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Scheduling of Irrigation Based on IW/CPE for Aerobic Rice – A Review

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ABSTRACT

The scheduling of irrigation according to the ratio between irrigation water depth (IW) and cumulative pan evaporation (CPE) rate for aerobic rice. During these days, the shortage of water resources is increasing continually due to climate change. It has led to the adaptation of rice farming under aerobic conditions. This saves irrigation water, labour, eliminates puddling, reduces seepage, percolation losses, and methane emissions. Aerobic rice cultivars produce higher plant growth, physiological, root growth, yield, water use efficiency, productivity, and soil nutrient uptake under different (0.6, 0.8, 1.0, 1.2, 1.4, 1.5, 2, and 2.5) IW/CPE ratios. Under these irrigation schedules, the yield of rice in aerobic soil is recorded at between 4.5 and 7.1 t ha^{-1} and the water use efficiency is from 25 to 70 kg ha^{-1}. However, the decline in yield or even crop failure under continuous monocropping, weeds, nematode problems, and aerobic rice micronutrient deficiency Our important findings in aerobic rice are: (1) Scheduling of irrigation based on various IW/CPE ratios recorded the higher rice plant height, number of tillers $hill^{-1}$, dry matter production, leaf area index, crop growth rate, relative growth rate, root length, productive tillers, number of grains $panicle^{-1}$, number of filled grain $panicle^{-1}$, total number of grains $panicle^{-1}$, test weight and yield; (2) The last 15 years of aerobic rice research findings focused on irrigation scheduling by IW/CPE ratio for driving economic water use; and (3) nutrient uptake increased with irrigation at more than 1.0 IW/CPE ratio with depth of 5 cm irrigation water. Declining water availability due to climate change makes it necessary to conduct more research on irrigation scheduling in rice crops in order to increase yield and water use efficiency.

Key words : *Aerobic rice, Constraints, Irrigation Schedule, IW/CPE, Growth, Yield, Water use efficiency.*

Introduction

Rice serves as the staple food for most of world population and grown with an area of 158.5 m ha, 470.6 mt of production and 4.43 t ha^{-1} of productivity. India is the world's second largest area of rice cultivation (103.5 mt) after China (145.7 mt), but still needs to produce 1.7 mt of rice every year to sustain our food security point of view (Dass and Chandra, 2013). In agriculture around 90 per cent of fresh water resources are utilized by rice in all Asian countries. In around the world about 80 per cent of rice is grown with 55 per cent in irrigated and 25 per cent in rainfed ecosystem, which majorly depends on fresh water resources (Belder *et al.*, 2005). In this connection, judicious use of irrigation water and

1*Assistant Professor, 2. Assistant Professor, 3. Professor suitable water saving practice in rice cultivation are needed in upcoming decades.

Usually, rice through aerobic cultivation is considered as one of the alternative approaches for conserving water, energy, and labour. Moreover, it is revealed that the emission of methane gas can be reduced by 80 to 85 per cent. It also ensures a reduction in the cost of raising a nursery and seedling transplanting (Kukal and Aggarwal, 2002). From this view, aerobic rice cultivation is a viable alternative to "produce more rice with less water utilization" to feed the growing population.

The urbanisation and rapid increase in the population reduce the availability of water for agriculture in India. Groundwater tables declined by an average of 0.5-0.7 m year^{-1} in the Indian states of Karnataka, Rajasthan, Punjab, Maharashtra, Haryana, and Gujarat. In Tamil Nadu and southern regions of India, about 1 million years^{-1} (Tuong and Bouman, 2003; Kadiyala *et al.*, 2012).

Asia's 2 m ha of irrigated rice under dry season and 13 m ha of irrigated rice under wet season may experience the physical scarcity of water (Fig. 1), and in South and Southeast Asia's 22 million ha of irrigated rice under dry season may suffer from economic scarcity of water by the year 2025 Tuong and Bouman (2003). For direct seeded rice, irrigation water savings of 35 to 57 percent have been calculated. In unpuddled rice cultivation, aerobic soil is kept near to saturation / field capacity as compared with continuously water logged rice cultivation (Sharma *et al.*, 2002; Singh *et al.*, 2002).

