were greater in the typically dry yala season of 2006 as compared to the relatively wet 2007 yala season. This was primarily because of greater vegetative growth at the expense of reproductive growth in 2007. Similar to the grain yields, the respective water productivities (i.e. grain yield per unit of water input) were also greater in 2006 (1.027 – 1.458 g kg^{-1}) than in 2007 (0.508 – 1.192 g kg^{-1}). It is concluded that in order to achieve adequate grain yields in rice cultivation on NCB soils in the Ampara District while achieving significant reductions in water inputs and significant increases in WP, T3 can be recommended as the most suitable alternative water management strategy during a typically-dry yala season. On the other hand, T2 can be recommended as most suitable for a relatively wet yala season.

Keywords: Oryza sativa, dry zone, water scarcity, alternative water management strategies, water productivity.

1. INTRODUCTION

Rice is the staple food of the majority of people in Asia, the continent that is home to 60% of the world's population (Bouman and Toung, 2000). More than 90% of the world's rice is produced and consumed in Asia (IRRI, 1997, Barker and Herdt, 1985; Tabbal *et al*., 2002), which accounts for about 35-60% of calories consumed by 2.4 billion people in the Asia (FAO, 2013). About 79 million ha of irrigated lowland rice fields of the world provides 75% of the total rice production (Bouman *et al*., 2007).

Rice is the major food crop cultivated in Sri Lanka. Total gross extent of rice grown in the *yala* season of 2015 was 480, 662 ha and the average yield was 4527 kg ha^{-1}.Total production of *yala* of 2015 was 1 942,408 MT. In comparisons, the gross extent of rice grown, average yield and total production in *maha* 2015 were 772,626 ha, 4527 kg ha^{-1} and 2 876 787 MT respectively (Anon., 2016). This reveals the variation in extent, yield and production of rice in the two seasons. The main reason for the reduction of gross extent sown and production during the *yala* season is water scarcity or poor irrigation facilities.

Ampara, Anuradhapura, Polonnaruwa, Kurunegala and Hambanthota districts are the main rice producing districts in Sri Lanka. Paddy is the main seasonal crop cultivated in both *yala* and *maha* season in the Ampara district. According to the world food programme (WFP 2009), nearly 60,500ha of paddy lands are under major irrigation systems. About 2, 300ha and 7, 250ha of paddy lands under miner irrigation and rainfed systems respectively. During the *yala* period, parts of paddy lands are abandoned due to water insufficiency.

Typically, evapotranspiration rates of rice fields are 4-5mm d^{-1} in the wet season and 6-7mm d^{-1} in the dry season and it can be high as 10-11mm d^{-1} in sub tropical regions (Tabbal *et al*., 2002). It is estimated that 1432 L of water is used for evapotranspiration when producing 1kg of rough rice (Tabbal *et al*., 2002). Irrigated rice receives an estimated 34-43% of the entire world's irrigation water or 24-30% of the entire world's developed free water resources (IRRI, 2009).

Water is becoming a scare resource. Per capita availability of water sources declined by 40-60% in many Asian countries between 1955 and 1990 (Gleick, 1993). In 2025, per capita availability of water resources in these countries are expected to declined by 15-54% compared with 1990 (Guerra *et al*., 1998). Therefore, it is very important to look at alternative water saving techniques for successful rice cultivation. Although rice grown under traditional practices in the Asian tropics and sub-tropics require 700 mm and 1800mm of water per cropping season, the actual amount of water utilized by the farmer are higher than the above requirement.

Ampara district of Sri Lanka, belongs to the low country dry zone and DL2b agro ecological region. Mean temperature of this region is 30^{0}C and annual rainfall is 900mm (Anon., 2006). Reddish Brown Earths (RBE), Low Humic Gley (LHG), Non-Calcic Brown (NCB), Immature Brown Loam (IBL) and Alluvial soils are the predominant soil types in the region. During the *maha* season all soils can be used for rice cultivation. However, during the *yala* season, all these soils require supplementary irrigation for rice production.

Gross extent of rice grown in Ampara district during *yala* season in 2015 was 83 133 ha and total production was 307 661 MT. During the *maha* season, gross extent sown and production were 65 973 ha and 309 335 MT respectively (Anon., 2016). However, during the *yala* season, production is lower than during the *maha* season due to water scarcity. The main irrigation tank "Senanayaka Samudraya" supplies irrigation water for the farmers of the surrounding area but it is not adequate during *yala* due to frequent and prolong drought period. Hence, farmers are generally reluctant to grow rice during *yala* season. Therefore, it is essential to develop methods for growing paddy in this environment in the *yala* season with minimum inputs of water using alternate water-saving irrigation techniques. The primary objective of this study was to investigate alternative water management strategies for rice cultivation in the *yala* season on Non-Calcic Brown soils in the Ampara district with a view of reducing total water input while incurring a minimum yield reduction so that water productivity is increased.

