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Research Article

Evaluation of safe alternative wetting & drying and its influence on growth, yield and water use of the efficiency of rice (*Orzya sativa l.*)

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Abstract

Due to the increase in scarcity of freshwater resources available for irrigated agriculture and escalating demand for food around the world, in the future, it will be necessary to produce more food with less water. Due to inadequate or unevenly-distributed rainfall, irrigation is essential to high rice yields. A field experiment of Alternative Wetting and Drying Irrigation (AWDI) was conducted during *kharif* season 2014 & 2015 at Soil & Water Management Research Institute, Tamil Nadu Agricultural University, Thanjavur, Tamil Nadu, India. The treatments ranged from delayed irrigations of T_1 to T_6 (10, 15, 20 cm depletion of water level below the ground level, 15cm depletion of water up to maximum tillering, up to panicle initiation & up to 10 days prior to harvest) and continuous submergence (T_7) of field irrigation water denoting the application of 5 cm flooded water condition, when the water level in the perforated PVC pipe fell at 10, 15 and 20 cm below ground level respectively. There was a significant (5% level) consequence of plant height, productive tillers, filled grains, yield and Water Use Efficiency (WUE) due to the influence of AWDI. The highest yield (5981 kg/ha) and WUE (7.56 kg/ha/mm) was recorded in treatment T_1. Longer water stress resulted in the loss of grain yield to the tune of 500 to 1000 kg/ha. This study found that in sandy loam soil at 10cm depletion of ponded water produced maximum yield (5809 kg/ha, besides the highest B.C ratio of 2.02) and WUE (7.56 kg/ha mm).

Keywords: AWDI, Grain yield, *Kharif* season, Rice, WUE

INTRODUCTION

The major sources of calories for more than 50 % of the worldwide population is provided by rice (Daniela et al., 2017) and it has been consumed more than 50 kg per capita per year as a major staple crop (FAO, 2016). In 2014/2015, 478 million tons of milled rice was produced worldwide and more than 90% of the production was directly used for human consumption. (USDA, 2016). Presently 4 billion peoples were affecting around the globe by the rising risk of water paucity and it is very critical to expanding the potential practices of agronomy to decrease the water use at the same time without affecting crop yield to support a mounting population (Mekonnen and Hoekstra, 2016). In India, more than 75% of the land is accounting for irrigable land and rice is the major crop (Smita Singh *et al.,* 2013). One of the foremost vital issues for paddy cultivation is regular irrigation without drying of field. Due to an increase in scarcity of freshwater resources available for irrigated agriculture and escalating demand for food around the world, in the future, it will be necessary to produce more food with less water. Since, irrigated agriculture and its productivity majorly depend on the availability of fresh water (Prihasto *et al*., 2018).

One-third of the world's freshwater could be effectively used to produce irrigated rice and a quantity of 2500 litres of water optimally required to produce 1 kg of rice (Linquist *et al*., 2014). In traditional cultivation, the major losses of irrigation water through evaporation, and percolation were estimated as 60 % and the water use efficiency is relatively very low in condition (Lampayan *et al*., 2015). Especially, during dry season irrigated rice cultivation, a rising quantity of the water needed for its production could be taken from untenable groundwater resources to meet the demand of increasing populations. This type of rice farming practices is more popular for increasing crop yields and consequences of better policy of irrigation water applications and more positive climatic conditions (Price *et al*., 2013).

Rice (*Orzya sativa L.*), is a staple food source and widely cultivated in India, were irrigation is indispensable to produce high yields due to insufficient and uneven distribution of rainfall. Paddy is generally transplanted into puddled soil in the irrigated lowland system. In India, the region of Cauvery delta the prevailing rice cultivation system is direct seeding or transplanting in a lowland field and kept continuously flooded with 5–10 cm throughout the growing season (Kunjammal *et al*., 2020). The improper drainage system, high underground water table and maintaining continuous submergence conditions are the high responsible for low productivity rice and have adverse effects on soil fertility in the long term flooded rice (Siopongco *et al*., 2013; Liang *et al*., 2016). The abundant water environment in which rice grows best differentiates it from all other important crops, but water is becoming increasingly scarce. From time immemorial, rice has been grown in low land areas under flooded conditions. In India, traditional rice cultivation needs 900 to 1200 mm of irrigation water, depends on the soil texture and cropping season (Subbalakshmi, 2020; Kunjammal *et al*., 2020).

