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REVIEW ARTICLE

Alternate wetting and drying (AWD) irrigation for rice to enhance water productivity and sustainable production: A review

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Abstract: Major challenges in rice growing ecosystems are increased productivity and reduced water requirement. Rice is especially sensitive to declining water availability towards maturity since it requires more water than any other food crop and has relatively low water productivity. One of the technology options that can help farmers cope up with water scarcity at the field level is alternate wetting and drying (AWD).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 20-30 % besides reducing greenhouse gas emissions 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 extension workers.Proper management of water in safe threshold is the foundation of AWD to realize potential yield while saving water. This paper is an attempt to enlighten stakeholders in rice production on AWD principles and practices, and its influence on water productivity.

Key words: Flooding, Rice, Transplanting, Water productivity

Introduction

Rice is a major staple food for the world's population with about two-thirds of the total rice production grown under irrigation (Muthayya *et al.,* 2014). India having an estimated population of 1.4 billion by 2025 requires another 30 m t or more of grains over the present production of 272 m t and this production has to come from improved productivity enabled through technological advances. Today this has to be achieved even with diminishing arable land, water scarcity, rising cost of cultivation and inclement weather due to climate change. 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. Gone are the days the luxury agriculture had and flooding would be crime in days to come. Water resources both surface and underground are shrinking and water has become a limiting factor in rice production (Farooq *et al.,* 2009). Rice production in tropics is also has several negative impacts. First rice requires higher water inputs than other cereal crops, increasing food demand from growing population and decreasing water availability, secondly global warming potential elevated to other crops by methane emission (Linquist *et al.,* 2012; Wassmann *et al.,* 2010), finally continuous flooding and intensive cultivation has led to poor soil health. Shrinking availability of water to agriculture, available are the two exclusive options; one is to minimize water lossesthrough better management practices thus ensure more water for crop production, and the other is to improve water productivity i.e., increase production per every unit of water applied. In India rice is grown in different ecosystems *viz.,* wet lands (45%), shallow rainfed lowlands (33%), rainfed uplands (15%) and deep water rice (7% in India).

In irrigation commands soil type influences the quantum of water at every irrigation besides its scheduling. For instance, coarse textured soils with greater percolation losses need shallow and frequent irrigation while in fine textured soils heavy irrigation at prolonged interval may be considered. Apart from soil, land levelling is one important management practice that has tremendous impact on water use as levelled land facilitates uniform water application in less time and thereby reduces local variability in soil moisture and ensures uniform crop stand. For instance, use of laser leveller is reported to save 6% of irrigation water. In traditional transplanting system in rice, puddling creates a hard pan below the plough zone and reduced soil permeability, while it enhanceshigh usage for puddling operation accompanied subsequently by heavy surface evaporation and deep percolation.

Water use and productivity

Rice is a major staple food crop with more than 50 kg of rice being consumed per capita per year worldwide (FAOSTAT 2016). Globally, over 478 million tons of milled rice was produced in 2014-15 of which over 90% was used directly for human consumption. While rice is essential for ensuring global food security, traditional rice cultivation, practiced in flooded paddy soils, demands higher water inputs than other cereal crops (Pimentel *et al.,* 2004). With the increasing threat of water scarcity currently affecting 4 billion people around the globe (Mekonnen and Hoekstra 2016), it is crucial to develop agronomic practices with the potential to reduce water use while maintaining or increasing yields to support a growing population.

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 based on total water withdrawals for irrigation, the relative area of irrigated rice land (compared with other crops), and the relative water use of rice fields. Total worldwide fresh water uses are estimated at 3,600 km^3 annually, of which 2,500 km^3 is used to irrigate crops (Falkenmark and Rockstrom 2004). The rest is used in industry and for domestic purposes. Approximately 56 % of the world's 271 million ha of irrigated area of all crops is in Asia, where rice accounts for 40-46 % of the net irrigated area of all crops (Dawe, 2005). Water requirement of irrigated rice among all the establishment methods was 900-2250 mm. It includes land preparation (150-200 mm), evapo-transpiration (500-1200 mm), seepage and percolation (200-700 mm), midseason drainage (50-100 mm) (Mahender Kumar and RavindraBabu, 2015).