The specific objectives were:

- To determine the impact of different combinations of water-saving irrigation regimes at different phenological stages of the crop for different durations on growth and yield of the rice crop.
- To determine the water input and water productivity (yield per unit of water used) of rice under different water-saving irrigation regimes.
- To identify the stages of the rice crop during which water input could be reduced without a significant adverse impact on yield.

2. MATERIALS AND METHOD

2.1 Experimental Site

The study was conducted at the Agricultural Farm of the Hardy Advanced Technological Institute, Ampara located in the Low Country Dry Zone (DL2b) of Sri Lanka during the *yala* season of year

2005. The Latitude and longitude are 7^0 16' 37.56'' North and 81^0 39' 17.66'' East respectively. The elevation of the location is 35 m above mean sea level. A flat terrain was used for the experiment.

The soil type of the experimental site was Non-Calcic Brown Soil which was shallow to moderately deep and moderately well drained (Panabokke, 1967). Climate of this region is characterized by a mean annual temperature of 27.45^0C rainfall of 1458.4 mm yr^{-1} 76% of relative humidity and 7.7 of sun shine hours (Source: Department of Meteorology, 2010 based on climatic data over ten years period).

2.2 Planting Material

The variety Bg 300 was used for the experiment as it is a short duration rice variety suitable for the *yala* season of the dry zone and gives an average yield of 5-6 MT ha^{-1} (Anonymous, 1995).

2.3 Treatments and Eexperimental Design

A total of six alternative water management strategies plus a control treatment in the form of seven irrigation treatments were tested. Life cycle of the rice plant was divided into three different phenological stages and different water-saving irrigation techniques were applied at different phenological stages. Brief descriptions of the treatments are given below:

Treatment 1 (T1): Continuous standing water (at 5 cm height) up to two weeks before harvesting (Control treatment)

Treatment 2 (T2): Continuous standing water (5cm height) supplied until heading and subsequently keeping the field under saturated conditions without standing water until two weeks before harvesting

Treatment 3 (T3): Standing water (5cm height) supplied up to panicle initiation and subsequently keeping the field under saturated conditions until two weeks before harvesting

Treatment 4 (T4): Standing water (5cm height) supplied up to panicle initiation and subsequently keeping the field under saturated conditions up to heading followed by allowing the field to dry up to crack formation until two weeks before harvesting

Treatment 5 (T5): Field maintained continuously under saturated conditions up to two weeks before harvesting

Treatment 6 (T6): Field maintained under saturated conditions up to heading followed by allowing the field to dry up to crack formation until two weeks before harvesting

Treatment 7 (T7): Field maintained under saturated conditions up to panicle initiation followed by allowing the field to dry up to crack formation until two weeks before harvesting

2.4 Crop Establishment and Maintenance

Land was ploughed to a depth of approximately 25 cm using a disk plough. The field was kept submerged for a week to loosen the soil and subsequently harrowed. After harrowing, the plots were separated with 1 m bunds constructed around the plots to the size of 5 m x 5 m. Fine leveling was done within the plots one week after harrowing. Basal fertilizer was incorporated at the rate of 12.5 kg ha^{-1} urea, 62.5 kg ha^{-1} triple super phosphate (TSP) and 37.5 kg ha^{-1} muriate of potash (MOP) one day prior to broadcasting according to the recommendations of the Department of Agriculture, 2005. Pre germinated seeds of the short duration variety of Bg 300 were broadcasted to plots at the rate of 80-100 kg ha^{-1}. The first top dressing was applied at the rate of 75 kg ha^{-1} Urea two weeks after broadcasting of seeds. The second top dressing was applied at the rate of 50 kg ha^{-1} Urea five weeks after broadcasting. The third top dressings were applied at the rate of 87.5 kg ha-^{1} Urea and 37.5 kg ha^{-1} MOP six weeks after broadcasting. Manual weeding was carried out to control weeds whenever weeds were present. Recommended pesticides were applied to control pests. The different experimental treatments were imposed after crop establishment.

2.5 Measurements

In each plot, a 1 m^2 area was randomly selected and demarcated for yield measurements. Numbers of hills per unit land area (1 m^2) were counted within the above sampling area three weeks after sowing. Two hills per plot outside the sampling area were used for growth measurements such as number of tillers per hill, number of leaves per hill, area per leaf, number of panicles per hill, number of grains per panicle. Oven dry weights of leaf, culm, root and panicle were measured using an electric oven by maintaining 60^0C temperature until it reach to a constant weight at two week intervals.

Randomly selected two hills within the sampling area were used to measure, number of panicles per hill, number of grains per panicle, number of filled grains per panicle, total grain weight, dry weight of the panicle and grain, mean individual grain weight. All plants from a $1m^2$ of sampling area in each plot were harvested at maturity for the determination of number of hills per m^2 ,number of panicles per m^2, grain yield per m^2 (at 14% moisture content).

