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Alternate Wetting and Drying (AWD) Irrigation - A Smart Water Saving Technology for Rice: A Review

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A B S T R A C T

The agricultural sector faces daunting challenges because of climate change, particularly amidst increasing global water scarcity, which threatens irrigated lowland rice production. By 2025, 15-20 million ha of irrigated rice is estimated to suffer from some degree of scarcity. Rice systems provide a major source of calories for more than half of the world's population; however, they also use more water than other major crops. Irrigated lowland rice not only consumes more water but also causes wastage of water resulting in degradation of land. In recent years to tackle this problem, many methods of cultivation have been developed. Among the different methods of water-saving irrigation, the most widely adopted is Alternate Wetting and Drying (AWD) irrigation method. AWD technique has developed by IRRI in partnership with national agricultural research agencies in many countries. Practical implementation of AWD was facilitated using a simple tool called a 'field water tube'. It is an irrigation practice of introduction of unsaturated soil conditions during the growing period that can reduce water inputs in rice without compromising yields. AWD technique can save water requirement up to 20-50% and improve water use efficiency besides reducing greenhouse gas emissions by 30-50%. which have impact on climate change. However, AWD has not been widely adopted, in part, due to the apprehension of yield reductions and hence demands greater efforts from researchers and extension workers. Safe AWD threshold level found to be 5-15cm water fall below surface in field water tube which needs to be validated in different soil types and different climatic conditions. Proper management of water in safe threshold is the foundation of AWD to realize potential yield while saving water.

Introduction

Rice is the dominant staple food crop of 2.7 billion people and is critically important for food security of the world. Of the world rice production 476 million tonnes, India is producing 22.1 % per cent of it (105 million tonnes of rice), in an area of 44 million hectares (FAO STAT, 2016). Water resources, both surface and underground are shrinking and water has become a limiting factor in rice production (Farooq *et al.,* 2009). Due to increasing scarcity of freshwater resources available for irrigated agriculture and escalating demand of food around the world in the future, it will be necessary to produce more food with less water. Since, more irrigated land is devoted to rice than to any other crops in the world, wastage of water resource in the rice field should be minimized (IRRI, 2004). Further, Tuong and Bouman (2005) estimated that by 2025, 2 million ha of Asia's irrigated dry-season rice and 13 million ha of its irrigated wet-season rice may experience "physical water scarcity" and most of the irrigated rice, approximately 22 million ha, in South and Southeast Asia may suffer "economic water scarcity". The universal truth is that no new water can be created than what we have at present; therefore, to conserve what is available and subject judicious use of every drop of water is the golden rule and rice cannot be an exception. Hence, while sustaining increasing productivity of irrigated rice, it is vital to meet the future demands of 130 million tons of rice by 2025. There is an immediate need to reduce and optimise irrigation water use in the light of declining water availability for agriculture in general and to rice in particular. Since irrigated rice production is the leading consumer of water in the agricultural sector and country's most widely consumed staple crop, finding ways to reduce the need for water to grow irrigated rice should benefit both producers and consumers contributing to water security and food security. To overcome this problem and increase the rice grain production to meet the food security we need to develop novel technologies that will sustain or enhance the rice production by increasing irrigation efficiencies. If rice is grown under traditional conditions, farmers resort to continuous submergence irrigation resulting in enormous wastage of water and lower water use efficiency. Hence it becomes essential to develop and adopt strategies and practices for more efficient use of water in rice cultivation. Among the on farm technical interventions like Alternate Wetting and Drying (AWD), evapo-transpiration (ETc) based water scheduling, Furrow Irrigated Raised Bed method (FIRB), aerobic rice, direct seeding and of late System of Rice Intensification (SRI) that have promise and potential to enhance water productivity in rice, AWD found to be promising for adoption by the farmers (Li and Barker, 2004).