The direct seeded rice helps in reducing irrigation water use by early crop maturation (Gill and Dhingra, 2002). First, the direct seeding concept was advanced in China during the mid'1980s. The concept of "aerobic rice" was recently coined by IRRI, in which total water requirements are estimated at 650 to 830 mm from sowing to harvest and also increase water productivity by 20 to 40 percent (Castaneda *et al.*, 2005).

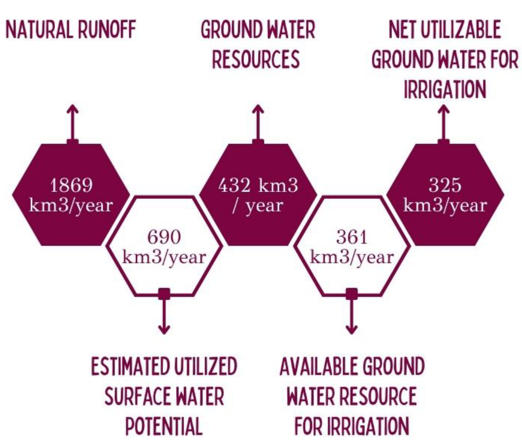

Fig. 1. Water availability and Use

Aerobic rice is one of the water saving technologies for growing rice by direct seeding with high yielding varieties in unpuddled conditions without flooding, and it is irrigated similarly to maize and pulse crops (Xiaoguang *et al.*, 2005). Aiming for high yield in aerobic rice cultivation requires supplementary irrigation and fertilizers, and yield is about 4.5 to 6.5 t ha^{-1}, which is roughly double the traditional upland varieties and approximately 20 to 30 per cent lower than the lowland cultivars grown in puddle transplanted rice cultivation (Belder *et al.*, 2005).

Aerobic rice occupies only about 10 to 15 percent of the land in India (Pasha *et al.*, 2011). Shortage of freshwater resources lead to the limits the production of the flooded / puddled rice crop in major rice producing countries like India and China (Shekara *et al.*, 2011). To achieve the highest rice production with shrinking resources, research are necessary to increase rice yield with supply of less irrigation water (Murthy *et al.*, 2012). Aerobic rice cultivation is not only a water-saving technique, but it also increases rice productivity (Kannan *et al.*, 2015).

Constraints in aerobic rice

Higher weed problems (Malik and Yadav, 2008), micronutrient deficiencies (Choudhury *et al.*, 2007; Kreye *et al.*, 2009), and nematode problems (Singh *et al.*, 2002; Choudhury *et al.*, 2007) were the primary constraints for limited grain yield in aerobic rice. Availability nutrient is a major constraint for growing rice in an aerobic conditions, the issues were immobilisation of phosphorus, increased leaching and volatilization of nitrogen in acidic soils (Ladha *et al.*, 2005). The alternate wetting and drying gradually reduced the increasing nitrogen mineralization when compared to flooded soil (Mikha *et al.*, 2005; Borken and Matzner, 2009) (Fig. 2).

In aerobic rice, high weed density was recorded in the aerobic field compared to puddled in the transplanted rice field. In the conventional rice cultivation method, weeds are suppressed by flooding standing water (Mahajan *et al.*, 2011). In an aerobic condition, increasing in duration of water stress or drought are reduces the yield of rice, and the dura-