At the field level, rice receives up to 2-3 times more water than other irrigated crops, but an unknown proportion of the water losses from individual fields are reused by other fields downstream. Assuming a reuse fraction of 25 %, it can be estimated that irrigated rice receives some 34-43 % of the total world's irrigation water, or 24-30 % of the total world's freshwater withdrawals. More than 75 percent of the world's rice is produced in irrigated rice lands, which are predominantly found in Asia. Rice grown under traditional practice in the Asian tropics and subtropics requires between 700 and 1,500 mm of water for a cropping season depending on soil texture (Bhuiyan, 1992). AWD relative water use was not affected by soil texture or number of drains. Carrijo *et al.,* (2017) analysed that even under mild AWD in clayey soils yield reduced not so in non-clayey soils. More research evidence are needed in this direction.

Alternate methods

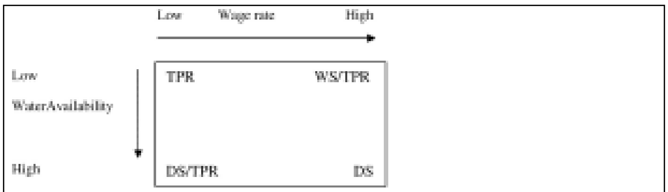


Fig. 1Factors affecting the choice of rice establishment methods
(Adapted from Pandey and Velasco, 2002)
TPR - transplanting, WS - wet seeding, DS - dry seeding

A number of water-efficient irrigation strategies, therefore, have been tested, advanced, applied and spread in different rice growing regions *viz.*, combining shallow water depth with wetting and drying (SWD), alternate wetting and drying (AWD), semi-dry cultivation (SDC), aerobic rice (AR), and non-flooded mulching cultivation (NFMC), intermittent dry spells and so on (Mao, 2001; Feng *et al.*, 2007; Zhang *et al.,* 2009). Among the various methods, the most widely promoted one for rice is AWD irrigation, also referred as 'alternate submergence-non-submergence' or 'intermittent irrigation'(Belder *et al.,* 2004; Tuong *et al.,* 2005; Cabangon *et al.,* 2011). Under AWD, fields are subjected to intermittent flooding (alternate cycles of saturated and unsaturated conditions) where irrigation is interrupted and water level is allowed to subside until the soil reaches a certain moisture level, after which the field is reflooded. AWD has been reported to reduce water inputs by 23 % (Bouman and Tuong, 2001) compared to continuously flooded rice systems.

Alternate wetting and drying

In alternate wetting and drying (AWD), irrigation water is applied to obtain flooded conditions after a certain number of days have passed after the disappearance of impounded water. The number of days of non-flooded soil in AWD before irrigation is scheduled can vary from one day to >10 days which is very important because water withheld is water saved. AWD consists of three key elements (Bouman *et al.*, 2007a): (1) shallow flooding for the first 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), (2) 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 (3) 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.

Another important in-built advantage with AWD which is critical in the context today's much scared global warming impacts is that it also has the potential of reducing greenhouse gas (GHG) emissions from rice fields, especially methane (Wassmann *et al.,* 2010 and Li *et al.,* 2006). Linquist *et al.* (2014) reported that AWD reduced global warming potential (CH_4+ N_2O) by 45-90% compared to continuously flooded systems. With the anthropogenic emissionsof GHGs now in the order of 48 Gt CO_2eq. year^{H1} (Montzka et al., 2011), there have been efforts worldwide to promote AWD in rice in an attempt to reduce GHGs emissions. For example, in the USA, theAmerican Carbon Registry recently approved a methodology called 'Voluntary Emission Reductions in Rice Management Systems' which allows farmers to receive carbon credits for various practicesthey adopt in their rice systems, including AWD.

Water productivity

In traditional rice cultivation, flooded irrigation with standing water is maintained throughout the rice growing season (Mao, 2001). However, now it is proved beyond doubt that there is no necessity to maintain continuous standing water since irrigated rice can withstand intermittent flood condition and possesses 'semi-aquatic nature' in the process of plant development (Bouman *et al.,* 2007a; Kato and Okami, 2010). Wu (1998) and Mao (2001) stated that AWD conformed to the physiological water demand of paddy by rationally controlling water supply during rice's key growth stages enables cut down of irrigation water.

