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Response of Water Stress Parameters to Alternate Wetting and Drying (AWD) Method of Water Management in Low land Rice *(Oryza sativa)*

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Abstract

Alternate Wetting and Drying (AWD) is an irrigation technique where water is applied to the field a number of days after disappearance of ponded water. The treatments consisted of continuous submergence besides 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 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. Irrigation water applied in AWD irrigation regimes amounted to 50.9 to 82.1% of continuous submergence (1390 mm).Water stress parameters *viz.,* relative water content (90.00 to 91.81% in 2013 and 92.19 to 92.77% in 2014) and leaf water potential (10.0 to 11.8 –bars in 2013 and 10.3 to 12.6 –bars in 2014) reflecting plant water balance were higher in continuous submergence depth of 3 cm from transplanting to PI and 5 cm from PI to PM, comparable values of RWC and LWP were also registered when the crop was flooded to a water depth of 5 cm between 15 DAT to PM as and when ponded water level drops to 5 cm BGL in field water tube and 10 cm BGL in field water tube. Likewise in AWD irrigation regime flooding to a water depth of 3 cm from 15 DAT to PI and 5 cm from PI to PM as and when ponded water level drops to 15 cm BGL in field water tube markedly lower the relative water content and leaf water potential.

Keywords

Relative water content; Leaf water potential; Alternate wetting and drying; Low land rice

Introduction

Moderate water stress can be defined as a situation in which reduced water availability leads to the affect the plant growth. Relative Water Content (RWC) has the ability of plant to maintain high water in the leaves under moisture stress conditions and has been used as an index to determine drought tolerance in crop plants [1]. Drought stress significantly reduced RWC during development stage [2]. Reduced soil water availability leads to low plant water potential, consequently, the leaves lose turgedness, the stomata closes, and cell elongation was halted [3]. There was a negative relationship between the net photosynthetic rate and water stress [4]. Water stress induces decrease in the shoot dry weight and relative water content [5]. Inadequate soil moisture leads to water deficits in leaf tissues, which affects many physiological processes and ultimately reduces the yield [6]. Flore et al. [7] stated that RWC was considered as an alternative measure of plant water status, reflecting the metabolic activity in tissues. David [8] observed that leaf relative water content had a significant influence on photosynthesis and found that reduction in by reducing the net photosynthesis by more than 50 per cent when relative water content was less than 80 percent.

Cowman [9] predicted that Leaf Water Potential (LWP) will vary diurnally because of the dynamic nature and complex interactions that took place between the various components of the soil plant atmosphere system. Some plant species can adapt to water stress by adjusting osmotically, so that, the physiological activity is maintained at low leaf water potential [10,11]. LWP was considered as a reliable parameter for quantifying plant water stress response [12]. Similarly, Cruz et al. [13] reported that the photosynthetic rate of rice leaves is highly susceptible to drought stress and it is decreased by 60 per cent when LWP decreased from -0.6 to -1.3 MPa. Likewise, Tanguilig et al. [14] observed that high transpiration rate in rice leaves may have caused the rapid decline in LWP if proper amount of water was not supplied to the growing medium.

The purpose of the current study was to investigate the response of water stress parameters *viz.*, relative water content and leaf water potential to safe alternate wetting and drying method of water management in low land rice (*Oryza sativa L.)*.

Materials and Methods

The experiment was laid out in a randomized block design with eight irrigation regimes comprising of two submergence levels above the ground (3 and 5 cm) and three falling levels below ground surface (5, 10 and 15 cm drop of water in field water tube) and farmers practice of continous standing water which were randomly allotted in three replications. 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 field capacity and permanent wilting point moisture content of the experimental soil was 31.11 and 21.25 per cent at 0.3 bars and 15 bars, respectively with 44.32 mm plant available soil moisture content water in 0-30 cm soil depth. The conventional flooding irrigation practice was followed till 15 Days After Transplanting (DAT) for proper establishment. The irrigation water was measured by water meter. After 15 DAT, the irrigation schedules were imposed as per the treatment requirements with the help of field water tube.

Relative water content (%)

Relative water content was calculated to examine rice plant reaction to water deficit stress. For this purpose, top-most fully expanded leaves of three plants from second and fifth rows in net plot area between 1300-1500 hours were sampled. Each sample was

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placed in a pre-weighed air tight vial. Vials were weighed in the laboratory to obtain leaf sample weight (F), after which the sample was immediately hydrated by placing them in distilled for about 24 hours to full turgidity under normal room light and temperature. After hydration the samples were taken out of water and well dried of surface moisture quickly and lightly with filter/tissue paper and immediately weighed to obtain fully turgid weight (TW). Samples were then oven dried at 80°C for 72 hours and weighed (after being cooled down in a desiccator) to determine dry weight (DW). All weighing was done to the nearest mg.