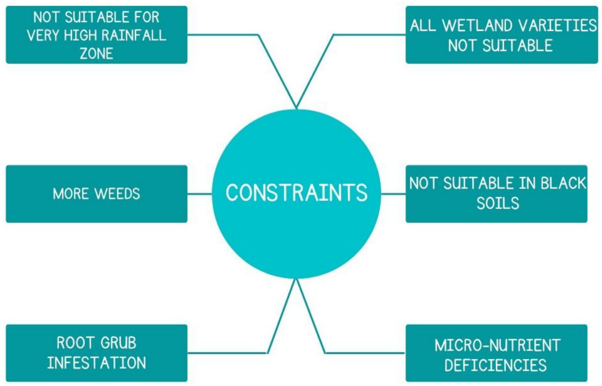

Fig. 2. Constraints in Aerobic Rice

tion of water stress varies with location to location and also soil types. Rice plants under aerobic condition experience deficiencies of different micronutrient such as Iron (Fan *et al*., 2012), Manganese (Kreye *et al*., 2009), and Zinc (Gao *et al*., 2012) when the soil pH is more than 6.0. Additionally, nutrient uptake may be reduced because of lower delivery rates to roots through mass flow and diffusion, as both of these processes are influenced by reduced soil moisture availability (Priyanka *et al*., 2012). The alternate wetting and drying techniques may cause grasses, broad leaved weeds, and sedges to germinate and grow, reducing rice yield by 50 to 91 per cent (Venkatesh *et al*., 2015; Bhargaw, 2018).

Irrigation scheduling (IW/CPE) and growth of aerobic rice

The irrigation scheduling of 1.0 IW/CPE ratio recorded the highest plant height at 60, 90 DAS, and harvest as compared with the irrigation scheduling of 0.8 IW/CPE ratio (Sreelatha *et al*., 2006). The highest plant height, dry matter production at harvest stage, and leaf area index at panicle initiation and flowering stage were recorded with a three-day irrigation interval (Maheswari *et al*., 2008).

Irrigation at an IW/CPE ratio of 2.5 recorded a significantly higher number of tillers, highest plant height and dry matter per hectare in aerobic condition (Shekara and Krishnamurthy, 2010). The dry matter production at the active tillering stage of irrigated aerobic rice was slightly higher than the alternate wetting and drying method of irrigation (He, 2010). According to Pasha *et al.* (2011) irrigating rice at seven day intervals during the vegetative stage and four day intervals during the reproductive stage resulted in a higher number of tillers per hectare and dry matter production than two day interval irrigation. The plant height, leaf area index, and dry matter accumulation were significantly higher in drip irrigation with irrigation scheduling at a 1.4 IW/CPE ratio, and it was followed by a 1.2 IW/CPE ratio and flood irrigation in rice (Sonit *et al*., 2015).

The highest plant height, number of tillers per hill^{-1}, and dry matter production at 90 DAS were recorded with a 1.5 IW/CPE ratio up to panicle initiation and 2.0 for the remaining period (Balamani *et al.,* 2012). The highest plant height was recorded with an irrigation regime of maintaining a constant of -10 kPa as compared to -20 kPa (Mahajan *et al.*, 2012).

The highest number of tillers and dry matter accumulation in aerobic rice was achieved when irri-

Table 1. Comparisons of different habitat of Rice cultivation

	Rainfed	Irrigated	Puddling	Nursery	Sowing	Water standing	Level of Fertilizer application	Drought tolerance	Weed intensity level	Yield level
Uplands	Yes	No	No	No	DS	No	Low	High	More	Very low
Lowlands	Yes	Yes	Yes	Yes	TP	Yes	High	Low	Less	High
Aerobic Rice	Yes	Yes	No	No	DS	No	High	Low to Moderate	More	High
System of Rice Intensification	No	Yes	Yes	Yes	PDS /TP	No	High	Low to Moderate	Less	High
Direct seeded Rice	Yes / No	Yes	No	No	DS	Yes / No	High	Low to Moderate	Less	High
Deep Water Rice	Yes	Yes	No	No	SS	Yes	High	Very Low	Less	Very low

Abbreviations: Direct seeded, Transplanted, Pre-germinated Direct Seeded, Self seeded, gating at a three-day interval as compared to five and seven-day intervals (Prabhakar *et al*., 2012). Taller plants and a greater number of tillers produced hill^{-1} with keeping the soil saturated throughout the crop growth period than drip irrigation at 100 or 150 percent PE (Reddy *et al*., 2013).

The scheduling of irrigation with 7 cm depth at 1 day after the disappearance of ponded water recorded the highest growth parameters, viz., plant height, leaf area index, and dry matter plant^{-1} over 7 cm of irrigation at 4 and 7 days after the disappearance of ponded water (Kumar *et al*., 2018). The highest plant height, dry matter accumulation, and number of tillers m^{-2} were recorded with the irrigation scheduling of 150% CPE over irrigation scheduling of 75% CPE and irrigation at 100% CPE (Narolia *et al*., 2014). With irrigation water applied, the highest drymatter production is 49 mm week^{-1}, with a total water requirement of 882 mm (Matsumoto *et al*., 2014).