Alternate wetting and drying irrigation practice

Alternate wetting and drying (AWD) irrigation is a water saving technology that reduces the water use in rice fields. AWD consists of three key elements, Firstly shallow flooding for 1-2 weeks after transplanting to help recovery from transplanting shock and suppress weeds (or with a 10 cm tall crop in direct wet-seeded rice), Secondly shallow ponding from heading to the end of flowering as this is a stage very sensitive to water-deficit stress, and a time when the crop has a high growth rate and water requirement, and finally AWD during all other periods, with irrigation water applied whenever the perched water table falls to about 15 cm below the soil surface. The threshold of 15 cm will not cause any yield decline since the roots of the rice plants are still able to take up water from the perched groundwater and almost saturated soil above the water table (Bouman *et al.*, 2007a). However, it was found in shallow to medium depth sandy/ clay soils the threshold level found to be 5-10 cm fall of perched water table below the soil surface (Kishore *et al.*, 2017) and 5cm fall of water table below soil surface in sandy loam soils (Sathish *et al.*, 2017). In AWD, irrigation water is applied to obtain flooded conditions after a certain number of days have passed after the disappearance of ponded water. The number of days of non-flooded soil in AWD before irrigation is scheduled can vary from one day to >10 days and large variability in the performance of AWD was caused by differences in the irrigation interval to soil properties and hydrological conditions in addition to varietal influence (Peng and Bouman, 2007). There is a specific form of AWD called ‘‘Safe AWD’’ that has been developed to potentially reduce water inputs by about 30 per cent, while maintaining yields at the level of that of flooded rice (Bouman *et al.,* 2007). The practice of safe AWD as a mature water saving irrigation technology entails irrigation when water depth falls to a threshold level of 5-15cm below the soil surface. AWD irrigation was generally administered with 5, 7 and 10 days interval, but the predetermined days of interval could not be treated as the demand driven approach perfectly (Latif, 2010). To solve the crucial problem, IRRI recommended field water tube for monitoring water depth in AWD irrigation management practices.

Field water tube (*Pani pipe*)

The field water tube (*Pani pipe)* can be made of 30-40 cm long plastic pipe and should have a diameter of 10-15 cm so that the water table is easily visible, and it is easy to remove soil inside. Perforate the tube (up to 15-20 cm length) with many holes on all sides, so that water can flow readily in and out of the tube. Hammer the perforated portion of tube into the soil so that 15-20 cm of perforated portion of tube protrudes above the soil surface. Take care not to penetrate through the bottom of the plow pan. Remove the soil from inside the tube so that the bottom of the tube is visible. When the field is flooded, check that the water level inside the tube is the same as outside the tube. If it is not the same after a few hours, the holes a probably blocked with compacted soil and the tube needs to be carefully re-installed. The tube should be placed in a readily accessible part of the field close to a bund, so it is easy to monitor the ponded water depth (Lampayan *et al*., 2009). The location should be representative of the average water depth in the field (*i.e.* it should not be in a high spot or a low spot).

After irrigation, the water depth will gradually decrease. When the water level has dropped to about 5-15 cm below the surface of the soil depending upon soil type and water table depth, irrigation should be applied to re-flood the field to a depth of about 5 cm. From one week before to a week after flowering, the field should be kept flooded, topping up to a depth of 5 cm as needed. After flowering, during grain filling and ripening, the water level can be allowed to drop again to 5-15 cm below the soil surface before re-irrigation (Bouman *et al*., 2007 and Kishore *et al*., 2017). Tuong (2007) recorded the successful usage of field water tube in AWD management regime to monitor the water depth and capable to indicate the right time of irrigation and saved water, without any yield penalty. Using of field water tube in AWD was safe to limit the water use to 25 per cent (Suresh Kulkarni, 2011) and 26.6 - 35.0 per cent (Kishore *et al*., 2017) without reduction in rice yield.