The genuine amount of irrigation water required for rice cultivation, including land preparation is much larger than the recommended field irrigation water requirement. In rice field, usually the farmers frequently stagnated significant quantity of water as continuous submergence condition due to the safety measure against the ambiguity in regular water supply and also it is a practice by farmers to apply the field to field irrigation could leads a large amount of water losses in terms of percolation, seepage, surface runoff which accounting 50 to 80% of the total irrigation water in to the field (Arif *et al*., 2012). In recent times, the term “water-saving irrigation techniques” has been introduced, which recommends, (i) alternate wetting/drying, i.e. allowing the soil to dry out to a certain extent before re-applying irrigation water (ii) reducing the depth of ponded water, (iii) keeping the soil just saturated (Kunjammal *et al*., 2020).

Alternate wetting and drying Irrigation (AWDI) is one of the water-saving techniques that has been developed to reduce irrigation water for rice. In AWDI the field is allowed to dry out for one or more days instead of continuous flooded (CF), after the disappearance of ponded water (Lampayan *et al*., 2015). In certain areas and under the right conditions, AWDI is a promising method in irrigated rice cultivation with twin benefits of higher yield and water saving. However, many factors play a role in determining the success of AWDI. Some of these factors can be influenced, such as irrigation management capacity and infrastructure, while others cannot be, such as soil physical conditions and rainfall (Xu *et al*., 2015). The augmented productivity of irrigation water is liable to be the decisive factor that will make policy makers and farmers adopt AWDI techniques in water scant areas and also the alternative of drying and wetting of the field can reduce organic and inorganic toxins in the rice field (Linquist *et al*., 2012; Linquist *et al*., 2014). In flood condition of irrigated rice field, allowing aeration at the end of the tillering stage and just prior to the flowering stage would improve the wetland rice yields (Liang *et al*., 2016).

AWDI is one of the best methods that can increase the water use efficiency and productivity of the rice field by decreasing percolation and seepage during the crop periods and also it is managed the irrigation water so that water will not be wasted, but it will help to facilitate higher nutrient uptake, root growth, and increase water productivity (Kunjammal *et al.,* 2020). AWDI combines the positive aspects of both aerobic and anaerobic cultivation of rice. The alternative wetting and drying succession consists of irrigating the field with flooding and then allowing it to dry out 10 cm / 15cm / 20 cm below the soil surface (as observed through the tubes); the field is then re-flooded up to 5 cm above the top of the soil surface and then the next drying cycle begins. The length of each drying and wetting cycle will depend on a number of factors, including the weather conditions, the rate of infiltration and percolation water through the soil, and age of the plants.

The availability of irrigation water in different sources is endangered by diminishing day by day and it threatens the sustainability of the irrigation system (Smita Singh *et al.,* 2013). In rice production, more than 75% is majorly produced from irrigated land. The irrigated rice cultivation practices have been recognized from centuries, but the intimidating of irrigation as "looming water crisis" might be changed in future by the method of adopting water saving technologies. In India, one of the most important problems has been identified as water scarcity whereby the competitive use of water among agriculture, domestic, and industry will make acute and conflict (Savitha and Usha, 2016). Water saving technology, such as AWDI was investigated in the early 1970s and is being rehabilitated by many researchers. Hence, AWDI is a water-saving technology that could decrease irrigation water quantity in paddy fields without declining crop yield. The core objective of this study was the invention of water management techniques to be adopted by the farmers for rice cultivation. The main objective was to focus on the numbers of AWDI irrigation treatments. Out of that, the best one was to select to maximize the rice (*Orzya sativa L*) yield and highest water use efficiency.