Leaf Relative Water Content (RWC) was determined according to the methods of Barrs and Weatherley (1962), based on the following equation:

$$\mathrm{RWC}(\%)=\frac{(\mathrm{FW}-\mathrm{DW})}{(\mathrm{TW}-\mathrm{DW})}\times 100$$

Where,

FW = Fresh weight of leaves,

DW = Dry weight of leaves after drying at 80 °C for 72 hours,

TW = Turgid weight of leaves after soaking in water

Leaf water potential (-bars)

The leaf water potential was measured by using pressure bomb techniques as described by Scholander et al. [15] and Warning et al. [16]. Measurements of leaf water potential was made at solar noon (1200-1300 hours) prior to each irrigation *i.e.,* when depth of water level dropped to 5, 10 and 15 cm in the field water tube as per the treatments. Second to the youngest, fully expanded leaves were cut at about 2.0 cm below the leaf collar. These were then covered with polyethylene bags, clipped at the collar to unify the pressure on leaf and to protect the vapor pressure loss and placed in a pressure chamber in such a way that the cut portion of the surface was just protruding into the atmosphere through the seal on the top of the chamber. The pressure was applied slowly to the leaf blade until the meniscus just returned to the cut surface. At this point the water potential was measured in the pressure gauge and it was taken to represent the leaf water potential of the sampled plant in a given treatment.

Crop yield (dependent variable) was assumed as a function of various growth traits and the following straight line model was established by least square technique [20] as follows:

$Y = a + bx$

Where,

Y = Grain yield of rice (g m^{-2})

a = Y–axis intercept

b = Regression coefficient

x = Independent variable i.e., Growth and yield components

Likewise, to characterize the crop weather relationship all growth and yield components and grain yield were related to weather elements adopting the above linear model.

Results and Discussion

Seasonal water input (Applied water + Effective rainfall)

Seasonal water input (Applied water + Effective rainfall) as influenced by different irrigation regimes is presented in Table 1. Sharp differences were observed in the amount of irrigation water applied, effective rainfall and seasonal water input between continuous submergence and AWD irrigation regimes in both the years. 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. Irrigation water applied in AWD irrigation regimes amounted to 50.9 to 82.1% of continuous submergence (1390 mm). Whereas, the effective rainfall was lowest in Continuous Submergence depth of 3 cm from transplanting to PI and 5 cm from PI to PM (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 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 continuous flooded treatment (1646 mm) suggesting that the AWD practice enabled water saving of 13.8 to 36.4% in different treatments.

In AWD irrigation, paddy fields were subjected to periodic irrigation and cyclic water deficits [17]. The duration for non-flooded fields before re-watering can vary from 1 day to more than 10 days [18], 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.) [18,19]. Bouman et al. [20] 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 in water level in field water tube being 15 cm below the soil. This suggested that the AWD experienced in this study exposed the crop 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 [21,22], India [23], and the Philippines [24], which confirmed that high water-saving potential does exist. Zhi [25] 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. [26] 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. [10] reported that irrigation water and total water input were separately saved 6 – 14% and 15 – 18%, respectively for AWD. Feng et al. [20] indicated that AWD reduced 36.6% irrigation water and 22.0% total water consumption. Yao et al. [22] showed that AWD saved 24% and 38% irrigation water in 2009 and 2010, respectively. Bueno et al. [27] 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. [28] and Bouman et al. [29] 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. [30] and Moya et al. [21] 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 and Roderick [31], 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.

Crop evapotranspiration in different crop growth sub-periods

The crop evapotranspiration (ETc) during the establishment period of rice crop was low and alike in all the treatments during both the years owing to less plant size (plant height and LAI) and uniform amounts of water application in all the treatments (Table 2). However, on an average the ETc in establishment period was marginally higher in 2013 when compared to 2014 (Table 3). The average ETc during establishment accounted for 13.37 and 12.22% only of the seasonal average ETc in 2013 and 2104, respectively. As the crop growth progressed the ETc in different crop growth sub-periods increased linearly through vegetative period up to reproductive period in all the treatments. The increased ETc in different treatments could be traced to total water input received (Table 1) in different treatments which was reflected in concurrent variation in LAI and its persistence (LAD). This (LAI and LAD) in turn depending on the prevailing evaporative demand of the atmosphere as reflected by reference crop evapotranspiration and USWB Class A Pan evaporation had similar effect on ETc and free water evaporation from ponded water depth in different crop growth sub-periods and different treatments. Therefore, the ETc in Continuous Submergence depth of 3 cm from transplanting to PI and 5 cm from PI to PM (I_1) was appreciably higher than AWD treatments during different crop growth sub-periods and in both the years. Likewise, the ETc in AWD treatments *viz.*, I_2 (Flooding to a water depth of 3 cm between 15 DAT to PM as and when ponded water level drops to 5 cm BGL in field water tube) and I_5 (Flooding to a water depth of 5 cm between 15 DAT to PM as and when ponded water level drops to 5 cm BGL in field water tube) was relatively higher over I_3 (Flooding to a water depth of 3 cm between 15 DAT to PM as and when ponded water level drops to 10 cm BGL in field water tube), I_4 (Flooding to a water depth of 3 cm between 15 DAT to PM as and when ponded water level drops to 15 cm BGL in field water tube), I_6 (Flooding to a water depth of 5 cm between 15 DAT to PM as and when ponded water level drops to 10 cm BGL in field water tube), I_7 (Flooding to a water depth of 5 cm between 15 DAT to PM as and when ponded water level drops to 15 cm BGL in field water tube) and I_8 (Flooding to a water depth of 3 cm from 15 DAT to PI and 5 cm from PI to PM as and when ponded water level drops to 15 cm BGL in field water tube) and comparable to I_1 during different crop growth sub-periods and in both the years. Further, it was noticed that the ETc attained peak values in reproductive crop growth sub-period in all the treatments owing to increased LAI and LAD, though the magnitude of ETc varied with the treatment.