Alternate wetting and drying intervals (AWDI) can save a significant amount of irrigation water (28%) without affecting grain yield (7.4 t ha^{-1} with AWD compared against 7.37 t ha^{-1} from normal planting with ordinary water management) (Chapagain and Yamaji, 2010). Water productivity was observed to be significantly higher in all combinations of practices in the intermittent irrigation plots; 1.74 g l^{-1} with SRI management and AWDI compared to 1.23 g l^{-1} from normal planting methods with ordinary water management.

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 provided to accelerate soil organic matter mineralization and inhibit soil N immobilization. This in turn increases soil fertility and make more essential plant-available nutrients to favour rice growth (Wu, 1998; Bouman *et al.,* 2007; Dong *et al.,* 2012; Tan *et al.,* 2013). Sun *et al.* (2012) elucidated differential responses to physiological and biochemical changes in rice wherein higher activities of ammonia assimilation enzymes (glutamine synthetase, glutamate synthase, and glutamate dehydrogenase) which are the main enzymes involved in plant N metabolism were obtained under intermittent irrigation than under impounded (flooded)condition.

In all, in intermittent flooding,rice root growth is promoted and well extended, plant N metabolism is strengthened and the leaf photosynthetic rate is further improved, and all these together help production of more assimilatesfrom above ground parts of plants which finally promote formation of high yield groups. Through these improvements in plant internal physiology and external morphology, AWD would not only reduce water consumption but also increase root and panicle biomass and maintain high grain yield (Yushi *et al.,* 2013).

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 1 kg of rough rice (Bouman, 2009). An increase of10% irrigation efficiency can help bring additional 14 million ha area under irrigation. Nevertheless, sole reduction in water use in puddle transplanted rice (PTR) results in proportional reduction in yield, unless various other management practices of rice cultivation have been simultaneously modified to enhance water productivity, without reducing the productivity of other factors, primarily land (*i.e.* yield), labour and fertilizer.

Rehman and Bulbul (2014) obtained the highest grain yield (5.69tha^{-1}) from treatment of irrigation when water is below 15cm from the soil surface and, interestingly the lowest grain yield (4.71t/ha) was obtained from continuous standing water. Thus, they revealed that grain yield in rice do not decrease when plants are subjected for a short water stress. But this would be a substantial saving in water. For instance, Lampayan *et al.* (2015) reported that AWD reduced total irrigation input by an average of 24% over two years of study. All farmer-co-operators acknowledged that AWD savedtime, labour, and expense, including a 20–25% reduction in the use offuel and oil. It reduced labour as farmers generally spent fewer hoursirrigating their crops.Yushi *et al.,* (2013) confirmed that AWD significantly reduced the number of irrigation (5 in 2010 and 3 in 2011) and the amount of irrigation water (41.9% in 2010 and 28.0% in 2011) compared to continuous flooding (CF).

Crop yields

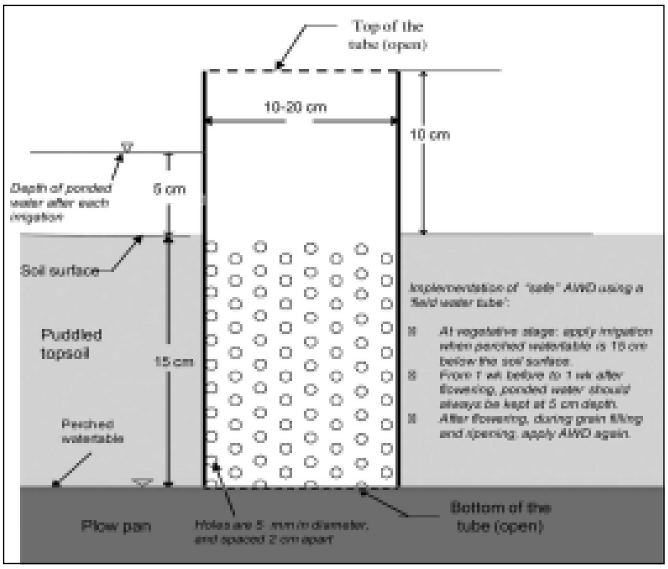
Water shortage during the dry season of irrigated rice farming in the Mekong Delta, Vietnam, is projected to become a growing problem due to climate change and upstream human development of the Mekong River Basin (Snidvongs and Teng, 2006). Water saving agricultural practices, therefore, are thus expected to become increasingly adopted by the farmers in the region, which is one of the most important rice-producing areas in the world, with typically three yearly irrigated rice crops. Already, alternating wetting and drying (AWD) practices are commonly used as a water-saving practice in many countries such as China (Cabangon *et al.,* 2004), the Philippines (Belder *et al.*, 2004), and Japan (Chapagain and Yamaji, 2010).

