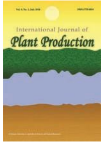

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Standardization of alternate wetting and drying (AWD) method of water management in low land rice (*Oryza sativa* (L.))

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Abstract

Alternate wettting and drying (AWD) systems save water compared with continuous submergence (CS) irrigation. However, the reported effect on yield varies widely and detailed characterizations of the hydrological conditions of AWD experiments are often lacking so that generalizations are difficult to make. We compared the effects of AWD and CS on crop and water productivity in rice in the field experimentations in India. The experiment was conducted in irrigated lowlands and followed AWD practices by using field water tube. Crop and water productivity was significantly differed between AWD and CS of irrigation. The average grain yield was 5.8–7.4 t ha^{-1} with AWD irrigation methods and 7.5–7.6 t ha^{-1} with CS. The pooled values of irrigation water applied, effective rainfall and seasonal volume of water input varied from 1390, 216 and 1646 mm, respectively under CS and 708 to 1142 mm, 238 to 300 mm and 1048 to 1420 mm, respectively under AWD irrigation regimes. Irrigation water applied in AWD irrigation regimes amounted to 50.9 to 82.1% of CS (1390 mm), averaged over two seasons, the crop in different AWD irrigation regimes used water 63.6 to 86.2% of the CS (1646 mm) suggesting that the AWD practice enabled water saving of 13.8 to 36.4% in different treatments. Therefore, in view of considerable water saving (26.6 to 35.0%) and higher water productivity the AWD method of water management is the best practice to meet the cope of water scarcity in lowland rice production.

Keywords: Alternate wetting and drying; Lowland rice; Field water tube.

Introduction

Reducing water input in rice production can have a high societal and environmental impact if the water saved can be diverted to areas where water availability is limited. A reduction of 10 per cent in water used in irrigated rice would free 150,000 million m^3, corresponding to about 25 per cent of the total fresh water used globally for non-agricultural purposes (Klemm, 1999). The available amount of water for irrigation is becoming scarce that threatens the sustainability of upland rice production as rice is very sensitive to water stress. Several water-efficient irrigation strategies had been tested, advanced, applied and spread in different rice growing regions. One is the aerobic rice system (Bouman et al., 2005) where rice is grown like any other upland crop, resulting in substantial water savings but also in a significant penalty on grain yield, especially with the use of high-yielding irrigated varieties (Peng et al., 2006).

Another important water-saving technique is System of Rice Intensification (SRI). The SRI was developed in Madagascar during early 1980s (Laulanie, 1993) is a system approach to increase rice productivity with less external and inexpensive inputs and alternate wetting and drying (AWD), also called alternate submergence/ non-submergence, or intermittent irrigation (Bhuiyan, 1992; Bouman and Tuong, 2001; Belder et al., 2004). Water productivity of rice with respect to total water input (irrigation plus rainfall) is on an average of 0.4 kg grain m^{-3} water (Tuong et al., 2005). Under water-saving regimes, an increase in water productivity to 0.8–1.0 kg grain m^{-3} water has been reported by many researchers (Belder et al., 2005; Kato et al., 2009).

In light of the concerns about irrigation water scarcity due to recurrent droughts in the Southern Telangana, India, the present experiment entitled "Standardization of alternate wetting and drying (AWD) method of water management in lowland rice (*Oryza sativa* (L.)) for up scaling in command outlets" was designed to standardize the permissible depth of water regime drop below the ground level *i.e.,* safe AWD management practice for rice cultivation.

Materials and Methods

Experimental site:

The field experiment was conducted in irrigated lowland rice area. The experiment was conducted during *kharif* 2013 and 2014 in a sandy clay soil at Water Technology Centre, College Farm, College of Agriculture, Rajendranagar ($17^0$32' N, $78^0$40' E. 542.6 m a.s.l.), in Hyderabad (India). Agro-climatologically the area is classified as Southern Telangana Agro Climatic Zone of Telangana State. The experimental soil was sandy clay in texture, moderately alkaline in reaction, non-saline, low in organic carbon content, low in available nitrogen (N), medium in available phosphorous (P_2O_5) and potassium (K_2O). The total plant available soil water in 0-30 cm soil depth was 44.32 mm.

Treatments and design

A field experiment was conducted during *kharif,* 2013 and 2014. The treatments consisted of continuous submergence (CS) throughout the crop growing season besides alternate wetting and drying (AWD) irrigation regimes with two ponded water depths of 3 and 5 cm and drop in ponded water levels in field water tube below ground level to 5, 10 and 15 cm depth. The eight treatments were laid out in randomized block design with three replications. The treatmental details is given in table 1. A short duration rice variety, MTU-1010 was planted adopting a spacing of 15×15 cm. The recommended dose of 120:60:60 N, P_2O_5 and K_2O kg ha^{-1} was applied. Total nitrogen was applied in the form of urea in three equal splits *viz.,* $1/3^{rd}$ as basal, $1/3^{rd}$ at active tillering stage and $1/3^{rd}$ at PI stage. The entire P was applied as basal in the form of single super phosphate (16% P_2O_5). Whereas, the K was applied in the form of muriate of potash (60% K_2O) in two equal splits *viz.,* as basal and top dressing at panicle initiation stage.

Table 1. Applied water (mm) as influenced by different AWD irrigation regimes during *kharif* 2013, 2014 and pooled means.