2.6 Water Input

Plots were irrigated according to the respective treatments from the adjacent water canal. Each plot was irrigated separately. During each irrigation event, flow rate and the time period required to irrigate the plot were measured. After a heavy rain, when the water level exceeded the required level of the treatment, water was drained out to maintain the desired water level according to the treatment. Total input of water for each treatment was calculated as the sum of irrigated water and rainfall from broadcasting to harvesting. The volume of water applied during an irrigation event was computed by multiplying flow rate by time.

2.7 Meteorological Data

Meteorological data such as daily rainfall, minimum and maximum temperature, minimum and maximum relative humidity were recorded daily at the experimental site.

2.8 Data Analysis

The statistical package SAS (SAS Institute, Cary, USA) was used for data analysis. Significance of the treatments was tested by Analysis of Variance. To evaluate the significance between treatment means, mean separation was performed with Least Significant Difference (LSD) test at 0.05 probability level. Pearson's Correlation Analysis was used to estimate the strength of the relationships between yield, growth and water use parameters.

3 RESULTS

3.1 Meteorological Parameters

Comparison of the rainfall regimes in *yala* 2007 and 2006 (Table 1) shows that there were more rain days in 2007 (i.e. 24 days in comparison to 6 days in 2006). This was especially during reproductive (i.e. from panicle initiation to heading) and grain-filling stages, which were completely, rain-free in 2006. Furthermore, there was more rain even during the vegetative stage (i.e. from sowing to panicle initiation) in 2007 (53.1 mm in comparison to 0 mm in 2006). According to the data base of Department of meteorology (2013), the probability of getting the *yala* rainfall of 2006 is less than 5%. Therefore, 2006 was a dry *yala* season. The probability of getting the *yala* rainfall of 2007 is more than 50%. Therefore, 2007 was a relatively wet *yala* season.

***Table 1:** Comparison of the rainfall regimes in yala 2007 and 2006.*

	yala 2006		*yala* 2007	
Growth stage	Total rainfall (mm) in 2006	No. of rain days	Total rainfall (mm) in 2007	No. of rain days
Pre - planting	31.8	5	30.9	3
Vegetative	0	0	53.1	5
Reproductive	0	0	34.1	5
Grain filling	18.2	1	95.0	11

A comparison of the temperature regimes of the two *yala* seasons (Table 2) shows that 2007 was a much cooler year than 2006 as the average temperature over the growing period was 2^0C lower than that of 2006.

Table 2: *Comparison of the average temperature regimes in yala 2007 and yala 2006.*

	yala 2006		*yala* 2007	
Growth stage	Average Temperature (^{0}C) in 2006	Standard Error (SE)	Average Temperature (^{0}C) in 2007	Standard Error (SE)
Vegetative	30	± 0.96	28	± 0.16
Reproductive	31	±0.17	29	±0.23
Grain filling	31	±0.15	28	±0.18

A comparison of the RH regimes of the two *yala* seasons shows that 2007 was a more humid (i.e. higher RH) season than 2006 (Table 3).

Table 3: *Comparison of the average RH regime in yala 2007 with that of yala 2006.*

	yala 2006		*yala* 2007	
Growth stage	Average RH (%) in 2006	Standard Error (SE)	Average RH (%) in 2007	Standard Error (SE)
Vegetative	68	± 0.72	78	± 0.98
Reproductive	68	±1.75	83	±0.61
Grain filling	66	±0.73	81	±1.50

3.2 Growth Analysis

3.2.1 Leaf area index (LAI)

Significant ($P<0.05$) differences in LAI between treatments were observed at all stages of *yala* 2006 (Figure 1) except at the vegetative stage of rice plants (3 WAS). The seasonal variation patterns of LAI of *yala* 2006 were similar in the majority of treatments. There was a gradual increase up to a maximum LAI at grain filling stage (11 WAS), followed by steep or gradual decreases towards the harvesting stage (13 WAS). Except in T1, T3 and T6, all other treatments showed increases in LAI from 3 to 5 WAS. At 5 WAS, the highest LAI was achieved by T2 while the lowest was achieved by T6. From the 5 WAS onwards, the seven experimental treatments showed a clear separation in to three groups (Figure 1-a). The first group consisted of T1 and T2, which received higher levels of water, had significantly greater LAI than the rest. This was followed by T3, which also had a higher water input, had significantly greater LAI than the third group which contained T4, T5, T6 and T7. This last group contained the treatments which

received lower levels of irrigation water. Plants in all treatments except T7 showed reductions in LAI during the final period from the 11 to 13 WAS. At 13 WAS, T2 had decreased its LAI to be closer to T3 than to T1.

During the *yala* 2007, Significant ($P<0.0001$) differences in LAI between different water treatments were observed (figure 1-b) in the reproductive phase (7 WAS). Initially LAI increased sharply up to the fifth week after sowing. Thereafter, treatments which received standing water showed sharp increases in LAI towards the reproductive phase (7 WAS) and the plants grown under saturated soil conditions except in T3 showed sharp reduction in LAI. A gradual increase in LAI was observed in T3. At the reproductive phase (7 WAS), plants in T2 and T1 developed significantly higher LAI compared to those in T7 which was exposed to crack formation during that period. Plants in all treatments except in T2 reached their highest LAI at 9 WAS. All treatments showed LAI reductions from 11 to 13 WAS. T2, which also had a higher LAI at 11 WAS was able to maintain it at 13 WAS with only a slight reduction and had the highest LAI at the harvesting stage at 13 WAS.