For AWD practices, the fields are managed as irrigated lowland rice but the top soil layer is allowed to dry out to some degree before irrigation is applied again (Bouman and Tuong, 2001; Belder *et al.,* 2004). The number of days under non-flooded soil conditions can vary depending on plant development stages and availability of water. The AWD practice has been found to give lower (Eriksen *et al.*, 1985; Bouman and Tuong, 2001), similar (Cabangon *et al.,* 2004; Chapagain and Yamaji, 2010) or higher rice yield (Belder *et al.*, 2005; Ceesay *et al.,* 2006; Zhang *et al.*, 2009) compared to conventional continuous flooding (CF) practices, but the underlying causes are generally unknown.Although AWDI plots with younger seedlings and wider spacing produced more yield (7.41 t/h) compared to the ordinary plots transplanted with normal seedlings at closer spacing (7.37 t/h), in general, rice yields under non-flooded conditions were lower compared with the same combinations in continuously flooded plots. Over 4 years of study LaHue *et al.* (2016) have reported that significant differences occurred between years, with mean yields ranging from 8.6 $\pm$ 0.9 t ha^{-1} in 2014 to 13.7 $\pm$ 0.3 t ha^{-1} in 2015. Many studies of AWD have reported reductions in yield.Norton et al., (2017) reported that AWD enhanced 12.0-15.4% higher grain mass over conventional flooding due to higher productive tillers and grain filling. Carrijoet al. (2017) found that although AWD reduced yields by 5.4% overall, the effect was moderated by the severity and timing of drying events, and soil characteristics such as pH <7 and soil organic C >1% protected against yield reductions.Severe AWD yield is reduced more in high pH soils than in low pH soils.

Concept and technology of AWD

The field water tube (*Panipipe*) can be made of 30 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 with many holes on all sides, so that water can flow readily in and out of the tube. Hammer the tube into the soil such that 15 cm top of the pipe protrudes above the soil surface. Take care not to penetrate through the bottom of the plough 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.,* 2014). 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)(Fig. 1). During AWD implementation, the field is irrigated to a depth of around 5 cm whenever the ponded water level has dropped to about 15 cm below the surface (as outlined in rice knowledge bank IRRI).



It involves the partial drainage of rice fields, which is done by irrigating the fields to the desired depth and then re-irrigating after some time, when the water dissipates. Demonstration trials and training have been conducted in eight countries in Asia, with large scale adoption in the Philippines, Vietnam and Bangladesh. AWD has reduced irrigation water input by up to 38% with no yield reductions if implemented correctly. Water pumping expenses and fuel consumption decrease also, thus increasing farmers' income by 38% in Bangladesh, 32% in the Philippines, and 17% in southern Vietnam, based on "with and without" AWD comparison.

Nutrient management

Local fertilizer recommendations as for flooded rice can be used. Apply fertilizer N preferably on the dry soil just before irrigation. The threshold of 15 cm water depth (below the surface) before irrigation is called 'Safe AWD" as this will not cause any yield decline. In Safe AWD, water savings are in the order from 15 to 30%. After creating confidence that Safe AWD does not reduce yield, farmers may experiment by lowering the threshold level for irrigation to 20, 25, 30 cm depth, or even deeper.

Challenges in maintaining the sustainability of rice farminghave been increasing with the increased scarcity of and competition for water resources, stagnant or declining yield levels with low grain quality, and increasing production costs due to high dependence on agri-inputs. However, despite these constraints, rice production must rise dramatically over the next generation to meet the world's food needs and especially those