Code	Description of Treatment	Applied water (mm)		
		2013	2014	Pooled
I_1	Continuous submergence of 3 cm up to PI and thereafter 5 cm up to PM	1330	1451	1390
I_2	AWD – Flooding to a water depth of 3 cm when water level drops to 5 cm BGL from 15 DAT to PM	1124	1160	1142
I_3	AWD – Flooding to a water depth of 3 cm when water level drops to 10 cm BGL from 15 DAT to PM	851	919	885
I_4	AWD – Flooding to a water depth of 3 cm when water level drops to 15 cm BGL from 15 DAT to PM	793	853	823
I_5	AWD – Flooding to a water depth of 5 cm when water level drops to 5 cm BGL from 15 DAT to PM	889	955	922
I_6	AWD – Flooding to a water depth of 5 cm when water level drops to 10 cm BGL from 15 DAT to PM	693	812	752
I_7	AWD – Flooding to a water depth of 5 cm when water level drops to 15 cm BGL from 15 DAT to PM	650	767	708
I_8	AWD – Flooding to a water depth of 3 cm from 15 DAT to PI and thereafter 5 cm up to PM when water level drops to 15 cm	699	769	734
General Mean		878	960	919

PI – Panicle Initiation; PM – Physiological Maturity; DAT – Days After Transplanting; BGL – Below Ground Level; AWD – Alternate Wetting and Drying

Description of field water tube

A practical way to implement AWD irrigation practice safely is by using a ‘field water tube’ (‘pani pipe’) to monitor the receding water depth on the field. The field water tube is made of plastic pipe having 40 cm length and 15 cm in diameter so that the water table is easily visible and it is easy to remove soil inside after installation and during siltation in the course of use in the field. The field tube also contains perforations of 0.5 cm in diameter and 2 cm apart, so that water can flow readily in and out. The field tube was hammered in to the soil in each net plot such that 15 cm protrudes above the soil surface. Care was taken not to penetrate through the bottom of the plough pan. After installation the soil from inside the field tube was removed so that the bottom of the tube is visible. A trial run was done by flooding the field plots to check whether the water level inside the tube is the same as outside the tube, to ensure that perforations are not blocked with compacted soil. The tube was placed in a readily accessible portion of the net plot to ensure that the location is representative of the average water depth of the field in the net plot i.e., it is not in a high or a low spot.

Imposition of AWD irrigation in the field through field water tube

Field water tubes were used to monitor and measure the gradually receding depth of water level in the field. After each irrigation the depth of water recedes owing to evapotranspiration, deep percolation and seepage losses. When the field is flooded after each irrigation water application event, the water seeps through the perforations in to the field water tube and the water level inside the tube is the same as that of outside the tube. However, with time as the submergence depth of water level recedes, so also in the field water tube the same was monitored and measured in each field tube treatment-wise using a scale. Three different irrigation regimes based on receding water level were imposed using field tube. Irrigation was applied to a water depth of either 3 or 5 cm when the water level in the field tube dropped to a threshold level of 5, 10 and 15 cm depending on the treatment during the base period. Irrigation was withheld 10 days ahead of harvest.

Water measurement

According to the treatment description, irrigation water was applied to reflood the field. Whenever the water level has dropped to a pre-determined threshold level of about 5, 10 and 15 cm below the soil surface in the tube, the plots were reflooded to submergence depth of 3 cm or 5 cm above the ground as per the treatment. While in continuous submergence treatment irrigation water was applied daily to maintain a submergence depth of 3 cm depth from 15 DAT to panicle initiation stage and 5 cm depth from panicle initiation to physiological maturity to minimize the water requirement at vegetative stage of crop.

Applied water (mm)

Each plot was irrigated separately and the amount of irrigation water was measured by water meter and expressed in ha mm. Irrigation water applied in AWD irrigation regimes amounted to 50.9 to 82.1% of continuous submergence (1390 mm). Depth of irrigation water (mm) applied to raise the water level in the field to pre-determined threshold level *i.e.,* 3 cm or 5 cm as per the treatment was computed by dividing the volume of water applied by the area of the plot. In some heavy rainfall events, excessive rainfall was drained off by drainage channel to keep the ponded water within the maximum allowable depths. Drainage depth was computed from the field water depth before and after drainage.

Effective rainfall (mm)

Total rainfall received during the crop growth period (August 1 to November 25) was 552.9 and 324.5 mm, during *kharif* 2013 and 2014, respectively. The effective fraction of this rainfall was computed from it. There are several empirical methods available for estimating effective rainfall in different countries and have been found to work quite satisfactorily in the specific conditions under which they are developed. Rice thrives under conditions of abundant water supply; hence the practice of land submergence was preferred. The depth of flooding was governed by the variety grown and its height, the height of field bunds and availability of water at the threshold level of each treatment. Thus the water requirement of rice crop includes evapotranspiration and percolation. Measuring effective rainfall in rice with the empirical methods is thus more complicated. Hence, in this experiment, the effective fraction of rainfall (mm) was calculated 24 hours after rainfall, following the field water balance sheet method Gupta et al. (1972). The daily balance is computed for each day by subtracting the daily consumptive use from the sum of the previous days balance and rainfall (mm).

Water productivity (kg m^{-3})

Water productivity is the economic yield per unit of total water input, irrigation water applied, crop evapotranspiration by the crop and expressed in kg m^{-3}.

$$\text{Water productivity (WI)} = \frac{\text{Grain Yield (kg ha}^{-1}\text{)}}{\text{Total Water Input (m}^{-3}\text{ha}^{-1}\text{)}}$$

Soil moisture measurement (%)

The regular soil samples were collected prior to each irrigation at threshold level *i.e.,* whenever water level dropped to 5, 10 and 15 cm in the field water tube as per the treatment schedule and oven dried for 72 hours at 105 °C. Then dry weight of the samples were assessed and expressed in percentage:

$$\text{Soil moisture content} = \frac{\text{Ww-Wds}}{\text{Wds}}$$

where,

Ww = Wet weight of the soil sample (g).

Wds = Dry Weight of the soil sample (g)

Statistical analysis

The data on various parameters studied during the course of investigation were statistically analyzed as suggested by Gomez and Gomez (1984). Wherever, statistical significance was observed, critical difference (CD) at 0.05 level of probability was worked out for comparison. Crop yield (dependent variable) was assumed as a function of various growth traits and yield components (independent variables) and the following straight line model was established by least square technique (Gomez and Gomez, 1984).