MATERIALS AND METHODS

Study area

Soil and Water Management Research Institute was established in 1972 at Kattuthottam, Thanjavur, Tamil Nadu, India and started research work on standardizing irrigation techniques for several field crops with special emphasis on rice. It is located 6 km from Thanjavur on the way to Nagapattinam (NH 67) with the latitude, longitude and altitude of $10^0 45'$ N, 79^0 E and 50 m (MSL), respectively. The study area consisted of sandy loam soil texture with pH of 6.9 and contained two irrigation bore wells and additional water supply from Neivasal Thenpathi 'A' channel connected through Grand Anicut canal from the Cauvery river distributaries.

Methodology

The experimental plots (4 m x 2.5 m) were laid out with Randomized Block Design (RBD) with seven irrigation treatments of 10, 15 and 20 cm depletion of ponded water up to 10 days prior to harvest, 15 cm depletion up to maximum tillering stage and panicle initiation stage and 10 cm depletion up to 10 days prior to harvest. A perforated PVC pipe of 40 cm long, 10 cm diameter (IRRI, 2012; Smita Singh *et al.,* 2013) was installed in the rice field and kept 5 cm above the soil surface and the rest of the 35 cm perforated PVC pipe kept underneath to measure the depletion of ponded water (Fig. 1). When the ponded water inside the pipe depleted into 10, 15 & 20 cm below the ground level, the next irrigation was given stage by stage (IRRI, 2012; Smita Singh *et al.,* 2013**)**. The number of irrigations, water consumed, growth, yield attributes and rice grain yield were recorded. Each of the plots was separated by 1.5 m with buffer zone in between each of the replications. This AWDI irrigation was initiated 10–15 days after the transplanting of seedlings and the wetting and drying cycles were continued until the beginning of flowering (Liang *et al*., 2016).

The last treatment (T_7) was continuous submergence (1 to 5 cm standing water) and the remaining treatments (T_1- T_6) stood stands for an application of 5 cm irrigation water above the surface soil. The details of the treatments are given in Table 1.

When the water level in the pipe fell into 10, 15 and 20 cm from the pipe's top surface, the next irrigation was given till the standing flooded water of 5 cm. The quantity of irrigation was measured by Parshall flume for every plot, whenever the field was irrigated. This process was continued till one week before the harvest stage, except one week before and after of flowering stage (In the flowering stage, it has been maintained continuous standing water (5 cm) in all the plots maximum of 15 days) because, during the rice cultivation at the end stage of tillering and just before the stage of flowering, it needs to be flooded due to short aeration periods (Liang *et al*., 2016). Hence, all the treatment plots were allowed for continuous flooding during flowering stage, after that the treatment of AWDI was continued.

Fig. 1. *Perforated PVC pipe to measure depletion of water.*

AWDI in field assessment

The study was initiated during *kuruvai* 2014 & 2015 (*Kharif* season) with short duration variety of ADT 45 with seven treatments (Table 1) and the AWDI was continued up to 10 days prior to harvest as per Smita *et al.,* 2013). The basal application and top dressing were applied as per recommended dosages similar to the farmer's practices. The quantitative information related to irrigation water usage, yield and all the yield contributing characters viz. plant height (cm), length of the panicle (cm), effective tillers (nos.), nos. of filled and unfilled grains per panicle, nos. of panicles, 1000 grain weight (gm), straw yield (kg/ha), grain yield (kg/ha), and water use efficiency (kg/ha mm) were analysed to obtain the effect for AWDI on rice production (Smita *et al.,* 2013 and IRRI, 2013).

Pooled data analysis

Comparative studies of two years yield pooling (*Kuruvai*, 2014 & 2015) data were also analysed. The highest yield and water use efficiency was obtained in 10 cm (treatment T_1) depletion of ponded water when compared to both years.

RESULTS AND DISCUSSION

AWDI is a water-saving technology that lowland (paddy) rice farmers can apply to reduce their water use in irrigated fields. In China, AWDI technology was adopted by many farmers and reduced the quantity of flooded water applied during irrigation (Linquist *et al*., 2014). In AWDI, irrigation water was applied to flood the field at a certain number of days after the disap-

Table 1. Effect of AWDI on Growth, yield and WUE during Kuruvai 2014 (Average value of 5 observations from 3 replications of treatments).