The ETc is a physical process taking place continuously from a periodically replenished source of water and variable potential *viz.*, soil moisture reservoir to a sink of virtually unlimited capacity i.e. the atmosphere. As long as the water availability matches the rate of water loss through transpiration by the crop canopy and evaporation from soil surface the ETa continues at potential rates as determined by the evaporative demand of the atmosphere [32] as witnessed in I_1, I_2 and I_5. However, as the crop removes water from the soil, the soil moisture content and soil water potential decreases leading to low soil water conductivity thereby resistance to water movement in the soil increases. This tend to decrease water flow in to the plant system causing marked reduction in ETc as could be observed in AWD irrigation regimes *viz.*, I_3, I_4, I_6, I_7 and I_8.

Variation of soil water content with crop growth stages

Rice crop irrigated at I_2 (Flooding to a water depth of 3 cm between 15 DAT to PM as and when ponded water level drops to 5

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

Code	Description of Treatment	Applied water (mm)			Effective rainfall (mm)			Total water input * (mm)			Water Saving (%)
		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	13.7
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	28.6
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	31.5
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	26.6
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	35.0
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	36.4
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	36.3
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 2: Crop evapotranspiration (ETc) (mm) of rice as influenced by irrigation regimes (continous submergence and AWD irrigation regimes) at different crop growth stages.

Growing period (DAT)	Treatments								
	3 cm and 5 cm continous submergence	AWD – 3 cm with 5 cm drop	AWD- 3 cm with 10 cm drop	AWD- 3 cm with 15 cm drop	AWD – 5 cm with 5 cm drop	AWD – 5 cm with 10 cm drop	AWD -5 cm with 15 cm drop	AWD- 3 cm and 5 cm with 15 cm drop	Reference crop evapotranspiration (ET_0)
2013									
Initial stage (0-15DAT)	75.17	75.17	75.17	75.17	75.17	74.17	75.17	75.17	55.69
Development stage (16-45DAT)	168.98	158.82	137.46	130.35	164.15	139.88	133.24	130.24	96.15
Reproductive stage (46-75DAT)	275.51	255.43	242.34	190.76	262.67	246.29	216.85	203.43	135.46
Late stage (76-100 DAT)	127.56	93.24	89.24	78.37	99.45	90.04	87.32	85.43	77.16
Total growing season	**647.33**	**582.66**	**544.21**	**474.65**	**601.36**	**550.38**	**512.58**	**494.27**	**364.46**
2014									
Initial stage (0-15 DAT)	67.35	67.35	67.35	67.35	67.35	67.35	67.35	67.35	48.34
Development stage (16-45 DAT)	108.69	98.89	88.76	78.32	103.43	94.04	82.63	80.22	54.41
Reproductive stage (46-75 DAT)	261.90	254.77	208.46	180.57	256.68	222.04	194.36	183.37	116.23
Late stage (76-100 DAT)	230.44	201.43	173.91	146.83	227.19	180.13	150.61	148.76	124.59
Total growing season	**668.38**	**622.44**	**538.45**	**473.07**	**654.65**	**563.56**	**494.95**	**479.70**	**343.57**

Table 3: Details of Treatment.

Treatment Details	
I_1	Continuous submergence of 3 cm up to PI and thereafter 5 cm up to PM
I_2	AWD – Flooding to a water depth of 3 cm when water level drops to 5 cm BGL from 15 DAT to PM
I_3	AWD – Flooding to a water depth of 3 cm when water level drops to 10 cm BGL from 15 DAT to PM
I_4	AWD – Flooding to a water depth of 3 cm when water level drops to 15 cm BGL from 15 DAT to PM
I_5	AWD – Flooding to a water depth of 5 cm when water level drops to 5 cm BGL from 15 DAT to PM
I_6	AWD – Flooding to a water depth of 5 cm when water level drops to 10 cm BGL from 15 DAT to PM
I_7	AWD – Flooding to a water depth of 5 cm when water level drops to 15 cm BGL from 15 DAT to PM
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

AWD- Alternate Wetting and Drying, PI- Panicle Initiation Stage, PM- Physiological Maturity Stage

cm BGL in field water tube) had maintained appreciably higher soil moisture content over entire crop growing season, since it received higher seasonal water input among AWD irrigation regimes (Figures 1 and 2). AWD irrigation regime I_5 (Flooding to a water depth of 5 cm between 15 DAT to PM as and when ponded water level drops to 5 cm BGL in field water tube) 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 (Flooding to a water depth of 3 cm between 15 DAT to PM as and when ponded water level drops to 10 cm BGL in field water tube) and I_6 (Flooding to a water depth of 5 cm between 15 DAT to PM as and when ponded water level drops to 10 cm BGL in field water tube) exhibited relatively lower soil moisture levels over the entire crop growing season in both the years when compared to I_2 and I_5. On an average the soil moisture content reduction in I_3 and I_6 treatments amounted to 12.51 % and 11.27 %, respectively when compared to I_2 and 10.29 % and 11.03 %, respectively when compared to I_5. On the other hand the soil moisture content in I_4 (Flooding to a water depth of 3 cm between 15 DAT to PM as and when ponded water level drops to 15 cm BGL in field water tube), I_7 (Flooding to a water depth of 5 cm between 15 DAT to PM as and when ponded water level drops to 15 cm BGL in field water tube) and I_8 (Flooding to a water depth of 3 cm from 15 DAT to PI and 5 cm from PI to PM as and when ponded water level drops to 15 cm BGL in field water tube) was appreciably lower relative to I_2 and I_5 in both the years. Among I_4, I_7 and I_8 the soil moisture content was in the decreasing order of $I_4 < I_7 < I_8$ in both the years.