Results

Weather conditions

The geographical area of Hyderabad comes under dry tropical and semi arid region. Winter is generally milder at Hyderabad. Mean weekly maximum temperatures ranged from 26.3 °C to 31.8 °C and 27.5 °C to 34.00 °C, while mean weekly minimum temperatures varied from 11.4 °C to 22.2 °C and 16.1 °C to 24.5 °C during *kharif,* 2013 and *kharif,* 2014, respectively. The mean weekly maximum relative humidity during the crop growth period varied from 83.6 to 95.9 per cent and 76.1 to 92.6 per cent during 2013 and 2014, respectively. During both years of experimentation, an amount of 521.9 mm and 324.5 mm of rainfall was received during the crop growth period, 2013 and 2014 respectively against a normal rainfall of 821.7 mm.

Variation of soil water content with crop growth stages

Rice crop irrigated at I_2 had maintained higher soil moisture content over entire crop growing season (Figures 1 and 2), since it received higher seasonal water input (1452, 1388 and1420 mm in 2013, 2014 and pooled, respectively) among the AWD irrigation regimes. AWD irrigation regime I_5 exhibited marginally lower soil moisture content over the entire crop growing season relative to I_2 in both the years. Whereas water input received in AWD irrigation regime I_3 and I_6 exhibited significantly lower soil moisture levels over the entire crop growing season in both the years when compared to I_2 and I_5. Figure 3 shows the scatter diagram between soil moisture and seasonal water input received. The soil moisture content showed significant () (P=0.05) and positive correlation with seasonal water input received with a calculated determination coefficient of $R^2 = 0.629$.

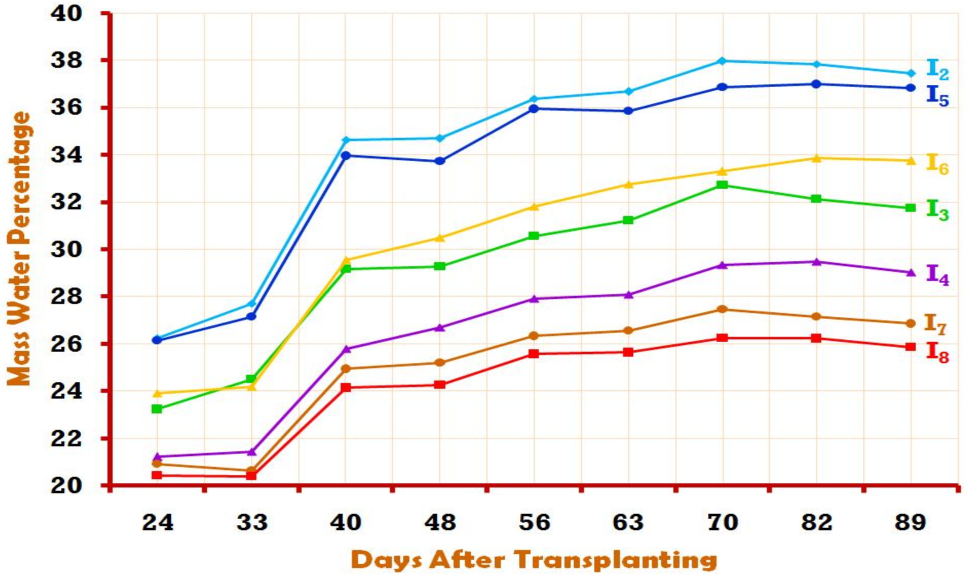

Figure 1. Variation in soil moisture as influenced by different AWD irrigation regimes during 2013

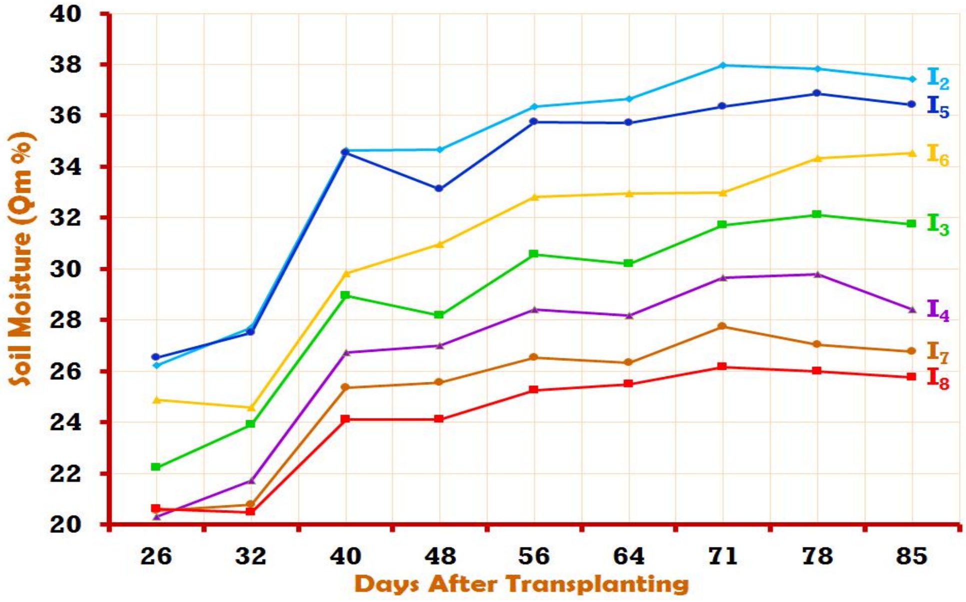

Figure 2. Variation in soil moisture as influenced by different AWD irrigation regimes during 2014.