The highest growth attributes in their study were recorded with irrigation scheduled for one day after the disappearance of water, which was on par with irrigation scheduled for two days after the disappearance of water (Sandhu and Mahal, 2014). The lowest growth attributes were recorded with an irrigation schedule of three days after the disappearance of water. The irrigation at critical stages viz., tillering, panicle initiation, flowering and grain filling with 60 mm of irrigation recorded the highest plant height and number of tillers per hill^{-1} in aerobic rice (Basha *et al*., 2017). Whereas, as per Gadad *et al*. (2018), irrigation at the tillering stage, panicle initiation stage, and at boot leaf stage recorded the highest growth attributes of plant height, number of tillers per hill^{-1}, and dry matter accumulation in aerobic rice. Sprinkler irrigation at 150 percent pan evaporation resulted in higher plant height and dry matter accumulation in aerobic rice than 125 percent pan evaporation (Kumar *et al*., 2018; Choudhary *et al*., 2018).

Irrigation scheduling (IW/CPE) and physiological of aerobic rice

The dry matter production was not significant between the water regimes of continuous flooding and alternate submergence. However, the physiological growth parameters, viz., LAI, CGR, and RGR, were significantly recorded at their highest with alternate wetting and drying (Belder *et al*., 2005). The highest LAI was recorded at 90 DAS for aerobic rice at a three day irrigation interval (Gill *et al*., 2006). Subramanian *et al*. (2008) reported that the highest leaf area index, crop growth rate, and relative growth rate were registered with irrigation at a 1.2 IW/CPE ratio than at 0.8, 1.0, and micro-irrigation.

In another study, aerobic rice with a 2.5 IW/CPE ratio had higher dry matter production, leaf area index, and relative growth rate than rice with 2.0, 1.0, and 0.8 IW/CPE ratios (Shekara and Krishnamurthy, 2010). Irrigation at seven day intervals during the vegetative stage and four day intervals during the reproductive stage produced the highest leaf area index, relative growth rate, and dry matter production when compared to two-day interval irrigation (Pasha, 2010).

Highest leaf area index, crop growth rate, relative growth rate, and dry matter production with irrigation scheduling of 1.5 IW/CPE ratio up to panicle initiation and 2.0 for the remaining period (Balamani *et al*., 2012). The effect of three irrigation schedules of 30, 50, and 70 mm CPE on the physiological growth parameters of direct-seeded basmati rice cultivar Pusa Basmati 1121 on a sandy loam soil revealed that the highest LAI, CGR, RGR, and DMP were obtained with an irrigation schedule of 30 mm CPE (Kaur and Mahal, 2014).

Irrigation scheduling (IW/CPE) and yield characters of aerobic rice

When rice cultivation was done under water stress conditions, the yield attributes, viz., number of filled grain panicle^{-1} and total number of grains panicle^{-1}, decreased (Zubaer *et al*., 2007). Gill and Singh (2008) stated that irrigation scheduling at 2 day intervals produced the highest number of productive tillers and number of panicles hill^{-1} than a 3 day interval of direct seeded basmati rice.

The yield parameters *viz*., number of productive tillers m^{-2}, number of grains panicle^{-1}, number of filled grains panicle^{-1}, and test weight, were higher with irrigation scheduling of 1.2 IW/CPE ratio over 1.0 and 0.8 IW/CPE ratios and micro sprinkler irrigation in aerobic rice (Maheswari *et al*., 2008). Jat *et al*. (2009) recorded the highest number of panicles per hill-1 with a 1.5 IW/CPE ratio in direct seeded rice than in puddled transplanted rice. Whereas the number of panicles hill^{-1} in aerobic rice is higher than in conventional rice cultivation with increased irrigation frequency (Hugar *et al*., 2009).