A comparison of the respective time courses of LAI between the two seasons (Figure 1) showed that the treatment differences were greater in 2006 than in 2007. However, the maximum LAI achieved by the well-watered T1 treatment was similar in both seasons. Furthermore, the water-stressed treatments such as T7 also achieved greater LAI in 2007 than in 2006, primarily because of the greater rainfall in 2007.

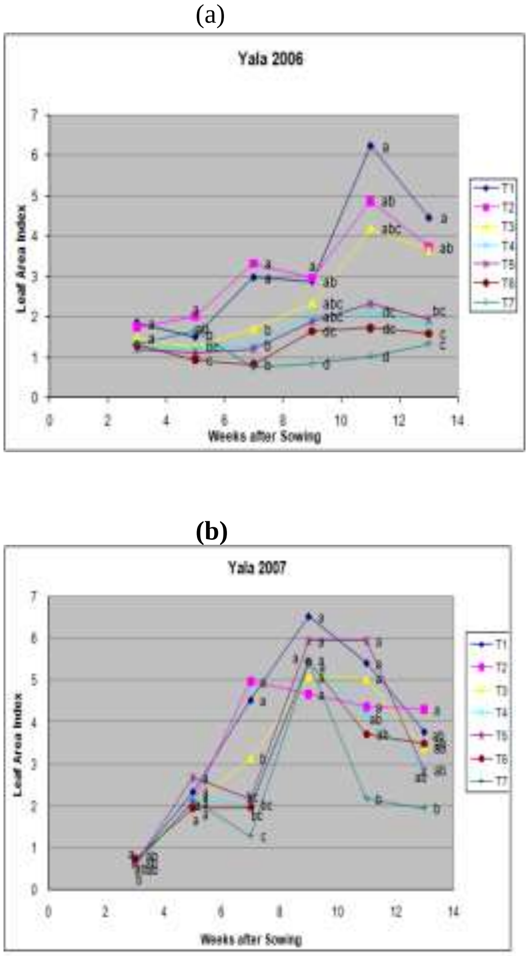

Figure 1: *Differences in leaf area index of rice plants subjected to different irrigation treatments in yala (a) 2006 and (b) 2007. Within each week means with same letters are not significantly different at P< 0.05.*

3.2.2 Total dry weight (TDW)

Significant differences (P< 0.05) in TDW were observed between treatments in 5, 9 and 11 WAS in *yala* 2006 (Figure 2-a). The highest TDW values were observed in T1 and T2 treatments which experienced the least water stress at 5 WAS and it was significantly different to T7. From 7 WAS onwards, plants in T1 and T2 had significantly greater TDW than the rest of the treatments (Figure 2-a). Among the rest, plants in T3 showed a significantly higher TDW from 9 WAS onwards.

By the 9 WAS, T1, T2 and T7 showed reductions in dry matter whereas the other treatments did not show such reductions. By the 11 WAS, there were two clear groups of treatments that could be identified based on TDW. The first group included T1 and T2 which were exposed to the least water stress and achieved the highest TDW towards the final harvest. These treatments showed increased TDW at the latter stages of season. The second group which had a lower final TDW, included treatments exposed to water stress conditions during more than one growth stage (T3-T7). The lowest TDW was recorded in T7 which was exposed to severe water stress throughout the season. T5 treatment which received the continuous saturated condition also showed lower TDW in comparison to all other treatments except T7.

Seasonal pattern of total dry matter accumulation of rice plants (figure 2-b) as affected by the different water treatments was similar in *yala* 2007, with a definite upward trend at the harvesting stage (13 WAS). At the latter stage of the vegetative phase (5 WAS), plants in T5 and T1 showed significantly higher TDW compared to those in T3. From 5 WAS onwards, TDW of T1, T2 and T3 showed continuous increases until harvesting. At 13 WAS, T1 showed the highest TDW followed by T2, in which the TDW was 9% lower. This was followed by T5 and T3, in which TDWs were, on average, 16% lower than in T1. T4, T6 and T7 formed the treatment group which had the lowest TDW at harvest, with an average reduction of 22% in comparison to the control.

Comparison of time courses of TDW between the two seasons (Figure 2) showed that the different water treatments were clearly separated in 2006, while they were more close together in 2007. This was primarily because of the differences in the rainfall regime of the two seasons. The very low rainfall received during *yala* 2006 enabled clear expression of the effects of different water regimes on dry matter production of the rice crop. In contrast, the higher and well-distributed rainfall regime of *yala* 2007 did not allow the development of water deficits to the same extent as in 2006, thus preventing the complete expression of the effects of the different water regimes. Furthermore, because of the higher rainfall in *yala* 2007, all treatments in 2007 (Figures 2-b) had greater TDW than their corresponding treatments in 2006 (Figures 2-a).