Relative water content (%)

Perusal of data presented in Figures 3 and 4 revealed that the relative water content at various growth stages of rice was influenced markedly by irrigation regimes during both the years, 2013 and 2014.

Continuous Submergence depth of 3 cm from transplanting to PI and 5 cm from PI to PM (I_1) maintained higher relative water content (90.00 to 91.81% in 2013 and 92.19 to 92.77% in 2014) throughout the crop growth period. Whereas, in AWD irrigation regimes *viz.,* I_2 (Flooding to a water depth of 3 cm between 15 DAT to PM as and when ponded water level drops to 5 cm BGL in field water tube) and I_5 (Flooding to a water depth of 5 cm between 15 DAT to PM as and when ponded water level drops to 5 cm BGL in field water tube) the relative water content (88.28 to 91.41 % in 2013 and 90.16 to 91.59% in 2014 in I_2 and 88.06 to 91.50% in 2013 and 88.06 to 92.31 % in 2014 in I_5) was comparable to continuous submergence treatment (I_1). This suggests that rice crop in these AWD irrigation regimes was able to extract water for 2 to 4 days during non-flooded period without any difficulty. Interestingly the relative water content level in I_6 (Flooding to a water depth of 5 cm between 15 DAT to PM as and when ponded water level drops to 10 cm BGL in field water tube) dropped marginally (85.32 to 89.78 % in 2013 and 86.32 to 90.68 % in 2014) relative to I_2

and I_5 indicating that the crop experienced very little water stress even when ponded water depth was allowed to drop to 10 cm BGL in field water tube for 6 to 7 days before re-flooding to a higher submergence depth of 5 cm. On the other hand flooding to a water depth of 3 cm between 15 DAT to PM as and when ponded water level drops to 10 cm BGL in field water tube (I_3) or 15 cm BGL in field water tube (I_4) and flooding to a water depth of 5 cm between 15 DAT to PM as and when ponded water level drops to 15 cm BGL in field water tube (I_7) markedly reduced the relative water content levels (81.42 to 87.22 % in 2013 and 82.32 to 88.25 % in 2014 in I_3; 80.35 to 83.66 % in 2013 and 81.25 to 84.64 % in 2014 in I_4; and 79.28 to 83.63 % in 2013 and 80.18 to 84.94% in 2014 in I_7) in comparison to I_1, I_2, I_5 and I_6 AWD irrigation regimes owing to difficulty in extracting water to meet the crop water needs. Likewise in AWD irrigation regime flooding to a water depth of 3 cm from 15 DAT to PI and 5 cm from PI to PM as and when ponded water level drops to 15 cm BGL in field water tube (I_8) markedly affected the relative water content (79.21 to 82.51 % in 2013 and 80.00 to 83.58 % in 2014) and the readings were comparable to I_7 AWD irrigation regime.

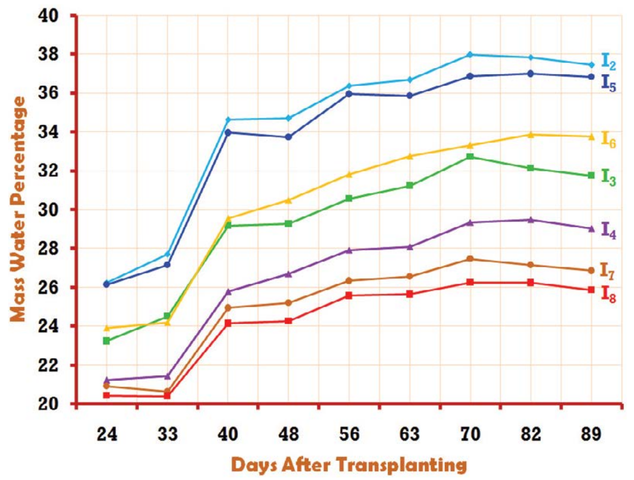

Figure 1: Variation in soil moisture as influenced by different AWD irrigation regimes during 2013.

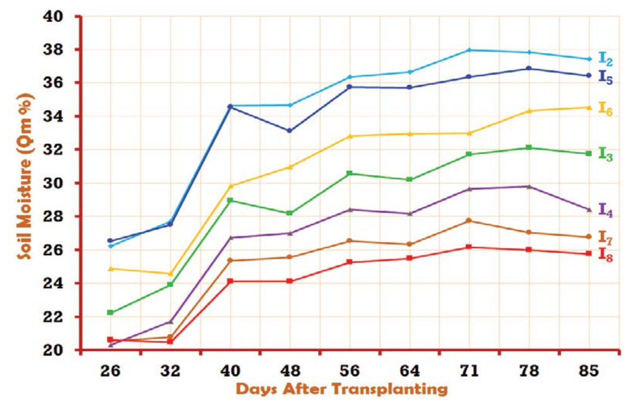

Figure 2: Variation in soil moisture as influenced by different AWD irrigation regimes during 2014.