The higher number of panicles m^{-2} under flooded conditions as compared to aerobic cultivation with a

4 day interval of irrigation (Reddy *et al*., 2010). The number of filled spikelets in panicle^{-1} increased with an increase in moisture regime from 1.0 to 2.0 IW/CPE ratio (Patel *et al*., 2010). Irrigation scheduling at 3 day intervals recorded the highest yield attributes of effective tillers m^{-2}, filled grains panicle^{-1}, and test weight. It was superior to higher irrigation intervals of 5 and 7 with regards to effective tillers m^{-2} and filled grains panicle^{-1} (Nayak *et al*., 2015). A 2.5 IW/CPE ratio irrigation regime resulted in more productive tillers per hill^{-1}, filled grains per panicle^{-1}, panicle weight, and grain yield in aerobic rice (Shekara *et al*., 2010).

Irrigation at seven-day intervals during the vegetative stage and four day intervals during the reproductive stage resulted in higher panicle number, panicle weight, and filled grains per panicle-1 than irrigation every two days in aerobic rice (Dunn and Gaydon, 2011). Sridharan and Vijayalaxmi (2012) observed that on clay loam soils, the highest number of panicles m^{-2} and test weight of aerobic rice were registered with irrigation at an IW/CPE ratio of 0.8 to 1.2.

The number of productive tillers m^{-2} and the number of filled grains panicle^{-1} were registered with irrigation once every 3 days in aerobic rice, while the test weight did not differ due to the different amounts of water applied (Prabhakar *et al*., 2012). Murthy and Reddy (2013) registered the yield attributes of number of panicles m^{-2}, total number of grains panicle^{-1}, and number of filled grains panicle^{-1} were higher with irrigation scheduled at 1.2 IW/CPE ratio in aerobic conditions. In aerobic rice, a greater number of panicles per hill^{-1} were recorded with irrigation at 80 to 90 per cent of available soil moisture (Kannan *et al*., 2015). Irrigation scheduling at a 3 day interval produced a higher number of productive tillers m^{-2} and filled grains panicle^{-1} (Nayak *et al*., 2016), whereas Dari *et al*. (2017) stated that irrigation scheduling at a 2.0 IW/CPE ratio recorded the highest numbers of effective tillers m^{-2} over 1.5 and 1.0 IW/CPE ratios. The irrigation scheduling of two-day intervals through sprinkler irrigation at 150 per cent pan evaporation produced the highest number of productive tillers per hill^{-1}, number of filled grains panicle^{-1}, test weight, and lowest number of ill-filled grains panicle^{-1} in aerobic rice (Choudhary *et al*., 2018). Lenka *et al*. (2019) found the highest number of productive tillers, filled grains per panicle, and test weight.

Irrigation scheduling (IW/CPE) and yield of aerobic rice

Irrigation of aerobic rice with a water depth of 5 cm at weekly intervals upto 45 and 60 days after emergence resulted in superior yield over fortnightly irrigations (Thyagarajan and Selvaraju, 2001). Irrigation one day after the disappearance of ponded water at a depth of 5 cm yielded the highest grain and straw yield in aerobic rice when compared to transplanted rice (Balasubramanian and Krishnarajan, 2001). About 5 to 38 per cent of yield gets reduced when there is a mild water stress or severe water stress condition, about 25 to 67 per cent yield reduction (Huaqi *et al*., 2002). When compared to continuous flooded rice cultivation, 5 day irrigation intervals resulted in a 12% yield reduction for aerobic rice (Nieuwenhuis *et al*., 2002).

The irrigation scheduling of 1.8 and 1.2 IW/CPE ratios recorded significantly higher grain yields than the IW/CPE ratio of 0.6 in upland rice (Jadhav *et al*., 2003). Irrigating rice with a 1.2 IW/CPE ratio recorded the highest grain and straw yield in aerobic condition (Zubaer *et al*., 2007). The irrigation three days after the water disappeared produced the highest grain yield of 7.11 t ha^{-1} (Luikham *et al*., 2004). The highest yield and harvest index were registered in relatively wet soil with a soil moisture tension of -10 to -12 kPa in the root zone compared to dry soil with a soil moisture tension of -40 kPa in aerobic rice (Bouman *et al*., 2005). Irrigation at every 4 day interval recorded the highest grain yield but did not differ statistically with irrigation at a 7 day interval (Khalifa *et al*., 2005). The highest grain yield was recorded with an irrigation schedule of once every four days, followed by irrigation for seven days and no irrigation for the subsequent six days in red soils during the summer season (Kumar *et al*., 2006). The highest yields of 5.7-6.1 t ha^{-1} were recorded with an irrigation schedule when the soil water tension at 15 cm depth exceeded -15 kPa (Tao *et al*., 2006). Varied irrigation regimes at 2 to 3 days increased the grain yield of aerobic rice (Ramakrishna *et al*., 2007).