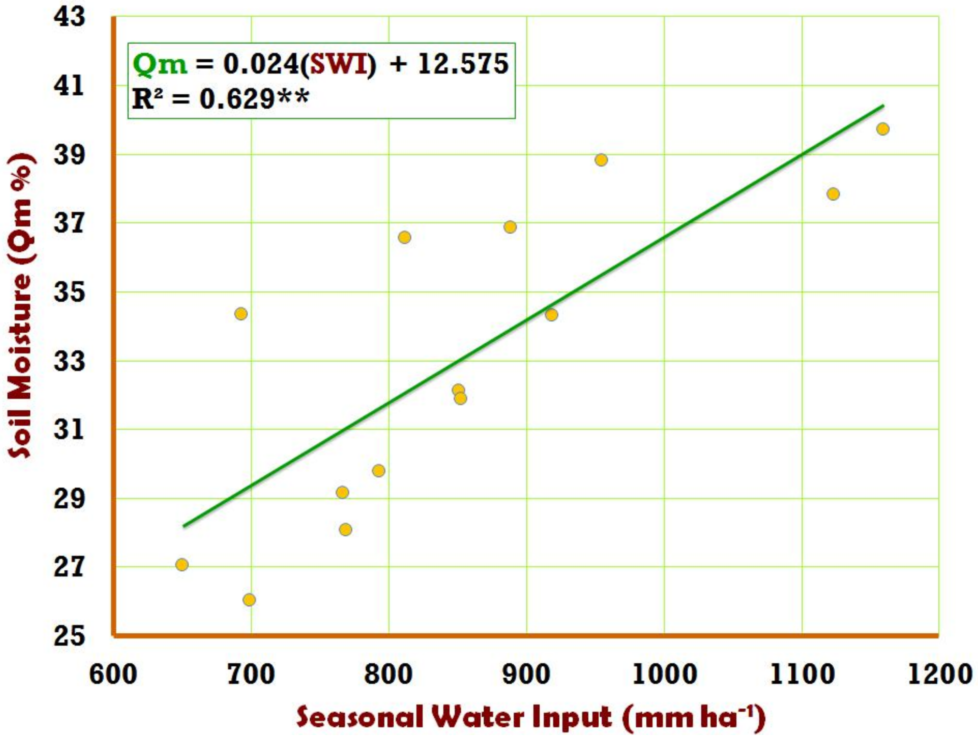

Figure 3. Regression of soil moisture content (Qm %) on seasonal water input (SWI, mm ha^{-1}) in rice.

Seasonal water input (Applied water + Effective rainfall)

The irrigation water applied effective rainfall and seasonal volume of water input varied from 708 to 1390 mm, 216 to 300 mm and 1048 to 1646 mm, respectively on pooled basis (Table 2). Irrigation water applied in AWD irrigation regimes amounted to 50.9 to 82.1% of I_1 (1390 mm). Whereas, the effective rainfall was lowest in I_1 as compared to AWD regimes, which varied between 238 to 300 mm. This suggested that the crop in AWD irrigation regimes *viz.,* I_2, I_3, I_4, I_5, I_6, I_7 and I_8 effectively used large proportion of total rainfall received relative to continuous submergence treatment. Whereas, the total water input amounted to 1056 to 1626 mm, 1013 to 1667 mm and 1048 to 1646 mm in 2013, 2014 and on pooled basis, respectively. Averaged over two seasons, the crop in different AWD irrigation regimes used 63.6 to 86.2% of the I_1 (1646 mm) suggesting that the AWD practice enabled water saving of 13.8 to 36.4% in different treatments.

Water productivity

The mean water productivity varied from 0.545 to 0.592 kg m^{-3} and 0.754 to 0.788 kg m^{-3} with respect to total water input (WP_{WI}) and irrigation water applied (WP_{IW}) indices, respectively in different years (Table 3).

Expectedly water productivity was inversely related to water input. Water productivity (WP_{WI} and WP_{IW}) in I_1 was lowest as compared to AWD irrigation regimes (I_2 to I_8) in both the years. On an average, AWD irrigation regimes (I_2 to I_8) registered 6.8 to 43.6% and 11.8 to 72.6% WP_{WI} and WP_{IW} indices, respectively when compared to I_1treatment. Among AWD irrigation regimes, I_6 had significantly higher WP_{WI} and WP_{IW} indices followed by I_7. AWD irrigation regime I_2 had water productivity indices (WP_{WI} and WP_{IW}) similar to continuous submergence (I_1). Likewise, the water productivity indices like (WP_{WI} and WP_{IW}) were comparable among I_3, I_5 and I_8 and higher over I_2 and I_4.

Growth parameters

Maintenance of continuous submergence depth of 3 cm from transplanting to PI and 5-cm from PI to PM (I_1) had significantly higher growth parameters over rest of the irrigation regimes except that it was on par with I_2, I_5 and I_6 at harvest both in 2013 and 2014 (Table 4). Whereas, lowest growth parameters were registered in I_4 at harvest in both the years.

Thus, improved growth performance in the form of plant height, tiller production, leaf area index and dry matter production by the crop in I_1, I_2, I_5 and I_6 might have been responsible for more number of panicles m^{-2} in these treatments These in turn contributed to large number of filled grains $panicle^{-1}$ and higher grain weight (test weight) with lower sterility % contributing to higher panicle weight.

Yield parameters

I_1 registered significantly higher yield parameters in 2013 and 2014 (Table 5). The yield parameters in AWD irrigation regime I_5 and I_6 was on par with I_1 indicating that irrigations can be delayed with higher depth (5 cm) of reflooding, the ponded water can be allowed to drop to greater level without affecting the crop performance in terms of yield parameters. No significant difference between irrigation management systems *viz.,* I_1, I_5 and I_6 for yield parameters indicates that plants subjected to AWD irrigation regimes of I_5 and I_6 did not undergo water stress in either the vegetative or reproductive phase.

Yield

Significantly higher grain yield (7503, 7634 and 7568 kg ha^{-1} in 2013, 2014 and pooled, respectively) was produced when the crop was irrigated at I_1 (Table 5). However, the grain yield in AWD irrigation regimes *viz.,* I_2 and I_5 and I_6 was on par with I_1 in 2013, 2014 and pooled. This indicates that the ponded water in AWD irrigation regimes of I_2 (3 cm ponded water depth); I_5 and I_6 (5 cm ponded water depth) can be allowed to drop to greater levels of 5 to 10 cm BGL in field water tube by delaying irrigation for 2 to 3 days in I_2, 3 to 4 days in I_5 and 6 to 7 days in I_6 before reflooding.

Table 2. Applied water, effective rainfall and total water input (mm) as influenced by different AWD irrigation regimes during *kharif* 2013, 2014 and pooled.