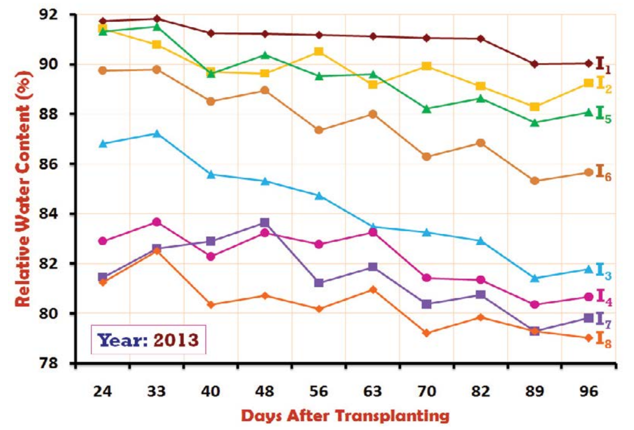

Figure 3: Variation of relative water content at various crop growth sub-periods as influenced by different irrigation regimes in 2013.

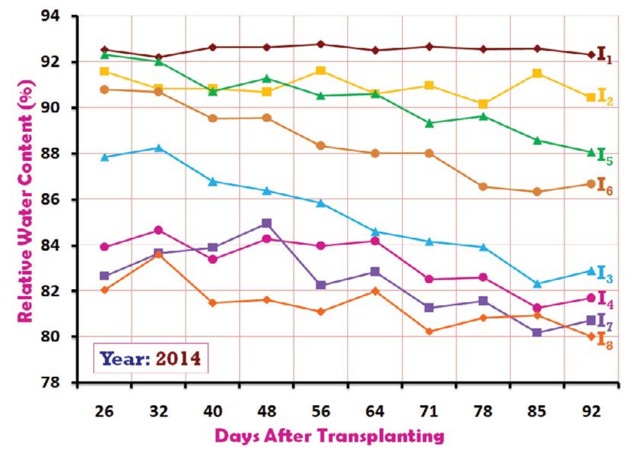

Figure 4. Variation of relative water content at various crop growth sub-periods as influenced by different irrigation regimes in 2014.

Relative water content is probably the most appropriate measure of plant water status in terms of the physiological consequence of cellular water deficit accurately indicating the balance between water input, absorbed water by plant and evapotranspiration rate [33]. Decrease in soil water content increases soil water tension (i.e., decreases soil water potential) and rice plant roots experience difficulty in absorbing water thereby reducing the plant water content. This influences the ability of the plant to recover from stress and consequently affects yield and yield stability [34,35]. Bunnag and Pongthai [36] reported significant differences in the RLWC among the cultivars subjected to water deficits. The RWC ranged from 99.5% - 99.8% in control plots to 92.9 to 86.1% in stressed rice plots. Therefore, these variations in relative water content could be traced to concurrent variation in ETc in different treatments which in turn was a function of seasonal water input and soil moisture content [37]. A good correlation existed between RWC versus ETc, total water input and soil moisture content with a calculated Determination Coefficient of R^2=0.868, R^2=0.639 and R^2=0.901 significant at P=0.01 (Figures 5, 6 and 7).

Leaf water potential (–bars)

Leaf water potential (LWP) measured during the crop growing season at various crop growth sub-periods as influenced by different irrigation regimes is depicted in Figures 8 and 9 for 2013 and 2014, respectively.

Continuous Submergence depth of 3 cm from transplanting to PI and 5 cm from PI to PM (I_1) registered markedly higher LWP in 2013 and 2014. LWP values in all AWD irrigation regimes were lower (–vely higher) than continuous submergence treatment. However, among AWD irrigation regimes *viz.*, I_2 (Flooding to a water depth of 3 cm between 15 DAT to PM as and when ponded water level drops to 5 cm BGL in field water tube) and I_5 (Flooding to a water depth of 5 cm between 15 DAT to PM as and when ponded water level drops to 5 cm BGL in field water tube) registered higher LWP (–vely lower) (13.0 to 15.5 -bars in 2013 and 12.9 to 16.5 -bars in 2014 in I_2 and 10.7 to 13.3 -bars in 2013 and 10.3 to 15.1 -bars in 2014 in I_5) in comparison to I_3 (Flooding to a water depth of 3 cm between 15 DAT to PM as and when ponded water level drops to 10 cm BGL in field water tube), I_4 (Flooding to a water depth of 3 cm between 15 DAT to PM as and when ponded water level drops to 15 cm BGL in field water tube), I_6 (Flooding to a water depth of 5 cm between 15 DAT to PM as and when ponded water level drops to 10 cm BGL in field water tube), I_7 (Flooding to a water depth of 5 cm between 15 DAT to PM as and when ponded water level drops to 15 cm BGL in field water tube) and I_8 (Flooding to a water depth of 3 cm from 15 DAT to