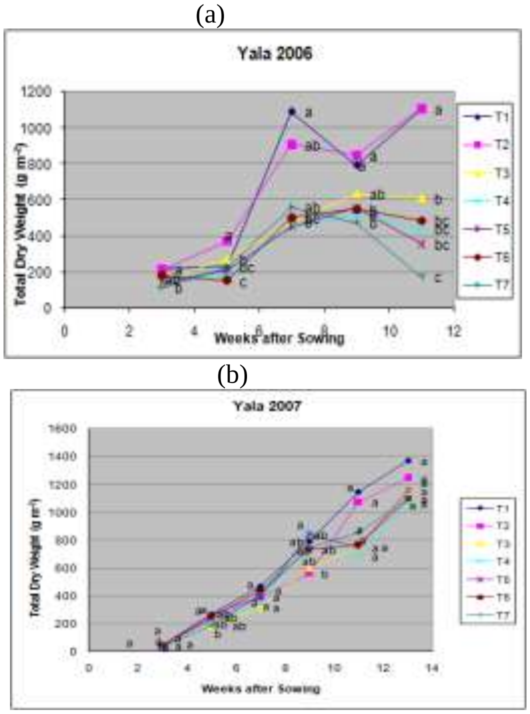

Figure 2: Variation in total dry weights of rice plants grown under different irrigation treatments in yala (a) 2006 and (b) 2007. Within each week means with same letters are not significantly different at P< 0.05.

3.3 Harvest Indices (HI) Yala 2006 and 2007

HI based on panicle dry weights, i.e. HI (panicle), did not show significant variation between different water regimes in *yala* 2006 (Table 4). Whereas the highest HI (panicle) of *yala* 2007 was noted in T1, T2, T4 and T5 treatments, which were significantly greater than T7.

***Table 4:** Harvest indices at the final harvest of rice under different water-saving irrigation treatments in yala 2006 and 2007*

Treatments	HI (Panicle)-2006	HI (Panicle)-2007
T1	0.473 a	0.516 a
T2	0.484 a	0.490 a
T3	0.415 a	0.453 ab
T4	0.489 a	0.477 a
T5	0.444 a	0.467 a
T6	o.444 a	0.429 ab
T7	0.407 a	0.358 b
CV (%)	15.1	14.9

Within each column, means with same letters are not significantly different at p=0.05 HI (Panicle) - Harvest index based on panicle dry weights

3.4 Yield and Yield Components

Grain yield 0f *yala* 2006 and 2007 varied significantly (p<0.0001) between different water saving irrigation regimes (Table 5 and 6). The plants in the control treatment (T1) of both seasons which received continuous standing water throughout the growing period achieved a significant higher yield compared to other treatments. In *yala* 2006 the second highest yield was obtained by the T3 treatment, which showed a 27% yield reduction in comparison to T1. T1 and T3 were followed by T2, which was in turn followed by treatments T4 and T5. T6 and T7 treatments which dried up to crack formation showed the lowest yields.

In *yala* 2007 the second highest yield was recorded in T2 which was exposed to least water stress. The treatments which had standing water during vegetative period followed by saturated condition at least up to heading stage (T3 and T4) showed significantly higher grain yield in contrast to the treatments which had not been exposed to standing water at least for one growth stage (T5, T6 and T7) during *yala* 2007.

Grains per panicle varied significantly in *yala* 2006 (p<0.01) between treatments (Table 5). The highest number of grains per panicle was recorded in T1, the control treatment. This was followed by the treatments T2, T3 and T4 which experienced saturated conditions at least for one growth stage. The treatments T5, T6 and T7 which received saturated water conditions at the vegetative stage formed the group that showed the next lower number of grains per panicle. Within this last group also, T7 showed the lowest number of grains per panicle. Percentage of filled grains and number of panicles per m^2 did not show significant variation between treatments at p= 0.05 level during the *yala* 2006. Mean individual grain weight (MIGW) of the treatments showed significant variation at p=0.05 level. The treatments which were exposed to least water stress situations (T1 to T3) had given the highest MIGW. It was significantly different to T4 and T7 treatments.

There were significant ($p<0.05$) treatment differences in all yield components except the mean individual grain weight during *yala* 2007 (Table 6). The highest number of panicles m^{-2} was achieved by plants in T1 and T2 which were exposed to least water stress conditions respectively. The highest number of grains per panicle was in plants in T1 and it was significantly greater than those of plants in T6 and T7 which were exposed to severe water stress. However, plants in T6 and T7 did not show significant differences in grains per panicle. The highest percentage of filled grains was achieved by plants in T1 and the least was recorded in T7.