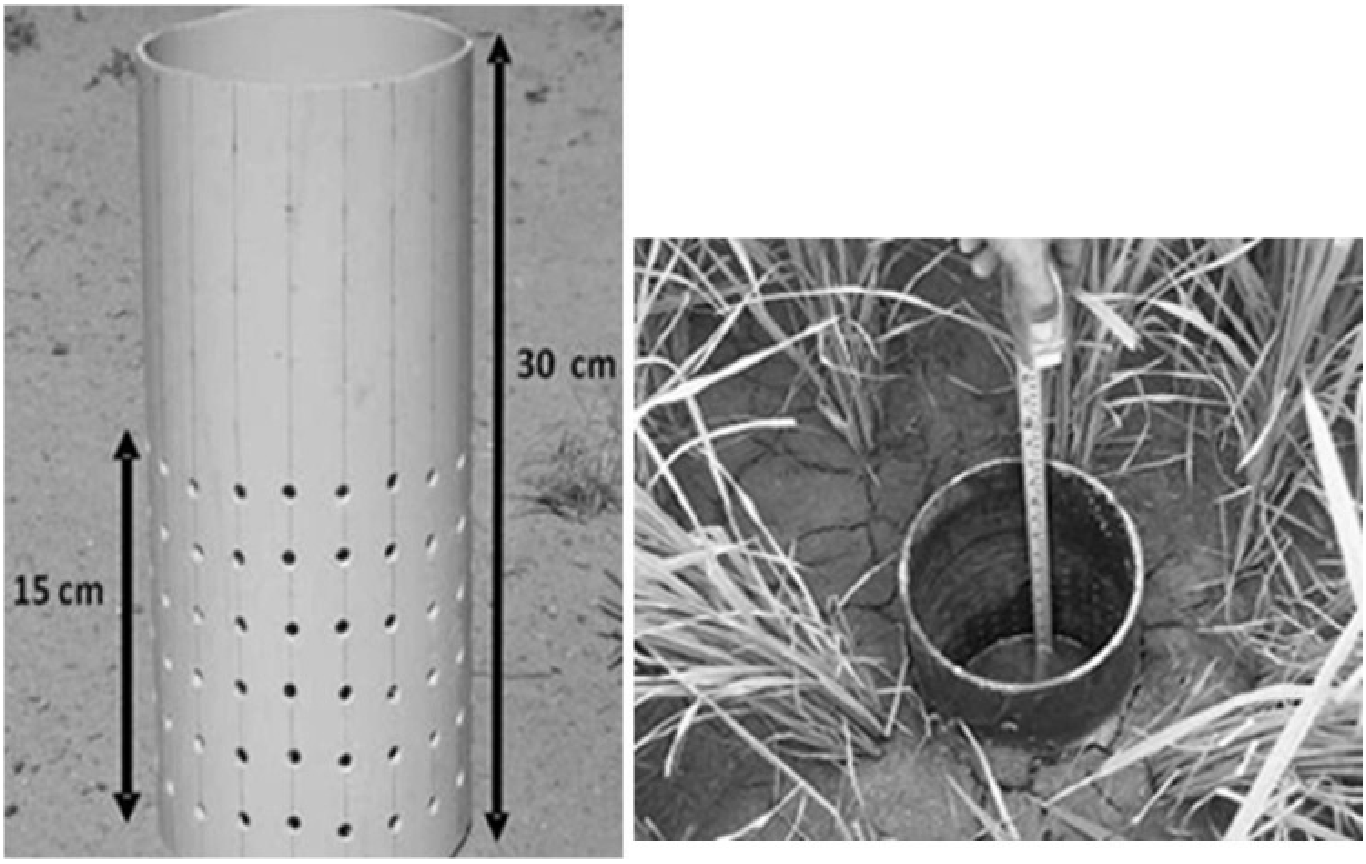


Fig 1: Field water tube as a simple tool to implement safe AWD (Bouman *et al.*, 2007 and Rice Knowledge Bank, IRRI)

of the poor. Hence, producing more rice with less resource input is a formidable challenge for ensuring the food, economic, social, and water security of the Asian region.

Table 1. Grain yield of rice under different crop establishment methods and irrigation treatments

Source	Treatment	Yield (t ha^{-1})
Bueno *et al*. (2010)	Flooded	8.59
	AWD	8.21
Yao *et al*. (2012)	Flooded	7.31
	AWD	7.26
Bouman *et al*. (2007)	Flooded	5.06
	Aerobic	4.36
Latif *et al*. (2009)	SRI	6.37
	BMP	6.15
	Farmers practice	4.94
Bhusan *et al*. (2007)	DSR	7.20
	TPR	6.60