Treat-ments	**Depletion level of water**	**Plant height (Cm)**	**Prod. Till-ers / (m^2)**	**Panicle length (Cm)**	**No. of Filled grains / Panicle**	**No. of Ill filled grains**	**No. of irriga-tions**	**Qty of water (mm)**	**Yield (kg/ha)**	**WUE (kg/ha mm)**	**B.C ratio**
T_1	10cm	101.73	561	19.99	99.33	14.3	11	782	5,809	7.43	2.02
T_2	15cm	98.53	546	19.60	96.50	14.9	11	770	5,437	7.06	1.90
T_3	20cm	95.00	473	19.37	82.33	17.5	10	809	4,642	5.74	1.63
T_4	15cm up to max. tillering	99.40	527	19.70	85.33	15.6	10	794	5,326	6.71	1.87
T_5	15cm up to PI	98.87	539	19.51	91.91	15.5	11	774	5,086	6.57	1.77
T_6	15cm up to PI	99.33	509	19.76	89.17	15.1	10	913	5,250	5.75	1.84
T_7	Submergence with-out stress	101.50	548	20.33	98.20	14.4	17	1215	5,676	4.67	1.89
SED		2.028	14.158	NS	2.203				158.66		
CD (0.05)		4.419	30.854		4.80				357.27		

T_1-Irrigation after 10 cm depletion of ponded water (from ground level) from (seven days after) transplanting to 10 days prior to harvest;T2-Irrigation after 15 cm depletion of ponded water from (seven days after) transplanting to 10 days prior to harvest;T_3-Irrigation after 20 cm depletion of ponded water from (seven days after) transplanting to 10 days prior to harvest;T_4-Irrigation after 15 cm depletion of ponded water upto max tillering stage (30 -35 DAT) and 10 cm depletion of ponded water upto 10 days prior to harvest;T_5-Irrigation after 15 cm depletion of ponded water upto panicle initiation stage (45DAT – 50 DAT) and 10 cm depletion of ponded water upto 10 days prior to harvest;T_6-Irrigation after 15 cm depletion of ponded water upto panicle initiation stage (45DAT – 50 DAT) and 3 days after disappearance of ponded water upto 10 days prior to harvest;T_7-Farmer's practice (Continuous submergence)

pearance of ponded water.

Effect of AWDI on growth and yield of rice

The first crop of *kuruvai* 2014 experiment was conducted by the variety of ADT 45 with seven treatments of 10, 15 & 20 cm depletion of ponded water up to 10 days prior to harvest, 15 cm depletion up to maximum tillering stage and panicle initiation stage and 10 cm depletion up to 10 days prior to harvest. The results revealed that, the consequences of AWDI on rice production were observed and are given in Table 2. The highest plant height (101.7 cm) was obtained in treatment T_1 (AWDI at 10 cm) followed by T_7 (101.5 cm) and the lowest height was recorded (95.0 cm) in T_3 (applying irrigation at 20 cm depletion of water 10 days prior to harvest). It was found that increasing water stress significantly (5% level, Table 2) resulted in a decrease in rice plant height in treatment T_3 (20 cm depletion of water). Similar results were found earlier for rice varieties (IRRI ,2 013; Kunjammal *et al*., 2020).

There also considerable effects observed from productive tillers per m^2 and No. of filled & ill-filled grains as shown in Table 2. One of the factors to maximizing rice grain yield majorly depends on the amount of water utilized for irrigation in treatment T_1 (10 cm depletion of ponded water in rice crop) as stated by Kunjammal *et al*. (2020) and Daniela *et al*. (2017). There was a significant (5% level, Table 2) reduction in the number of tillers in rice due to the delayed irrigation, especially in the stages of vegetative and reproductive phases which would be one of the impacts of yield loss (Muhammad Ishfaq *et al*., 2020) and the same was seen in treatment T_3. The no. of filled grains to be highest in T_1 (99.3 with 14.3 nos. of ill filled grains), followed by treatment T_7 (98.2 with 14.4 nos. of filled grains) and least was recorded in T_3 (82.3 with 17.5 nos. of ill filled grains). No significant effects were recorded in panicle length.

The trail of the experiment was repeated in *kuruvai* 2015 with the same variety (ADT 45) and there was no significant variation in all the treatments and merely similar results were obtained (Table 3). The maximum plant height, filled & ill filled grains, yield and WUE were recorded in T_1 and the least was observed in T_3.