A comparison of the two seasons showed that the yields and yield components were higher in 2006 (Table 5) than in 2007 in all water treatments

Table 5: *Variation of yield and yield components of rice under different water-saving irrigation regimes in yala 2006.*

Treatments	Yield (gm^{-2}) (% yield reduction)*	No. Panicles m^{-2}	Grains/panicle	% of filled grain	MIGW (g)
T1	941 a	499 a	93 a	84.3 a	0.026 a
T2	593 bc (37%)	351 b	77 abc	86.7 a	0.026 a
T3	688 b (27%)	491 a	83 ab	85.1 a	0.026 a
T4	561 c (40%)	449 ab	68 abc	78.5 ab	0.023 c
T5	565 bc (40%)	458 a	60 bc	78.8 ab	0.025 abc
T6	481 c (49%)	502 a	57 dc	75.8 ab	0.025 abc
T7	528 c (44%)	407 ab	32 dc	68.4 b	0.023 bc
CV (%)	13.6	15.8	25.1	13.0	7.3

Within each column, means with same letters are not significantly different at p=0.05. *Calculated relative to the control (T1) treatment. MIGW - Mean individual grain weight.

Table 6: *Variation of yield and yield components of rice under different irrigation regimes in yala 2007.*

Treatments	Yield (g m^{-2}) (% yield reduction)*	No. Panicles per m^{2}	Grains per panicle	% of filled grain	MIGW (g)
T1	664 a	341 a	101 a	77.2 a	0.025 a
T2	546 b (18%)	356 a	69 bc	59.5 ab	0.022 a
T3	349 c (47%)	279 ab	88 ab	56.0 abc	0.022 a
T4	300 c (55%)	300 ab	54 cd	50.5 bc	0.022 a
T5	209 d (69%)	197 b	59 cd	58.5 bc	0.025 a
T6	213 d (68%)	296 ab	44 d	42.2 bc	0.020 a
T7	217 d (67%)	270 ab	43 d	37.2 c	0.020 a
CV (%)	14.8	30.1	20.5	26.9	20.5

Within each column means with same letters are not significantly different at P< 0.05. *Calculated relative to the control (T1) treatment. MIGW-Mean individual grain weight.

3.5 Water Productivity (WP)

There was significant ($p<0.05$and $P<0.0001$respectively) variation in WP between the different water regimes in *yala* 2006 and 2007(Table 7). Interestingly in *yala* 2006, the highest WP (i.e. 1.458 g kg^{-1}) was observed in T7, which had the lowest water input and the second lowest grain yield. In contrast, T1, which required the highest water input and had the highest yield, had a WP of 1.362 g kg^{-1}. On the other hand, the lowest WP was observed in T2, in which the yield reduction was proportionately greater than the reduction in water input. In comparison to T2, WP of T7 was substantially greater because the proportional yield reduction was much less than the proportional reduction in water input. Treatments T3, T5 and T6 which were maintained under saturated conditions during Stage II (i.e. from panicle initiation up to heading) also had comparatively higher WP levels ranging from 1.263 to 1.355 g kg^{-1}. On the other hand, the WP of T4, which was also maintained under saturated conditions during Stage II, was lower (i.e. 1.155 g kg^{-1}) than those of T3, T5 and T6. This was because of the greater water input of T4 for the maintenance of standing water during Stage I. Further, T7 achieved 22% higher WP compared to T4 without significantly reducing the yield.

However, in *yala* 2007 highest grain yield and WP were observed in T1, which was significantly greater than T2, which in turn had a significantly greater WP than the rest. All the treatments which were exposed to water stress condition from panicle initiation to end of the season in *yala* 2007 (i.e. T3 to T7) had lower WP than the treatments receiving standing water at least up to the heading stage (i.e. T1 and T2). The total water input and grain yield of T2 were significantly lower than in T1. In T2, yield reduction was greater than the reduction of water input thus reducing its WP significantly lower than that of T1. The WP of other treatments (i.e. T3 – T7) did not show significant variation with the WPs of all of them being within the range of 0.508 – 0.651 g kg^{-1}. In these treatments, proportional reductions in grain yield were greater than the proportional reductions in total water use thus causing significant reductions in WP relative to the control. However, total water input of those treatments (i.e. T3-T7) showed significant variations between treatments. Furthermore, the grain yield of T3 and T4 were significantly higher than in T5 to T7. In contrast, T3 had comparatively higher water input than T4.

Table 7: Grain yield and water productivity of the different water regimes in *yala* 2006 and 2007

Treatment	*Yala* 2006		*Yala* 2007	
	Grain yield (g m^{-2})	Water Productivity (g kg^{-1})	Grain yield (g m^{-2})	Water Productivity (g kg^{-1})
T1	941 a	1.362 ab	664 a	1.192 a
T2	593 bc	1.027 c	546 b	0.996 b
T3	688 b	1.355 ab	349 c	0.651 c
T4	561 c	1.155 bc	300 c	0.584 c
T5	565 bc	1.313 abc	209 d	0.508 c
T6	481 c	1.263 abc	213 d	0.546 c
T7	528 c	1.458 a	217 d	0.565 c
CV (%)	13.6	15.5	14.9	15.9

Within each column, means with same letters are not significant at p=0.05.

4.