Crop yield

A review of reports on AWD yields shows a mixed picture depending on the severity of soil moisture deficit (Davies *et al.,* 2011). The AWD practice has been found to give lower (Bouman and Tuong, 2001; Yadav *et al.,* 2012), similar (Cabangon *et al*., 2004; Chapagain and Yamaji, 2010; Yao *et al*., 2012) and higher rice yield (Belder *et al*., 2004; Yang *et al.*, 2009; Zhang *et al*., 2009) compared to continuous flooding practice. Kannan (2014) reported that the conventional method of irrigation practice produced higher grain and straw yields and it was comparable with AWD irrigation regime of 5 and 10 cm drop of water table. Irrigation to rice two days after disappearance of ponded water at vegetative phase was found to be the best irrigation practice for getting higher grain yield (Uppal *et al.,* 1991 and Patel, 2000). AWD improves yield by increasing the proportion of productive tillers, reducing the angle of the top most leaves (thus allowing more light to penetrate the canopy), modifying shoot and root activity *i.e.* altered root-to-shoot signaling of phytohormones *viz.*, Abscisic Acid and cytokinins (Yang and Zhang, 2010) and also remobilization of carbohydrates from stems to the grain could represent another important mechanism of improving grain filling under AWD treatments (Yang and Zhang, 2010). The total dry matter, grain and straw yield were significantly influenced by different irrigation schedules on red sandy loam soils was recorded by Avil Kumar *et al.* (2006), maximum grain yield (4240 kg ha^{-1}) was recorded with irrigation daily (continuous submergence) and it was significantly superior to the remaining treatments, irrigation once in 4 days (3710 kg ha^{-1}), irrigation once in 5 days (3350 kg ha^{-1}), irrigation once in 6 days (3020 kg ha^{-1}), irrigation for 5 days and no irrigation for 5 days (3800 kg ha^{-1}) and irrigation for 7 days and no irrigation for 7 days (3610 kg ha^{-1}) but irrigation once in 2 days for which grain yield was comparable (4011 kg ha^{-1}). Likewise, Tabbal *et al*. (2002) recorded that maintaining a very thin film of water layer at saturated soil condition or AWD can reduce water requirement by almost 40-70 per cent compared to traditional practice of continuous submergence without any significant yield loss. On the other hand, hair line crack formation under AWD irrigation practice at 5cm drop of water level in the field water tube and 3 days after disappearance of ponded water (DADPW) (5751 kg ha^{-1}) also attained on par yield with recommended submergence of 2-5 cm water level as per crop stage (5926 kg ha^{-1}) (Sathish *et al*., 2017). 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 continuous submergence was recorded by Kishor *et al*. (2017). The multi location trials on intermittent irrigation conducted in rice in India at six stations *viz.*, Pusa, Madhepura, Pantnagar, Ludhiana, Hissar and Kota, revealed that the paddy yield noticed at par with traditional method of water management except at Hissar and Pantnagar locations, where in paddy yield was comparatively low in intermittent irrigation (Chaudhary, 1997). The lower rice yield (58% lower than flooded rice) observed in alternate wetting and drying water management practice was mainly due to lower leaf area index (LAI) at booting and anthesis, less shoot dry weight and lower root length density from booting to harvest by (Grigg *et al.,* 2000). Under AWD water management of rice in Telangana state, Sharath Chandra *et al.* (2017) noticed that the variety Bathukamma (6468 kg ha^{-1}) recorded significantly higher grain yield than Telangana Sona (5820 kg ha^{-1}), Sheetal (5748 kg ha^{-1}) and was at par with Kunaram Sannalu (6318 kg ha^{-1}).

Water use and productivity

There are no precise data available on the amount of irrigation water used by all the rice fields in the world. However, estimates can be made on total water withdrawals for irrigation, the relative area or irrigated rice land (compared with other crops) and the relative water use of rice fields. Water requirement for irrigated rice among all the establishment methods was 900-2250mm. It includes land preparation (150-200 mm), evapo-transpiration(500-1200 mm), seepage and percolation (200-700 mm), midseason drainage (50-100mm) (Mahender Kumar *et al*., 2015). Kumar *et al.* (2008) observed that the total quantity of water required by rice ranges between 1004 to 1014 mm and 1324 to 1348 mm for unpuddled and puddled condition, respectively. Higher amounts of carbon were released from roots in to the soil under non flooded and AWD regimes than in continuously flooded cultivation leading to higher microbial numbers and biomass in the rhizosphere of rice (Tian *et al*., 2012).

Shantappa *et al.* (2014) conducted a field experiment at Hyderabad based on the different water levels and noticed that continuous submergence showed significantly higher quantity of water applied (1433 mm) than alternate wetting and drying (1151mm) and saturation (960 mm). Recommended submergence of 2-5 cm water level as per crop stage consumed more water (1819.7 mm) in field experiment on sandy loam soil at Hyderabad than irrigation of 5 cm, when water level falls below 5 cm from soil surface in field water tube (1271.7 mm), irrigation of 5 cm at 3 days after disappearance of ponded water (1154.7 mm) and irrigation of 5 cm, when water level falls below 10 cm from soil surface in field water tube treatments were recorded least water consumption (1085 mm) among different irrigation regimes (Sathish *et al*., 2017). 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. Whereas, the effective rainfall was varied between 238 to 300 mm suggesting that the crop in AWD irrigation regimes 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 (Kishore *et al*., 2017). Flooded irrigation with standing water throughout the rice growing season was used in the traditional rice cultivation (Mao *et al*., 2001). A typical vertical cross-section through a puddled rice field shows a layer of 0-10 cm of ponded water. 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). Based on experiments with AWD in lowland rice areas in China and the Philippines, Bouman and Tuong (2007) reported that total (irrigation + rainfall) water inputs decreased by around 15-30 per cent without a significant impact on yield. Continuous water submergence recorded more irrigation requirement (1,200 and 1,080 mm) compared with 1- day drainage (840 and 680 mm) and 3- day drainage (600 and 560 mm in first and second year of study, respectively). Water application during rice cultivation has certain degree of changeability and flexibility.