Code	Description of Treatment	Applied water (mm)			Effective rainfall (mm)			Total water input* (mm)		
		2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
I_1	Continuous submergence of 3 cm up to PI and thereafter 5 cm up to PM	1330	1451	1390	256	176	216	1626	1667	1646
I_2	AWD – Flooding to a water depth of 3 cm when water level drops to 5 cm BGL from 15 DAT to PM	1124	1160	1142	288	188	238	1452	1388	1420
I_3	AWD – Flooding to a water depth of 3 cm when water level drops to 10 cm BGL from 15 DAT to PM	851	919	885	309	194	251	1200	1153	1176
I_4	AWD – Flooding to a water depth of 3 cm when water level drops to 15 cm BGL from 15 DAT to PM	793	853	823	315	214	264	1148	1107	1127
I_5	AWD – Flooding to a water depth of 5 cm when water level drops to 5 cm BGL from 15 DAT to PM	889	955	922	308	184	246	1237	1179	1208
I_6	AWD – Flooding to a water depth of 5 cm when water level drops to 10 cm BGL from 15 DAT to PM	693	812	752	326	227	276	1059	1079	1069
I_7	AWD – Flooding to a water depth of 5 cm when water level drops to 15 cm BGL from 15 DAT to PM	650	767	708	366	233	300	1056	1040	1048
I_8	AWD – Flooding to a water depth of 3 cm from 15 DAT to PI and thereafter 5 cm up to PM when water level drops to 15 cm	699	769	734	345	204	274	1084	1013	1048
SEm ±		12.17	14.69	17.90	4.13	3.03	3.94	12.26	13.36	12.93
CD at P = 5%		36.19	44.54	54.29	12.53	9.18	11.96	37.18	40.54	39.23
General Mean		878	960	919	314	202	258	1232	1203	1218

(* 40 mm for nursery raising)
PI – Panicle Initiation; PM – Physiological Maturity; DAT – Days After Transplanting; BGL – Below Ground Level; AWD – Alternate Wetting and Drying

Table 3. Total water input water productivity (WP_{TWI}, kg m^{-3}) and irrigation water applied water productivity (WP_{WI}, kg $m^{-3}$of rice as influenced by different irrigation regimes during *kharif* 2013 and 2014.

Code	Rice irrigation regimes	Water productivity (kg m^{-3})					
		WP_{TWI}			WP_{IW}		
		2013	2014	Pooled	2013	2014	Pooled
I_1	I_1 – 3 cm continuous submergence up to PI and 5 cm up to PM	0.461	0.457	0.459	0.564	0.526	0.545
I_2	I_2 – AWD at 3 cm submergence from 15 DAT to PM when water level drops 5 cm BGL	0.463	0.518	0.490	0.599	0.620	0.609
I_3	I_3 – AWD at 3 cm submergence from 15 DAT to PM when water level drops 10 cm BGL	0.547	0.613	0.580	0.772	0.770	0.771
I_4	I_4 – AWD at 3 cm submergence from 15 DAT to PM when water level drops 15 cm BGL	0.511	0.554	0.532	0.741	0.720	0.730
I_5	I_5 – AWD at 5 cm submergence from 15 DAT to PM when water level drops 5 cm BGL	0.564	0.631	0.597	0.784	0.779	0.781
I_6	I_6 – AWD at 5 cm submergence from 15 DAT to PM when water level drops 10 cm BGL	0.646	0.673	0.659	0.988	0.894	0.941
I_7	I_7 – AWD at 5 cm submergence from 15 DAT to PM when water level drops 15 cm BGL	0.599	0.660	0.629	0.973	0.895	0.934
I_8	I_8 – AWD at 3 cm submergence from 15 DAT to PI and 5 cm up to PM when water level drops 15 cm BGL	0.570	0.633	0.602	0.885	0.834	0.859
General Mean		0.545	0.592	0.569	0.788	0.754	0.771

PI – Panicle Initiation; PM – Physiological Maturity; DAT – Days After Transplanting; BGL – Below Ground Level; AWD – Alternate Wetting and Drying

Table 4. Growth parameters of rice as influenced by different irrigation regimes at harvest during *kharif* 2013 and 2014.

Code	Description of Treatment	Plant height		No. of tillers hill^{-1}		Lead area index		Dry matter production g hill^{-1}	
		2013	2014	2013	2014	2013	2014	2013	2014
I_1	Continuous submergence of 3 cm up to PI and thereafter 5 cm up to PM	106.8	107.8	17.9	19.5	1.03	1.05	54.04	56.37
I_2	AWD – Flooding to a water depth of 3 cm when water level drops to 5 cm BGL from 15 DAT to PM	96.8	98.3	14.9	15.6	0.98	1.00	46.83	50.80
I_3	AWD – Flooding to a water depth of 3 cm when water level drops to 10 cm BGL from 15 DAT to PM	92.8	96.3	14.0	14.5	0.83	0.86	46.51	48.46
I_4	AWD – Flooding to a water depth of 3 cm when water level drops to 15 cm BGL from 15 DAT to PM	82.1	86.2	10.9	12.2	0.65	0.66	27.9	31.46
I_5	AWD – Flooding to a water depth of 5 cm when water level drops to 5 cm BGL from 15 DAT to PM	103.0	106.0	16.4	18.5	1.01	1.03	52.64	53.10
I_6	AWD – Flooding to a water depth of 5 cm when water level drops to 10 cm BGL from 15 DAT to PM	101.2	102.6	15.5	17.7	0.87	0.89	48.87	51.54
I_7	AWD – Flooding to a water depth of 5 cm when water level drops to 15 cm BGL from 15 DAT to PM	90.9	94.7	12.4	13.6	0.79	0.80	45.78	46.25
I_8	AWD – Flooding to a water depth of 3 cm from 15 DAT to PI and thereafter 5 cm up to PM when water level drops to 15 cm	90.6	93.3	12.3	12.9	0.72	0.73	33.13	35.06
Standard Error mean SEm ±		4.5	3.2	1.0	1.2	0.04	0.03	2.04	2.00
Critical difference CD at P value = 5%		13.6	9.7	3.2	4.6	0.11	0.09	6.19	6.06
General Mean		95.5	98.1	14.4	15.5	0.86	0.87	44.46	46.63

PI – Panicle Initiation; PM – Physiological Maturity; DAT – Days After Transplanting; BGL – Below Ground Level; AWD – Alternate Wetting and Drying

Table 5. Yield parameters and yield (Kg ha^{-1}) of rice as influenced by different irrigation regimes at harvest during *kharif* 2013 and 2014.