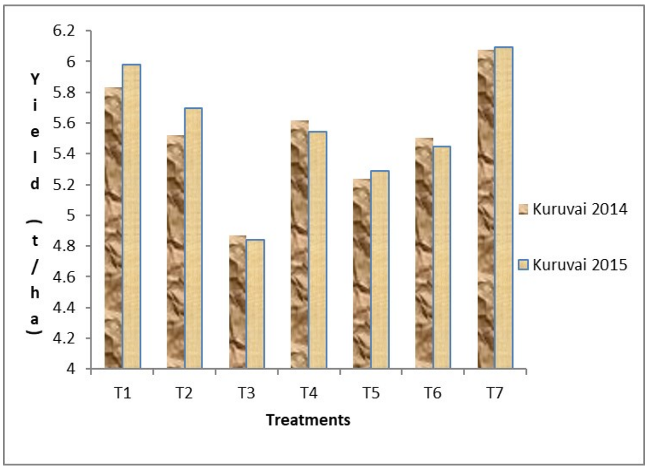

Fig. 2. *Comparative performance of rice crop yield difference during 2014 & 2015.*

Table 2. Effect of AWDI on Growth, yield and WUE during Kuruvai 2015 (Average value of 5 observations from 3 replications of treatments).

Treat-ments	Depletion level of water	Plant height (Cm)	Prod. Tillers / (m^2)	Panicle length (Cm)	No. of Filled grains / Panicle	No. of Ill filled grains	No. of irriga-tions	Qty of water (mm)	Yield (kg/ha)	WUE (kg/ha mm)	B.C ratio
T_1	10cm	107.81	608	23.6	158.8	14.7	12	777	5878	7.56	2.05
T_2	15cm	106.37	578	22.3	149.6	15.3	11	754	5426	7.20	1.89
T_3	20cm	103.80	510	20.6	123.3	17.1	11	760	4741	6.23	1.66
T_4	15cm up to max. tiller-ing	106.13	558	21.9	127.7	15.3	12	710	5351	7.53	1.88
T_5	15cm up to PI	106.00	524	21.6	127.6	15.5	11	744	5230	7.02	1.82
T_6	15cm up to PI	105.47	520	21.8	124.9	15.5	11	794	5275	6.64	1.85
T_7	Submerg-ence with-out stress	106.87	592	21.6	150.2	15.1	17	1044	5429	5.20	1.81
SED		2.583	14.031	NS	9.485				158.66		
CD (0.05)		5.629	30.571		20.660				357.27		

Effect of AWDI on water saving

The highest WUE (7.43 kg/ha/mm) was recorded in irrigation with 10 cm depletion of ponded water up to 10 days prior to harvest consumed 11 nos. of irrigations (782 mm) with significant (5 % level, Table 1) higher grain yield of 5809 kg/ha. This was followed by irrigation with 15 cm depletion of ponded water up to 10 days prior to harvest also received 11 irrigations (770 mm) and recorded a grain yield of 5437 kg/ha with the WUE of 7.06 kg/ha/mm. Further irrigation with 20 cm depletion of ponded water up to 10 days prior to harvest received 10 Nos. of irrigations (809 mm) with the WUE of 5.74 kg/ha/mm and recorded significantly (5% level) lower grain yield of 4642 kg/ha. The 10 and 15 cm depletion of ponded water was saved 30% (approx. 430 mm) of irrigation when compared to conventional. Similar results were substantially reported found in Daniela *et al*., 2017; Kunjammal, 2020; Muhammad Ishfaq *et al*., 2020), whereas the farmers practice of continuous submergence without stress consumed 1215 mm of water. The WUE in conventional observed 4.67 kg/ha/mm which is significantly higher amount of water (430 mm) when compared T_1 & T_2 and recorded a grain yield of 5676 kg/ha which is found to be on par with T_2. Similar results were substantial by Daniela *et al*. (2017), Kunjammal (2020) and Muhammad Ishfaq *et al*. (2020) who have reported that the higher productivity of rice was obtained with reduced quantity of water when compared to traditional flooded practices of rice.