Mao *et al.* (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 *et al*., 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 (Bouman *et al.*,2007; Dong *et al.*, 2012; Tan *et al.*, 2013). Reductions in irrigation water in AWD by 40-50 per cent, 20-50 per cent and over 50 per cent, respectively compared to continuous flooding of rice crop were noticed respectively by Keisuke *et al*., 2007, Singh *et al*.,1996 and Zhao *et al*., 2010. Continuous submergence consumed highest total water use (122.2 cm) produced the lowest grain yield (4.71 t ha^{-1}) resulting in to lowest water use efficiency (84.34 kg ha^{-1}cm). on the contrary, application of irrigation water to 5 cm depth when water level in PVC pipe fell to 15 cm below ground level gave the highest yield (5.69 t ha^{-1}) consequently the highest water use efficiency (85.55 kg ha^{-1} cm) with quite a large water saving (15 cm) compared to continuous submergence (Rahman and

Shiekh, 2014). There was saving of water by 36.5, 28.5 and 40.4 per cent respectively compared to continuous submergence, though there was reduction in grain yield by 5.4, 6.5 and 12.3 per cent due to irrigation of 5 cm at 3 DADPW, irrigation of 5 cm when water falls below 5 cm from soil surface in field water tube and irrigation of 5 cm when water falls below 10 cm from soil surface in field water tube, respectively (Sathish *et al*., 2017).

Water Productivity (WP) is a concept of partial productivity and denotes the amount or value of product (in our case, rice grains) over volume or value of water used. Discrepancies are large in reported values of WP of rice (Tuong, 1999). These are partially caused by large variations in rice yields, with commonly reported values ranging from 3 to 8 tons per hectare. But the discrepancies are also caused by different understandings of the denominator (water used) in the computation of WP. To avoid confusion created by different interpretations and computations of WP, it is important to clearly specify what kind of WP we are referring to and how it is derived. Common definitions of WP are

WP_T: weight of grains over cumulative weight of water transpired.

WP_{ET}: weight of grains over cumulative weight of water evapo-transpired.

WP_I: weight of grains over cumulative weight of water inputs by irrigation.

WP_{IR}: weight of grains over cumulative weight of water inputs by irrigation and rain.

WP_{TOT}: weight of grains over cumulative weight of all water inputs by irrigation, rain, and capillary rise.

Breeders and physiologists are interested in the productivity of the amount of transpired water (WP_T), whereas farmers, agronomists and irrigation engineers/managers are interested in optimizing the productivity of irrigation water (WP_I). To regional water resource planners, who are interested in the amount of food that can be produced by total water resources (rainfall and irrigation water) in the region, water productivity with respect to the total water input by irrigation and rainfall (WP_{IR}) or to the total amount of water that can no longer be reused (WP_{ET}) may be more relevant. Water productivity of rice with respect to total water input (irrigation plus rainfall) ranges from 0.2 to 1.2 g grain kg^{-1} water, with 0.4 as the average value, which is about half that of wheat (Tuong *et al.,* 2005). Comparing WP among seasons and locations can be misleading because of differences in climatic yield potential, evaporative demands from the atmosphere or crop management practices such as fertilizer application.