Code	Description of Treatment	Number of panicles (m^{-2})		Panicle weight (g)		Test weight (g)		Grain yield (kg ha^{-1})		
		2013	2014	2013	2014	2013	2014	2013	2014	Pooled
I_1	Continuous submergence of 3 cm up to PI and thereafter 5 cm up to PM	298	302	19.93	20.60	24.27	24.40	7503	7634	7568
I_2	AWD – Flooding to a water depth of 3 cm when water level drops to 5 cm BGL from 15 DAT to PM	284	287	17.13	18.50	23.19	23.63	6733	7197	6965
I_3	AWD – Flooding to a water depth of 3 cm when water level drops to 10 cm BGL from 15 DAT to PM	272	274	16.90	17.20	22.73	23.29	6572	7078	6825
I_4	AWD – Flooding to a water depth of 3 cm when water level drops to 15 cm BGL from 15 DAT to PM	251	260	15.64	16.30	21.54	22.83	5877	6142	6009
I_5	AWD – Flooding to a water depth of 5 cm when water level drops to 5 cm BGL from 15 DAT to PM	295	300	18.73	19.50	23.90	24.10	6977	7446	7211
I_6	AWD – Flooding to a water depth of 5 cm when water level drops to 10 cm BGL from 15 DAT to PM	291	295	18.03	19.10	23.57	23.87	6849	7262	7055
I_7	AWD – Flooding to a water depth of 5 cm when water level drops to 15 cm BGL from 15 DAT to PM	269	272	16.67	17.00	22.63	23.30	6329	6866	6597
I_8	AWD – Flooding to a water depth of 3 cm from 15 DAT to PI and thereafter 5 cm up to PM when water level drops to 15 cm	256	268	16.00	16.90	22.13	22.97	6189	6420	6304
Standard Error mean SEm ±		8	8	0.66	0.78	0.55	0.31	286	210	197
Critical difference CD at P value = 5%		24	26	1.99	2.36	1.66	0.95	869	638	598
General Mean		277	282	17.37	18.13	22.99	23.54	6628	7005	6816

PI – Panicle Initiation; PM – Physiological Maturity; DAT – Days After Transplanting; BGL – Below Ground Level; AWD – Alternate Wetting and Drying

Discussion

In AWD irrigation, paddy fields were subjected to periodic irrigation and cyclic water deficits. The duration for non-flooded fields before reflooding can vary from 1 day to more than 10 days (Bouman et al., 2007) and is closely related to both external factors (rainfall, ambient temperature, solar radiation etc.) and internal factors (soil type and properties, hydrological conditions, plant status etc.) (Tuong et al., 2005; Dong et al., 2012). Bouman et al. (2007) reported that water table under AWD may drop to a depth of 15 cm below the soil surface where rice roots will still be able to take up water from the saturated soil and the perched water in the rhizosphere and believed the "15 cm" was the threshold of "Safe AWD" to avoid the potential of yield decline. In our experiments, the maximum number of days during the dry periods under AWD was 8 in 2013 and 7 in 2014, with a maximum drop of water level in field water tube being 15 cm below the soil. This suggested that the crop exposed to water deficits with in the safe AWD threshold over relatively long periods of time.

Several field experiments on AWD compared to continuous flooding were conducted in Asia countries such as China (Cabangon et al., 2004; Yao et al., 2012), India (Mahajan et al., 2012) and the Philippines (Cabangon et al., 2011), which confirmed that high water-saving potential does exist. Zhi (2001) explored the impact of AWD on water use and found that irrigation water use was reduced by 7 to 25% with the AWD technique. Singh et al. (1996) reported that, in India, the AWD irrigation approach can reduce water use by about 40 – 70% compared to the traditional practice of continuous submergence, without a significant yield loss. Belder et al. (2004) reported that irrigation water and total water input were separately saved 6 – 14% and 15 – 18%, respectively for AWD. Feng et al. (2007) indicated that AWD reduced 36.6% irrigation water and 22.0% total water consumption. Yao et al. (2012) showed that AWD saved 24% and 38% irrigation water in 2009 and 2010, respectively. Bueno et al. (2010) reported 33 – 41% in AWD30 (irrigations at –30 kPa) and 26 – 37% in AWD 60 (irrigations at –60 kPa) depending on the genotype. Belder et al. (2007) and Bouman et al. (2007) summarized data in Asia and reported that AWD decreased total water input by 15 – 30% with comparable yields relative to continuous flooding. Studies by Cabangon et al. (2001) and Moya et al. (2004) in China found similar results. Similar observations were made in our study and AWD significantly decreased the irrigation water and total water consumptions (10.7 to 34.8% in 2013, 16.7 to 35.2% in 2014 and 13.7 to 35.0% on pooled basis) in treatments registering higher yields on par with continuous flooded crop. Additionally, the reduced irrigation frequency and irrigation water input meant the labour force and water resources were both economized. These results were confirmed by Rajesus et al. (2009), who reported that "Safe AWD" reduced farmers' hours of irrigation use by about 38% with similar yields and profits and the reduced irrigation time had given rise to a corresponding savings in the amount of irrigation water and pumping energy costs.