The second crop of *kuruvai* 2015 also recorded similar results with *kuruvai* 2014. The highest grain yield of 5878 kg/ha, WUE (7.56 Kg/ha/mm) were found to be in T_1 and the farmer's practice of continuous submergence condition without stress (consumed 1044 mm of irrigation water) recorded 5429 kg/ha of grain yield with the WUE of 5.20 kg/ha/mm.

Economics

Irrigation with 10 cm depletion of ponded water up to 10 days prior to harvest obtained maximum yield of 5809 kg/ha, besides the highest B.C ratio of 2.02 when compared with other treatments (Table 2). This was followed by treatment T_1 & T_7 with B.C ratio of

Table 3. Pooled data analysis for rice grain yield (kg/ha) from Kuruvai 2014 & 2015.

Treat-ments	2014				2015			
	` Replication I	Replication II	Replication III	Avg.	Replication I	Replication II	Replication III	Avg.
T1	6146	5583	5700	5810	6221	5691	5722	5878
T2	6013	5450	5567	5677	5712	5250	5325	5429
T3	4805	4608	4512	4642	4498	4733	4992	4741
T4	5308	5407	5265	5327	5357	5238	5458	5351
T5	5250	5014	4755	5006	5188	5126	5375	5230
T6	5057	5253	5439	5250	5365	5358	5102	5275
T7	5342	5384	5584	5437	5436	5444	5398	5426

1.90 and the least B.C ratio was found to be treatment T_3 (20 cm depletion) of 1.63. Similar results were found in *kuruvai* 2015, also (Table 3).

Pooled data analysis

Comparative studies of two years pooling (*Kuruvai* 2014 and 2015) data were also analysed (Table 3) and depicted in Fig.2. The highest average yield was obtained in (5844 kg/ha) in 10 cm depletion of ponded water, followed by treatment T_2 which is on par with treatment T_7. The lowest yield was observed on treatment T_3 (20 cm depletion of ponded water) (4860 kg/ha) for both the years pooled data analysis. The yields in treatments T_3 (4840 kg/ha) were significantly lower at 20% of yield when compared to that of treatments of T_1 and T_7. Reduced plant height, no. of effective tillers hill^{-1}, grain yield, and No. of panicles were found with the increasing water stress. The maximum water productivity (1.3 kg/m^3) was found to be in treatment T_1 (AWDI for rice in 10 cm depletion of ponded water), whereas the conventional method in treatment T_7 (continuous submergence of flooded) was less than 0.5 kg/m^3 as also reported earlier by Kunjammal *et al*. (2020) for rice varieties.

Conclusion

A major policy inference of the study was that sandy loam soil at 10cm depletion of ponded water produced maximum yield (5809 kg/ha), besides the highest B.C ratio of 2.02) and WUE (7.56 kg/ha mm) with 430 mm of water saving (30% water saving) when compared to the traditional method of irrigation. Irrigation with safe AWDI at 20 cm was recorded with the lowest yield (4672 kg/ha) for both the years and the conventional irrigation (flooding) was consumed more than 17 numbers of irrigation and recorded comparatively lesser grain yield (5676 kg/ha) and obtained the least WUE of 4.67 kg/ha mm. Reduced plant height, no. of effective tillers hill^{-1}, grain yield, and no. of panicles were found to increase water stress. Longer water stress (at 20 cm and 15 cm depletion of ponded water) resulted in the loss of grain yield to the tune of 500 to 1000 kg/ha.

The practice of AWDI can reduce the irrigation water losses (especially deep percolation losses) by a considerable quantity without affecting the yield. If the irrigation water is so scanty, the interval between the irrigation becomes longer, then safe AWDI is quite not possible and the penalty of grain yield is inevitable. When the AWDI is implemented to the communal based irrigation system, it has to be adopted with a certain prototype to the farmers, so that the delivery of irrigation water to the farmers group in uniform manner and they realize the benefits of AWDI. Finally it was recommended that, in sandy loam soil the irrigation with safe AWDI at 10 cm was found to be the best in terms of yield and WUE.

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Conflict of interest

The authors declare that they have no conflict of interest.

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