DISCUSSION

Response of rice crop growth to alternative water management strategies

Rresults of both field experiments showed that reduction of water input reduced leaf area growth in comparison to the control treatment (i.e. T1 with continuous standing water). In 2006, which did not receive any rainfall during the vegetative and reproductive stages (Table 1), the reductions in leaf area index increased with decreasing water input across the treatments. However, it is interesting to note that the T2 treatment which had a 17% lower total water input than the control (Table 7), showed the same level of total biomass accumulation as the control (Figure 2), despite a 22% reduction in maximum LAI (Figure 1). This shows that even during a typically dry *yala* season in the dry zone, there is scope for reducing water input during the grain-filling stage without adversely affecting the biomass accumulation of the rice crop. This reduction in water input can be achieved by maintaining saturated soil conditions during the grain-filling stage (i.e. T2) instead of standing water (i.e. T1). Growth performance of plants in T3, which showed intermediate LAI and TDW levels (Figures 1 and 2), indicate that extending the duration of saturation culture to the reproductive stage adversely affected both leaf area growth and biomass accumulation of the crop in a typically dry *yala* season. Similarly, results of *yala* 2006 showed that maintaining saturated conditions throughout the life cycle (i.e. T5) and allowing the soil to dry down to crack formation (i.e. T4, T6 and T7) causes significant reductions in crop growth.

Results of *yala* 2007 showed that there is greater scope for reducing water input without adverse effects on crop growth in *yala* seasons with intermittent mid-seasonal rainfall. In such a season, maintaining saturated soil conditions throughout the season (i.e. T5) not only enabled a maximum LAI level which was closer to that of T1 (Figure 1) but also maintained it for a longer duration than T1. Furthermore, treatments which were allowed to dry up to crack formation during the grain-filling stage (i.e. T4 and T6) were also able to maintain a higher LAI than T1 at harvest. It could be noted that all treatments could develop a maximum LAI exceeding 5 in a season with intermittent mid-seasonal rainfall (i.e. 2007 *yala*). This was in contrast to the typically dry *yala* season (i.e. 2006), in which none of the alternative water management treatments achieved a maximum LAI of 5, with only T2 and T3 achieving maximum LAI values above 2 (Figure 1).

In a season with intermittent mid-seasonal rainfall such as in 2007, all alternative water management treatments achieved final total dry weights greater than 1000 g m^{-2} (Figure 2). In contrast, only T2 achieved a final TDW greater than 1000 g m^{-2} in the typically dry *yala* season such as 2006, with the final TDWs the rest of the alternative water management treatments being less than 600 g m^{-2} (Figure 2). Therefore, in terms of crop growth, water-saving irrigation strategies have a greater scope in *yala* seasons with intermittent mid-seasonal rainfall to achieve adequate LAI and TDW levels which are either on par or less than 25% lower in comparison to the control treatment.

Response of rice yields and yield components to alternative water management strategies

Grain yields of all water-saving irrigation regimes as well as the yield of the control treatment were greater in the typically dry *yala* season of 2006 as compared to the relatively wet 2007 *yala* season (Tables 5 and 6). Eventhough there was scope for reducing water input during the grain-filling stage without significantly reducing the TDW at harvest, all the water-saving irrigation regimes caused significant yield reductions in comparison to the control.

In 2006, T3, in which both the reproductive and grain-filling stages were kept in saturated soil conditions instead of standing water, showed the lowest yield reduction (i.e. 27%). T3 was followed by T2 (i.e. 37% yield reduction), where only the grain-filling stage was kept in saturated soil conditions. In 2007 also, T2 and T3 were the treatments that showed the lowest yield reductions. However, the order was reversed with T2 showing a lower yield reduction (18%) in comparison to T3 (47%).

Results of the present experiment agreed with the findings of Humphreys *et al*., (2004) who also reported that grain yield decreased when soil water content was below saturation. In agreement with the present study, Yadav *et al*., (2011) also showed that drought stress during more sensitive stages such as panicle initiation and flowering reduced grain yield.

When the results of both seasons of field experiments are taken in to account, both T2 and T3 can be recommended as the two water-saving irrigation regimes which cause the minimum yield reduction when water input is reduced from the maximum that is required for maintaining continuous standing water. The lower grain yields of 2007 were caused primarily by the lower numbers of panicles m^{-2}, lower percentage of filled grain and lower mean individual grain weights (Tables 5 and 6). Therefore, it is clear that the greater overall growth in terms of TDW in 2007 (Figures 2-b) occurred at the expense of reproductive growth.

Influence of alternative water management strategies on the water productivity (WP) of rice plants

Increasing rice crop WP is one way of producing more rice with less water (Zwart and Bastiaanssen, 2004). Zwart and Bastiaanssen, (2004) found that a rice crop WP ranged from 0.6 – 1.6 g kg^{-1}. The range of water productivities in the two seasons of field experimentation of the present study was 0.508 – 1.458 g kg^{-1} which was very close to the range observed by Zwart and Bastiaanssen, (2004). However, the greater WP of 2007 was brought about primarily by the significantly lower grain yields of treatments T4 – T7 in comparison to treatments T1 – T2.