Studies have demonstrated that excessive irrigation with large depths of standing water in paddy fields would lead to high water losses by evaporation (Tuong et al., 2005), percolation (Bouman et al., 2007; Tan et al., 2013), seepage (Cabangon et al., 2004; Liang et al., 2008) and surface runoff (Wang et al., 2010). Therefore, greater water productivity was consistently observed in AWD irrigation regimes than continuous flooding irrigated crop (Belder et al., 2004; Cabangon et al., 2004 and Yao et al., 2012). Our results were in accordance with these studies, since safe AWD significantly decreased water losses without concurrent reduction in grain yield as evident in I_2, I_5 and I_6 AWD irrigation regimes. Tuong et al. (2005) reported water productivities (WP_{TWI}) of 0.24 to 0.84 kg grain m^{-3} water in China, similar to what we found (0.461 to 0.673 kg grain m^{-3}) in our study in Rajendranagar, Hyderabad. Likewise, Bouman et al. (2005) obtained WP_{TWI} values of 0.46 to 0.68 kg grain m^{-3} water on aerobic rice in the Philippines. This was evident from significant (P=0.5) and negative correlation between WP and increased water input in terms of total water input (TWI) (Figure 4), irrigation water applied (IW) (Figure 5) with a determination coefficient of $R^2 = 0.711$, $R^2 = 0.851$.

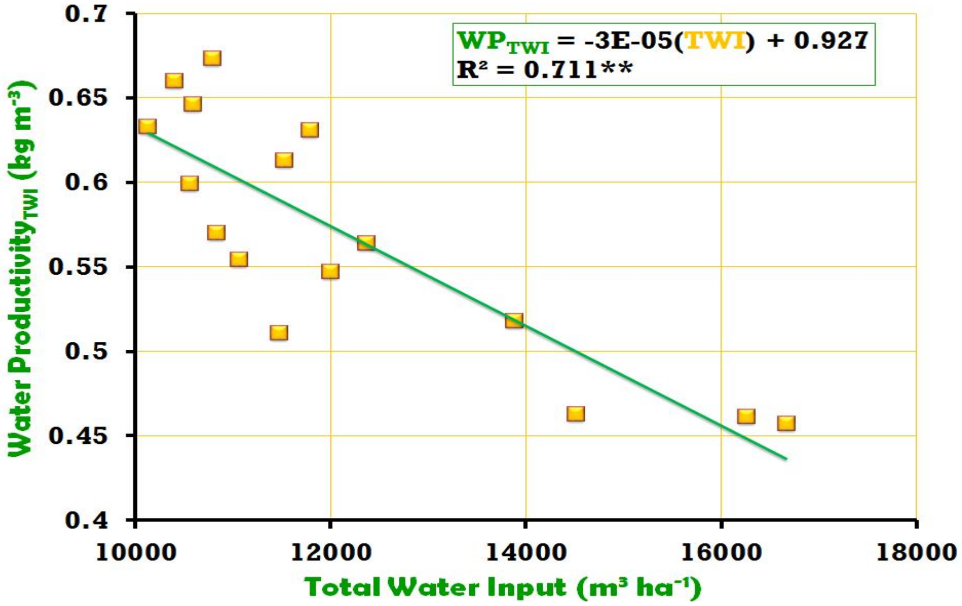

Figure 4. Regression of total water input water productivity (WP_{TWI}, kg m^{-3}) on total water input (TWI, m^3 ha^{-1}) in rice.

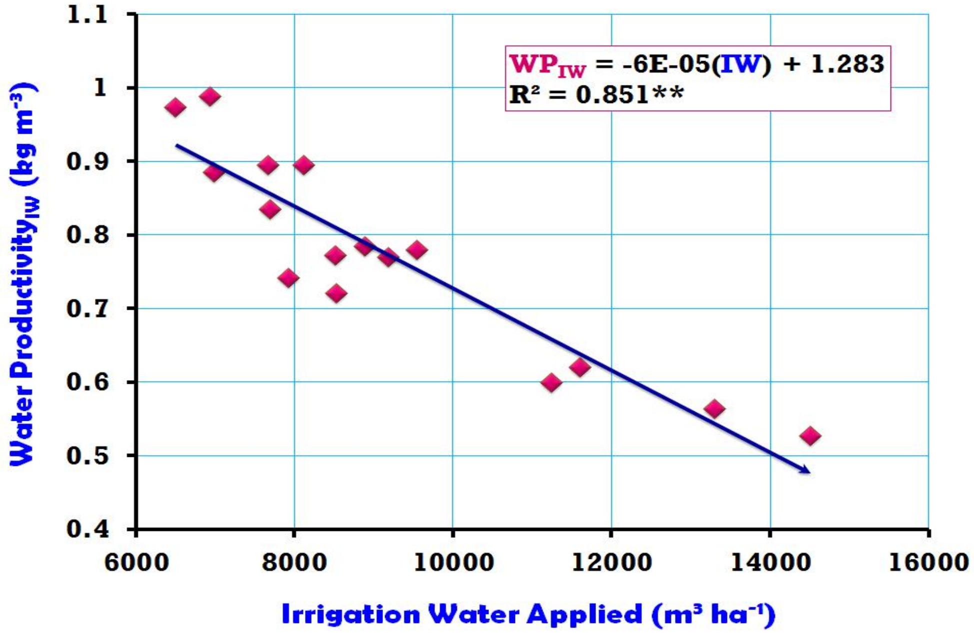

Figure 5. Regression of irrigation water applied water productivity (WP_{WI}, kg m^{-3}) on irrigation water applied (IW, m^3 ha^{-1}) in rice.

Belder et al. (2005) and Tomar et al. (2006) also observed that in place of continuous submergence optimum yield could be obtained by adopting an intermittent irrigation schedule of 3 to 5 days after disappearance of ponded water. However, allowing the ponded water depth of 3 cm in I_3 to drop to a greater depth of 10 cm with an irrigation interval of 3 to 4 days before reflooding as well as allowing ponded water depth of 5 cm in I_7 to drop to 15 cm BGL in field water tube with 7 to 8 days irrigation interval affected the grain yield significantly relative to I_1 owing to difficulty in extracting sufficient water.