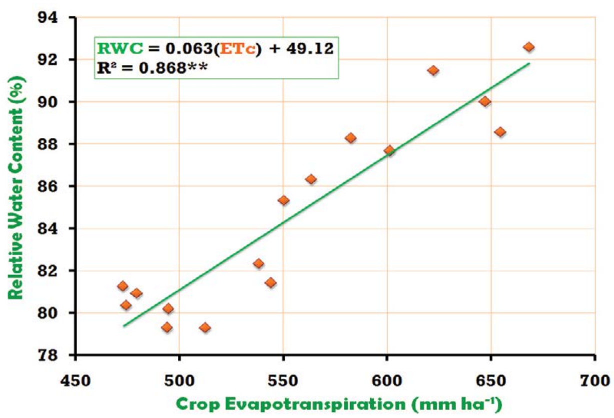

Figure 5: Regression of RWC on seasonal crop evapotranspiration.

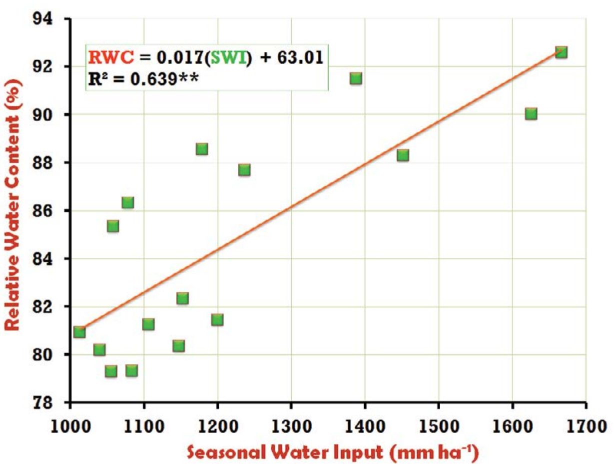

Figure 6: Regression of RWC on seasonal water input.

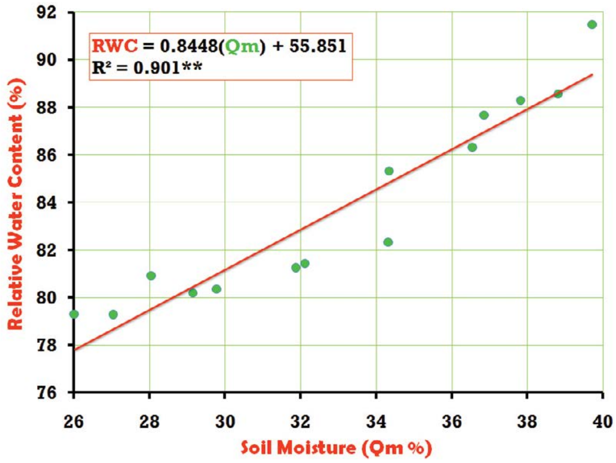

Figure 7: Regression of RWC on soil moisture content (Qm %).

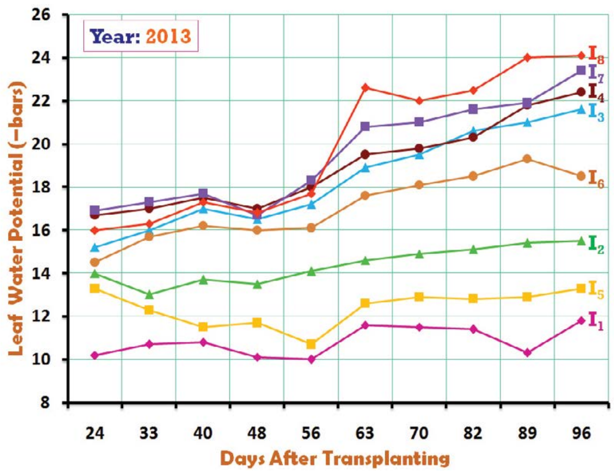

Figure 8: Variation of leaf water potential at various crop growth sub-periods as influenced by different irrigation regimes in 2013.

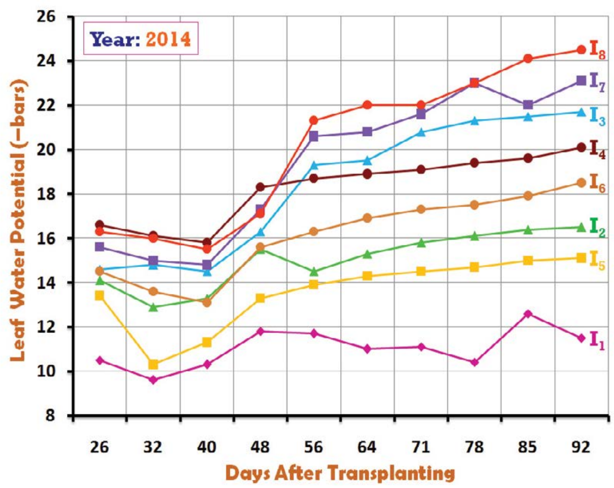

Figure 9: Variation of leaf water potential at various crop growth sub-periods as influenced by different irrigation regimes in 2014.