In terms of water productivity, T2 had a stable WP with 1.03 and 1.00 g kg^{-1} in both seasons (Tables 7). In contrast, T3 had a high WP in 2006 (i.e. 1.36 g kg^{-1}), which was on par with that of the control. However, in 2007, T3 had a much lower WP (i.e. 0.65 g kg^{-1}), which was significantly lower than those of both the control and T2. Hence, in a typically dry *yala* season such as 2006, T3 could be recommended to farmers instead of T2, because of two reasons, namely: (a) It has a lower water input than T2 and in a dry season, the treatment with the lower water input should be preferred to an alternative which has a higher water input; (b) T3 has a higher grain yield and WP than T2 in a typically dry *yala* season. On the other hand, in a relatively wet *yala* season with intermittent mid-seasonal rainfall, T2 could be recommended ahead of T3 because: (a) It has a higher grain yield and WP; (b) The additional water input is unlikely to be a constraint because of the mid-seasonal rainfall.

It is notable that in 2006, the rest of the water-saving irrigation regimes (i.e. T4 – T7) also had comparatively lower yield reductions (40 – 49%) (Table 5) than the corresponding treatments in 2007 (55 – 69%) (Table 6). In particular, T4 and T5 treatments, which had significantly lower water inputs than T1 – T3 had proportionately lower yield reductions in comparison to T2. Accordingly, both T4 and T5 had greater WPs than T2. Therefore, in a typically dry *yala* season such as 2006, water-saving irrigation regimes such as T4 and T5 can also be recommended because of their lower water inputs and greater WPs. However, in a relatively wet *yala* season such as 2007, T4 and T5 cannot be recommended because of their greater yield reductions (i.e. 55% and 69% respectively) in comparison to the control.

There is no single yield-determining yield component in the rice crops grown during *yala* in Ampara district (and most likely in the dry zone). The yield-determining yield component could vary with the seasonal variation of water availability during a given individual season. For example, in the typically dry *yala* season of 2006, the number of grains per panicle, which is determined during the reproductive phase of the rice plant (i.e. between panicle initiation and heading), has been the yield component that has been most responsible for the observed yield variation between different water-saving irrigation regimes. This implies that in a typically dry *yala* season, ensuring adequate water availability during the reproductive phase is most critical in designing water-saving irrigation regimes. However, during the relatively wet *yala* season of 2007, the number of grains per panicle did not have a significant correlation with yield, thus indicating that adequate water availability during the reproductive phase was not the primary factor responsible for the observed yield variation between different treatments. Instead, it has been the water available during the vegetative and grain-filling phases that has been responsible for the observed yield variation in 2007.

5. CONCLUSIONS

1. There is scope for reducing the water input with a minimum (i.e. 18% - 27%) reduction in yield in rice cultivation on Non-Calcic Brown soils of the Ampara District of Sri Lanka during the *yala* season by adopting alternative water management strategies. However, the most suitable water-saving irrigation regime will depend on season-specific factors such as the amount of mid-seasonal rainfall received and the consequent balance between vegetative and reproductive growth.

2. In order to achieve maximum vegetative growth in terms of leaf area index (LAI) and total dry weight (TDW) during a typically dry *yala* season reduction in water input is only possible during the grain-filling stage by maintaining saturated soil conditions and in a relatively wet *yala* significant reductions in water input are possible without reductions in LAI and TDW by maintaining saturated soil conditions instead of standing water during the vegetative and reproductive stages.

3. All water-saving irrigation regimes cause yield reductions in rice in the *yala* season under the conditions of the present experiments (i.e. NCB soils in Ampara District). While ensuring minimum yield reductions, it is only possible to reduce the water inputs during the reproductive and grain-filling stages from standing water to saturated soil conditions, irrespective of the amount of mid-seasonal rainfall. In a typically-dry *yala* season, both the reproductive and grain-filling stages can be maintained under saturated soil conditions instead of standing water. In a relatively wet *yala* season, the reproductive stage can be maintained with standing water using the additional mid-seasonal rainfall, while maintaining saturated conditions instead of standing water during the grain-filling stage. However, additional vegetative growth in a relatively wet *yala* season occurs at the expense of reproductive growth, thus reducing the grain yield in spite of greater water inputs.

4. There is scope for increasing water productivity (WP) in rice cultivation on NCB soils in the Ampara District up to an upper limit of around 1.46 g kg^{-1} by reducing water input through water-saving irrigation regimes.

5. Yield analysis indicated that rice yields in the *yala* season of Ampara District are source-limited. Initiating a larger sink size as indicated by the number of grains per panicle could have a negative impact on grain-filling in a relatively wet *yala* season where assimilates could be diverted to promote vegetative growth at the expense of reproductive growth. This does not happen in a typically dry *yala* season and consequently initiating a larger sink size does not have an adverse impact on grain-filling.

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