Loss of fertilizer-derived N_2 from continuous flooded soils has been found to be rather low (<10%, Nicolaisen *et al.,* 2004) but only a little information is available on N budgets and soil microbial activities in AWD-based rice systems. The alternating oxic and anoxic top soil conditions imposed by AWD irrigation may lead to increased N losses from coupled nitrification-denitrification (Nicolaisen *et al.,* 2004; Liu *et al.*, 2010). Reddy and Patrick (1975) observed that about 24% of the total N applied was lost in a laboratory experiment after 32 cycles of alternate anoxic and oxic soil conditions. Likewise, greenhouse (Eriksen *et al.,* 1985) and field studies (Liu *et al.,* 2010) revealed that AWD can increase fertilizer loss via denitrification, whereas other researchers have shown that AWD does not enhance N_2 loss (Khind and Ponnamperuma, 1981; Fillery and Vlek, 1982). These somewhat conflicting results may be due to differences in soil type, N fertilization regime, intensity of soil desiccation, soil nitrifying activity, rate of N uptake in rice, and methodology applied.

Although denitrification loss may sometimes be significant, ammonia (NH_3) volatilization is typically the most important pathway of fertilizer N loss from irrigated rice field (Eriksen *et al.,* 1985; Fillery and Vlek, 1982; De Datta *et al.,* 1991). However, very little research has been done to quantify the impact of AWD on ammonia volatilization. Work done so far does not agree on the effects of AWD on ammonia volatilization rates. Ventura and Yoshida(1977) found that ammonia volatilizationwas lower in AWD than in CF soils. Contradicting this, Patel *et al.*(1989) reported that ammonia volatilization was almost the same for AWD and CF if the water level was kept shallow and that increasing the water level reduced volatilization significantly. The latter fact proved right as many recent studies revealed that high irrigation water level reduces ammonia loss, most likely due to an NHþ 4 dilution effect (Win *et al.,* 2009 and 2010). On the other hand, shallow irrigationwater has been suggested to lower ammonia volatilization due to enhanced ammonium (NH_4) binding in the soil (Li *et al.,* 2008). Nevertheless, drainage and re-flooding of paddy fields before and after applying urea may reduce ammonia loss (Zhu *et al.,* 1989). Whereas, Banerjee *et al.* (2002)reported that the total amount of NH_3 volatilization in rice ranged from 13.8 kg N ha^{-1} in the unfertilized plots at intermittent wetting and drying to 29.3 kg N ha^{-1} in the urea treatment at a saturated soil moisture regime

Xuezhi *et al.* (2013) revealed that AWD reduced irrigation water without a significant impact on grain yields and increased the mean water productivity by 16.9 % compared with continuously flood irrigation (CFI). The mean nitrogen productivity of 135 kg ha^{-1} N level was 22.2 % higher than that of 180 kg ha^{-1} N level, although grain yields substantially increased because of nitrogen fertilization application. The percolation was also reduced by 15.3 % in 2007 and 8.3 % in 2008 compared to CFI.

Pests and diseases

Low incidences of diseases and pests have been observed in AWD. This lower incidence with AWDI was considered tobe due to a less favorable environment for disease and pestdevelopment due to alternate wetting and drying periods.Chaboussou (2004) reported that plants which are notsubjected to chemical (inorganic) fertilization and agrochemicalprotection measures are more resistant to lossesfrom pests or diseases, enough so that chemical protectionbecomes less necessary or uneconomic because of adverseeffects on plant metabolism and nutrition.Increased weeding requirement with SRI has beenconsidered as a major shortcoming of the innovation. It isgenerally assumed that weeds will become a major problemwith intermittent irrigation. However, it is worth notinghere that there was no extra time requirement forweeding in AWDI plots in this experiment. This could bethe combined effect of having standing water on the fieldfor a fortnight after transplanting, and the single applicationof a herbicide 10 days after transplanting. However, arrowhead (Sagittaria spp.) was commonlyobserved followed by someother narrow leaved weeds.