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PI and 5 cm from PI to PM as and when ponded water level drops to 15 cm BGL in field water tube) regimes. This suggests that rice crop in I_2 and I_5 these AWD irrigation regimes was able to extract water for 2 to 4 days during non-flooded period without any difficulty and maintained the LWP. Among the later AWD irrigation regimes the LWP was primarily a function of seasonal water input and concurrent ETc. Expectedly the LWP in I_6 dropped marginally (14.5 to 19.3 -bars in 2013 and 13.1 to 18.5 -bars in 2014) relative to I_2 and I_5 indicating that the crop experienced very little stress even when ponded water depth was allowed to drop to 10 cm BGL in field water tube for 6 to 7 days before re-flooding to a ponded water depth of 5 cm. On the other hand when the ponded water depth was allowed to drop to 10 cm (I_3) and 15 cm (I_4) BGL in field water tube before re-flooding to a ponded water depth of 3 cm and drop in ponded water depth to 15 cm BGL in field water tube before re-flooding to a higher ponded water depth of 5 cm (I_7) markedly reduced the LWP levels (15.2 to 21.6 -bars in 2013 and 14.5 to 21.7 -bars in 2014 in I_3; 16.7 to 22.4 -bars in 2013 and 15.8 to 20.1 -bars in 2014 in I_4; and 16.7 to 23.4 -bars in 2013 and 14.8 to 23.1 -bars in 2014 in I_7) relative to I_1, I_2 and I_5 AWD irrigation regimes owing to difficulty in extracting water to maintain the turgor potential consequently the LWP. Likewise in AWD irrigation regime of flooding to a water depth of 3 cm from 15 DAT to PI and 5 cm from PI to PM as and when ponded water level drops to 15 cm BGL in field water tube markedly affected the LWP (16.0 to 24.1 bars in 2013 and 15.5 to 24.5 in 2014) and the readings were comparable to I_7 AWD irrigation regime.

Leaf relative water content (RWC) has also been proposed as a more important indicator of water status than other water potential parameters under water deficit conditions [35,37]. The method is simple. It estimates the current water content of the sampled leaf tissue relative to the maximal water content it can hold at full turgidity. It is a measure of water deficit in the leaf. Normal values of RWC range between 98% in turgid and transpiring leaves to about 40% in severely desiccated and dying leaves. These results suggest that RWC-based water management can be used for timing water input for a given variety at a specific crop growth sub-period or during the entire growing period under AWD irrigation regime to maintain optimal water regime and crop ET for optimal growth and yield.

LWP is recognized as an index for whole plant water status [38,39] and maintenance of high LWP (–vely lower) is considered to be associated with optimal crop performance under water deficit conditions with dehydration avoidance mechanisms [37,39,40]. The maintenance of LWP is determined by the interaction of numerous mechanisms. These include access to soil water and the pattern of soil water uptake by roots, loss to atmosphere controlled by stomatal conductance, canopy size, leaf rolling and death, and possible internal resistance to water transport [35,40]. Measurements of LWP and its components showed that turgid osmotic potential values of about -10 to -13 bars were common in rice grown in the wet season and that loss of turgor pressure, was about -15 bars midday LWP [41]. Other reports showed leaf rolling or wilting in rice to occur across the LWP range -10 to -19 bars [42] and -9 to -23 bars [43]. In our study the LWP varied 10.1 to 11.8 -bars in 2013 and 9.6 to 12.6 -bars in 2014 in I_1; from 12.2 to 19.6 -bars in 2013 and 12.9 to 17.5 -bars in 2014 in I_2; and 15.2 to 22.8 -bars in 2013 and 14.5 to 22.3- bars in 2014 in I_5 treatments, wherein higher growth and yield traits were recorded. On the other hand, Jongdee et al. [44] measured LWP values ranging from 6.6 to 60 -bars for pre-dawn and 13.3 to 60.0 -bars for mid-day in rice genotypes subjected to range of water deficits.

Further, variation in rice LWP subjected to variable levels of water input was studied by several workers [21,41,44]. The results reported revealed that LWP declined with decrease in water input levels or progressive in increase water deficits. In our experiments as well variation in LWP could be traced to concurrent variation in ETc which in turn was a function of seasonal water input and soil moisture content in different treatments [13]. Figures 10, 11 and 12 show a scatter diagram with highly significant (P=0.01) correlation between LWP versus ETc, seasonal water input and soil moisture content. The calculated Determination Coefficient indicated that the explained variation in LWP by ETc, seasonal water input and soil moisture content accounted for R^2=0.825, R^2=0.658 and R^2=0.657 respectively.