The water productivity of rice is much lower than those of other crops. On an average, 2500 litres of water is used, ranging from 800 litres to more than 5000 litres to produce one kg of rice (Bouman, 2009). In general irrigation water productivity in continuously flooded rice found to be typically ranges between 0.2 - 0.4 kg m^{-3} of grain water in India assessed through secondary data and remote sensing technique. Rice irrigation water productivity was found highest in Jharkhand (0.75 kg m^{-3}) followed by Chhattisgarh (0.68 kg m^{-3}) and Bihar (0.48 kg m^{-3}) among different states in India and lowest was Maharashtra (0.17 kg m^{-3}) followed by Punjab (0.22 kg m^{-3}). Where as in Telangana and Andhra Pradesh irrigation water productivity for rice found was 0.30 and 0.31 kg m^{-3} while physical water productivity was 0.46 and 0.44 kg m^{-3} respectively (Sharma *et al.,* 2018). AWD involves practice of water scarcity in irrigated rice cultivation and enables more effective water and energy use there by the water productivity i.e. the volume of irrigation water required to produce a certain quantity of rice increases compared to conventional cultivation (Lampayan *et al.,* 2009 and Bouman *et al*., 2007). Anbumozhi *et al*. (1998) observed increased water productivity (1.26 kg m^{-3}) in plot at 9 cm ponding depth compared to continuous flooding (0.96 kg m^{-3}). Whereas, water saving rice irrigation practices increases water productivity up to maximum of 1.9 kg m^{-3} (Bouman and Tuong, 2001). Likewise, Chapagain and Yamaji (2010) recorded higher water productivity (1.74 g L^{-1}) in AWD compared to continuously flooded rice (1.23 g L^{-1}). Higher water productivity (0.63 and 0.37 kg m^{-3}) by AWD in SRI and normal transplanting methods was obtained in comparison to saturation and flooding practices (Shantappa *et al.,* 2014). Expectedly water productivity was inversely related to water input. Water productivity of continuous submergence (0.56 kg m^{-3}) was lowest as compared to AWD - Flooding to a water depth of 5 cm when water level drops to 10 cm below ground level (0.94 kg m^{-3}) (Kishor *et al.,* 2017). Irrigation once in seven days to maintain field saturation consumed lowest amount of water (80.30 cm) and saved 41 per cent irrigation water over 2.5 to 5.0 cm continuous submergence till 15 days before harvest without any significant reduction in grain yield (Ganesh, 2000). The irrigation schedule of one day after disappearance of ponded water consumed 604 mm less irrigation water and recorded higher water use efficiency (76 kg $ha^{-1}day^{-1}$) when compared to irrigating a continuous submergence in rice at Chhattisgarh (Pandey *et al.,* 2010). Rezaei *et al.* (2009) stated that longer irrigation interval (5 and 8 days) decreased the water use, by 40 and 60 per cent, respectively in comparison to full irrigation, but increased the water productivity without any yield loss. The majority of the farmers who practices the AWD gave positive feedback about the effectiveness of AWD as a water-saving technology as follows: (1) no yield difference from the farmers' practice of continuous flooding (2) saves water (3) saves time and labour and thus less expensive (4) heavier and bigger grains with good shape (5) more tillers and (6) fewer insect pests and diseases (Palis *et al*., 2004).

Green House Gas (GHG) emissions

Rice cultivation under flooded conditions is responsible for 10-16% GHG emissions from agriculture in different countries. The growing of rice in flooded fields produces methane- a potent green house gas because the standing water blocks oxygen from penetrating the soil, creating conditions conducive for methane producing bacteria. The dominant species of methanogens were *Methanobacterium formicicum, Methanobrevibacter sp., Methanosarcinamazeii* and *Methano sarcinabarker*i (Li *et al*., 2006). Application of fertilizers, especially organic manure and submergence with deep water increased the population and activities of methanogenic bacteria in rice soils. The methanogenic bacteria that survived in soil could form methane after addition of water and incubation. Shorter flooding intervals and more frequent interruptions of flooding in rice fields reduces the emission of methane by reducing the populations of methane producing bacteria and stimulating the breakdown of methane by other bacteria (Li *et al.,* 2006 and Wassmann *et al.,* 2010). AWD reduces the amount of time rice fields are flooded and is assumed o reduce the production of methane by about 30-50%. Draining practice had a strong effect on methane emission (Kazuyuki Yagi *et al.*, 1996). Intermittent dry and irrigated in partially flooded condition reduced methane emission by 60% and 83% respectively (Vu *et al.*, 2005 and Min *et al.*, 1997).

In conclusion, improved water management in rice production systems has the potential to significantly reduce agricultural green house gas emissions, while reducing fresh water use, increasing the profitability of rice farming, and maintaining the yields of one of humanity's staple crops. From the above discussion it can be concluded that the safe AWD irrigation practice and concept using field water tube installed in rice paddies was found to be technically feasible for field application in view of its low cost, simplicity and can be locally fabricated. AWD irrigation had significant effect on water saving and water productivity of rice. There was a saving of irrigation water by 20-50% over normal submergence. Water productivity and reduced GHGs emissions are the positives that are driving scientists to refine the technology for every ecosystem and make it more farmer friendly.

Details on timing of drying, particularly vegetative and reproductive stages duration of drying need to clear before recommendation. However, AWD has not been widely adopted, in part, due to the apprehension of yield reductions and hence demands greater efforts from researchers and extension workers. Safe AWD threshold level found to be 5 - 15cm water fall below surface in field water tube which needs to be validated in different soil types and different climatic conditions. Proper management of water in safe threshold is the foundation of AWD to realize potential yield while saving water. Much work remains to be done to reliably estimate these benefits and to encourage adoption of these practices at the necessary scale. None the less, improved water management in rice production systems is likely to be an important item on the menu for a sustainable food future.

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