Active soil aeration

One strategy proposed is the system of rice intensification(SRI) as a more efficient, resource saving, and productiveway to practice rice farming. It involves changes in certainmanagement practices which jointly provide better growingconditions for rice plants, particularly in the root zone, thanthose presently provided to the plants grown under traditional practices.SRI is a set of ideas and insights that emphasize the use of younger seedlings (15 days) planted singly and at widerspacing, together with the adoption of intermittent irrigation,organic fertilization, and active soil aeration to the extentpossible (Uphoff 2007; Stoop *et al.,* 2002).SRI, developed in Madagascar with the help of Malagasyfarmers, involves reduced water applications, including adoption of Alternate Wet and Dry Irrigation(AWDI) as a part of a new strategy of rice intensification,growing rice under mostly aerobic soil conditions. TheAWDI approach in cultivating riceis being increasingly used inparts of Asia, especially in China, Japan, and India, which meansrice fields are not kept continuously submerged but areallowed to dry intermittently during the rice-growing period (Van der Hoek *et al.,* 2001). AWDI can increase theproductivity of water at the field level by reducing seepageand percolation during the crop-growth period. While yield increases have been the focus of much discussion and evaluation of SRI, here we are also concerned with water productivity because of its importance for sustainable rice production.

The bigger challenge in adoption of AWD nutritional value of rice grain grown under aerobic or intermittent dry condition particularly, cadmium, arsenic, zinc iron etc. More evidenced proof is needed in this direction. Meharg *et al.* (2009) and Xu *et al.,*(2008) have showed cultivation of rice under anaerobic condition facilitate the mobilization of inorganic arsenic into soil solution. Further, reducing water usage during rice cultivation can decrease arsenic accumulation 10-fold in grain (Xu *et al.,* 2008; Norton *et al.,* 2019). Under more aerobic condition due to non-flood limited the activity of mercury methylating microbes and may be an effective way to reduce methyl mercury concentrations in rice ecosystems. Some micronutrients such as zinc become less available in flooded soils, but its availability and uptake into grains increased substantially in aerobic soils, as in uplands (Wissuwa *et al.*, 2008). Whereas in flooded soils availability of iron would be higher lead to toxicity as experienced in some coastal areas in Asia and in over 50% of paddy soils in Africa (Becker and Asch, 2005; Cherif *et al.*, 2009). The global challenge of sustainable rice cultivation, therefore, requires reducing the amount of water used for rice irrigation. Adoption of AWD by the rice growers need to be convinced in terms of water saving, yield sustenance, soil health.

Greenhouse gas (GHG) emissions

Rice cultivation practices that result in unsaturated soil conditions by way of reducing the continuous flood can save water and provide other benefits including reductions in methane emissions (Carrijo *et al.,* 2017; Li *et al.,* 2006; Wassmann *et al.,* 2010). Xu *et al.* (2015) reported that intermittent dry and irrigated in partially flooded condition reduced methane emission by 60% and 83% respectively.Whereas CO_2 and N_2O fluxes increased by 65% and 9% respectively. Although CO_2 and N_2O emissions increased, the global warming potential (GWP) and greenhouse gas intensity (GHGI) of all three GHG decreased by up to 25% and 29% (p<0.01), respectively. LaHue *et al.* (2016) reported that methane emissions occurred throughout the growing season in continuously flooded plots.Kazuyuki Yagi *et al.* (1996) also opined that the draining practice had a strong effect on CH_4 emission. Total emission rates of CH_4 during the cultivation period were 14.8 and 8.63 g m^{-2} for 1991 and 9.49 and 5.18 g m^{-2} for 1993 in the continuously flooded and intermittently drained plots, respectively. Min *et al.*(1997) observed that application of fertilizers, especially organic manure and submergence with deep water increased the population and methanogenic activities of methanogenic bacteria in rice soils. The methanogenic bacteria that survived in air-dried rice soil could form methane after addition of water and incubation. The dominant species of methanogens were Methanobacteriumformicicum, Methanobrevibacter sp., Methanosarcinamazeii and Methanosarcinabarkeri.

Conclusion

Overall, AWD appears promising and worthy technology and hence efforts are under way to popularize it in ecosystems severely constrained with water and where there is no alternative except rice. 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. Studies, however, on diseases like blast and usage change in pesticides are much warranted. Further, nutrient management, particularly those of micronutrients and breeding varieties especially suited for this system of rice culture would take the technology to the next level. Management guidelines are to be standardized in order to extrapolate these technologies to other similar locations using the available data listed in this paper. Details on timing of drying, particularly vegetative and reproductive stages duration of drying need to clear before recommendation. Literature have proven that AWD is promising water saving technology in rice growing ecosystem, but increased efforts are needed to scale out large scale adoption by minimizing local constraints.

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