Two reviews [45,46] have noted the general lack of plant water deficit measurements during yield determining growth stages when water deficit mediated yield reduction was assumed to have taken place. More commonly the specific processes photosynthesis, transpiration, translocation, cell division and enlargement have been related to degree of plant water deficit as measured by leaf water potential. Both RWC and LWP measurements made in our study therefore may provide objective information on the plant water status [47]. The findings further suggested that maintenance of RWC and

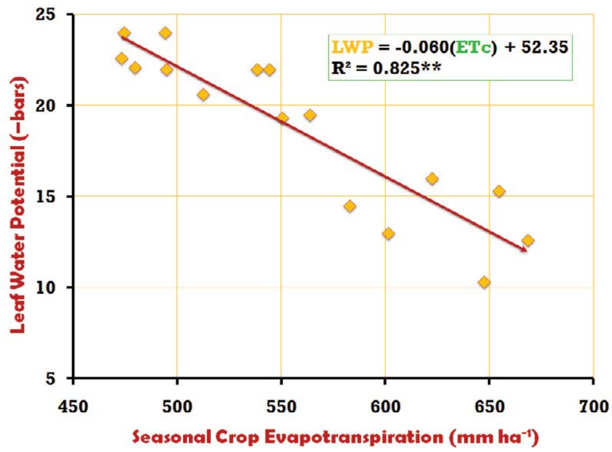

Figure 10: Regression of LWP on seasonal evapotranspiration.

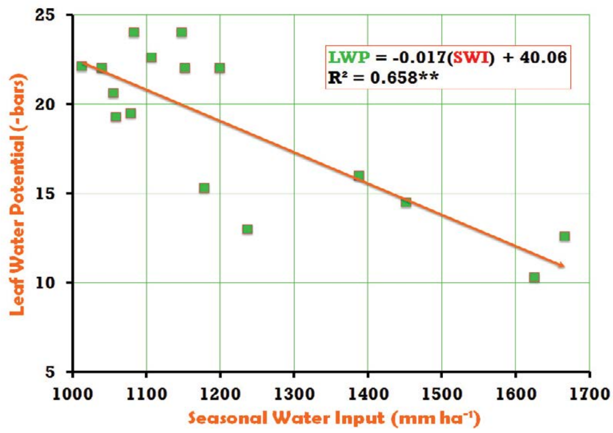

Figure 11: Regression of RWC on seasonal water input.

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LWP may be used as a criterion for assessing crop performance under AWD irrigation regimes [48,49]. However, given the high cost of the Pressure Chamber Apparatus and other related equipment, the LWP can be predicted from RWC value, which is potentially an inexpensive alternative lab tool and could be used instead for assessing plant water status and for determining the timing of water input in rice irrigated with AWD practice. In order to predict LWP for each day during the crop season correlations were analysed between LWP and RWC measured over the growing season. LWP was found to be significantly correlated to RWC with a calculated Determination Coefficient of R^2=0.812 significant at P=0.01 (Figure 13) [50].

Conclusion

Water stress parameters *viz.,* relative water content and leaf water potential reflecting plant water balance were higher in continuous submergence depth of 3 cm from transplanting to PI and 5 cm from PI to PM, Comparable values of RWC and LWP were also registered when the crop was flooded to a water depth of 3 cm between 15 DAT to PM as and when ponded water level drops to 5 cm BGL in field water tube (I_2) and Flooding to a water depth of 5 cm between 15 DAT to PM as and when ponded water level drops to 5 cm 32BGL in field water tube (I_5). Expectedly the LWP in Flooding to a water depth of 5 cm between 15 DAT to PM as and when ponded water level drops to 10 cm BGL in field water tube (I_6) dropped marginally relative to I_2 and I_5 indicating that the crop experienced very little stress even when ponded water depth was allowed to drop to 10 cm BGL in field water tube for 6 to 7 days before re-flooding to a ponded water depth of 5 cm.

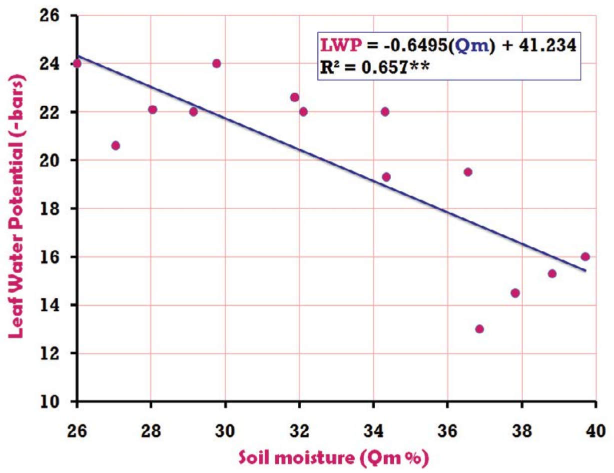

Figure 12: Regression of RWC on soil moisture content (Qm %).

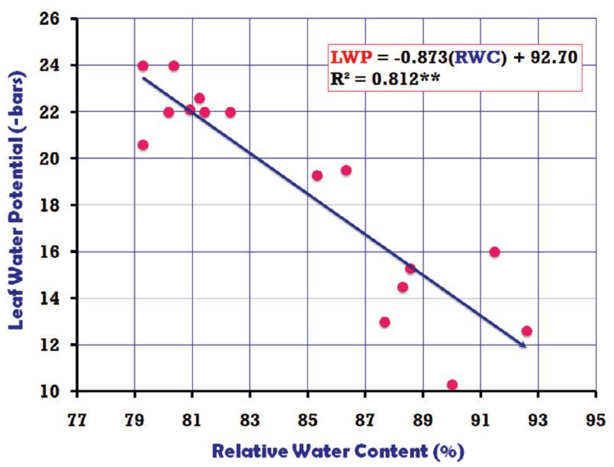

Figure 13: Regression of RWC on LWP.

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