Flooded irrigation with standing water throughout the rice growing season was used in the traditional rice cultivation (Mao, 2001). However, recent evidence suggests that there is no necessity to maintain continuous standing water since irrigated rice had formed adaptability to the intermittently flooded conditions and possessed of "semi-aquatic nature" in the process of rice development (Bouman et al., 2007; Kato and Okami, 2010). Water application during rice cultivation has certain degree of changeability and flexibility. Wu (1998) and Mao (2001) stated that AWD conformed to the physiological water demand of paddy rice by rationally controlling water supply during rice's key growth stages so that irrigation water was cut down. Besides, with wetting and drying cycles, AWD strengthens the air exchange between soil and the atmosphere (Mao, 2001; Tan et al., 2013), thus sufficient oxygen is supplied to the root system to accelerate soil organic matter mineralization and inhibit soil N mobilization, all of which should increase soil fertility and produce more essential plant-available nutrients to favour rice growth (Wu, 1998; Bouman et al., 2007; Dong et al., 2012; Tan et al., 2013).

The dependence of grain yield on seasonal water input (SWI) (Figure 6) and soil moisture content (Qm) (Figure 7) was evident from significant and positive association between these traits. The explained variation as indicated by determination coefficient (R^2) in grain yield by SWI, Qm was $R^2 = 0.791^{**}$ and $R^2 = 0.798^{**}$.

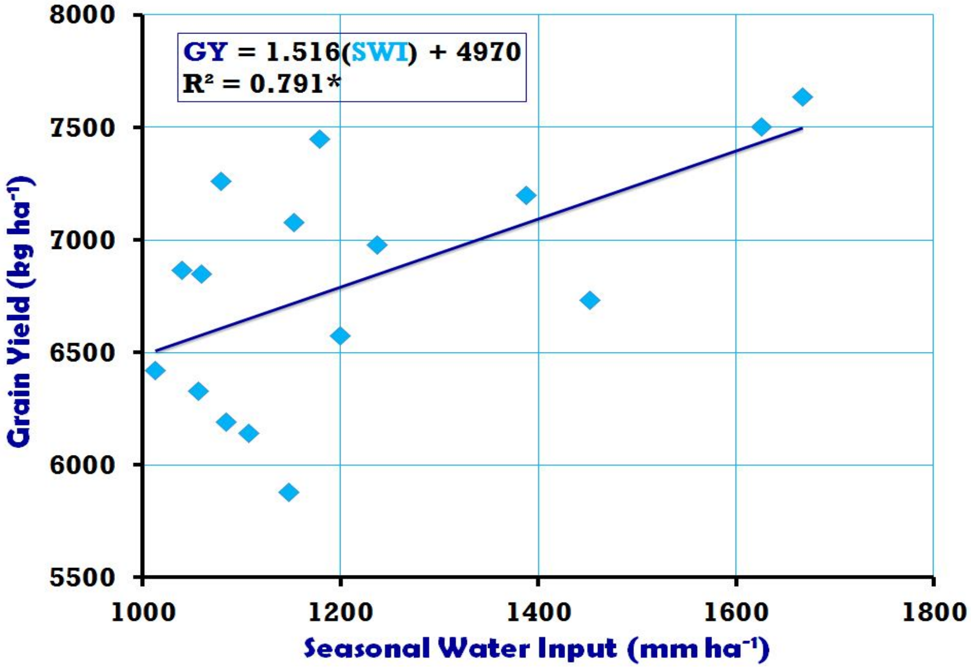

Figure 6. Regression of grain yield (GY, kg ha^{-1}) of rice on seasonal water input (SWI, mm ha^{-1}).

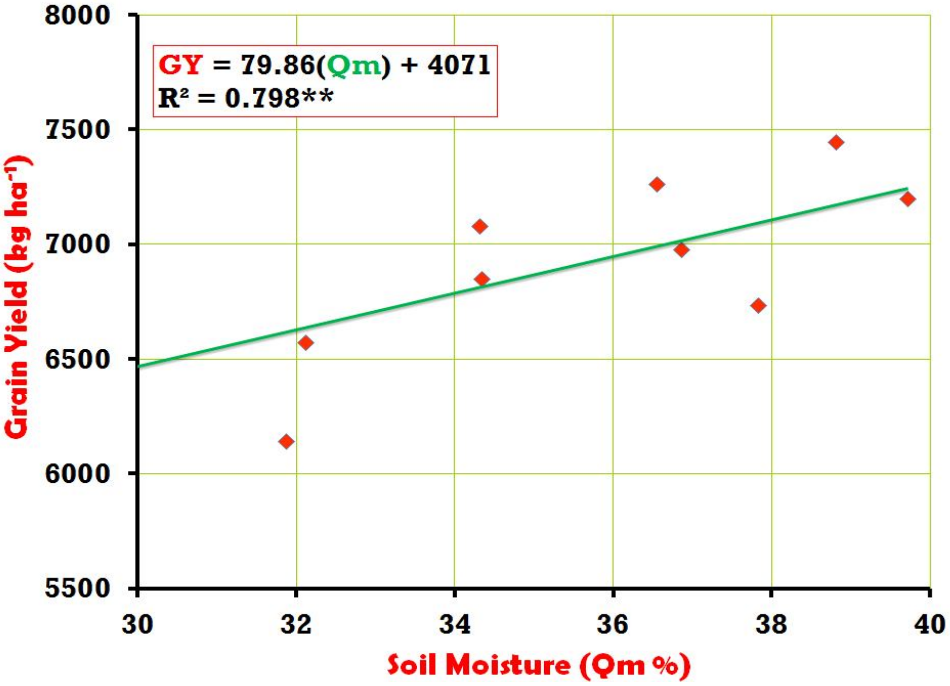

Figure 7. Regression of grain yield (GY, kg ha^{-1}) of rice on soil moisture content (Qm, %).

Conclusion

Rice crop performance viz., growth traits, yield components and grain yield under continuous submergence of 3 cm depth from transplanting to panicle initiation and 5 cm from panicle initiation to physiological maturity and AWD irrigation regimes *viz.,* flooding to a water depth of 5 cm between 15 DAT to physiological maturity as and when ponded water level drops to either 5 and 10 cm BGL in field water tube was found to be safe AWD practice with respect to higher yield (7055 to 7211 kg ha^{-1}), considerable water saving (26.6 to 35.0%) and higher water productivity suggesting that rice crop can be successfully grown by adopting an appropriate AWD irrigation regime without any significant yield decline under sandy clay soils of Rajendranagar, Telangana State of India.

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