The 1.2 IW/CPE ratio had the highest grain and straw yield compared to the 0.8 and 1.0 IW/CPE ratios and micro sprinkler irrigation once every 3 days in aerobic conditions (Maheswari *et al*., 2007). The irrigation regimes at two day intervals recorded the highest grain yield compared to irrigation at three-day intervals (Gill and Singh, 2008). Irrigation regimes at 20 mm CPE (irrigation once every 5-6 days) recorded a statistically equal yield (45.47 q ha^{-1}) to that of 30 mm CPE (43.67 q ha^{-1}) (irrigation once every 8-9 days) (Murali *et al*., 2009).

The highest grain yield was observed with irrigation to fill soil cracks with 5 cm of irrigation in aerobic rice (Mostafazadeh-Fard *et al*., 2010). The irrigation schedule of 2.5 IW/CPE recorded the highest grain yield (Shekara and Krishnamurthy, 2010). The highest grain and straw yields were registered in the summer season while irrigating at an interval of once every 5 days rather than irrigation at once every 24 hours (Pasha *et al*., 2011). Rice grain and straw yield of aerobic rice were highest when irrigation was scheduled at once at a 3 day interval as compared to other schedules of 5 and 7 day intervals (Prabhakar *et al*., 2012).

In the bed-furrow method of irrigation, scheduling of irrigation at 1.5 IW/CPE upto panicle initiation and 2.0 IW/CPE ratio for the remaining period during the kharif season recorded the highest grain and straw yield (Gandhi *et al*., 2012). The delayed irrigation regime of 0.6 IW/CPE from 15 to 45 DAS and 0.8 IW/CPE from 46 DAS to harvest recorded the highest grain yield for aerobic rice (Asma *et al*., 2013). The scheduling of irrigation at 1.2 IW/CPE recorded the highest grain yield of aerobic rice in the north coastal zone of Andhra Pradesh (Murthy and Reddy, 2013).

Maintaining water saturation from 25 DAS to physiological maturity recorded the highest grain and straw yield with less quantity of water as compared to irrigation depth at 2.5 cm from 25 to 40 DAS in the rice-rice cropping system (Denesh *et al*., 2013). More grain yield and straw yield with an irrigation schedule at a 1.0 IW/CPE ratio (Devi *et al*., 2014). The irrigation water was applied with 40 per cent of critical depletion, no yield reduction was observed, and more rainwater use efficiency in dry seeded rice (Vashisht and Satpute, 2015). Irrigation scheduling of -20 kPa produced higher grain and straw yields of aerobic rice (Verma *et al*., 2015).

The yield of rice increased with the decrease in irrigation interval up to 5 days, and a further decrease in irrigation interval did not exhibit any beneficial effect in the aerobic system (Nayak *et al*., 2016). The irrigation regime of 0.6 IW/CPE from 15 to 45 DAS and 0.8 IW/CPE ratio from 46 DAS to maturity recorded the highest grain and straw yield, compared to the other irrigation schedules (Mehala *et al*., 2016). The highest grain and straw yields were recorded with an IW/CPE ratio of 2.0, followed by 1.5, 1.0, and 0.5 in the aerobic system of rice cultivation (Rao *et al*., 2016). Irrigation scheduling at saturated condition was found to be comparable to maintaining soil water threshold through irrigation at -10 kPa, which recorded the highest grain and straw yield of aerobic rice (Kumawat *et al*., 2017).

The highest grain yield was recorded with continuous submergence as comparable with that of irrigation scheduling at a 3.0 IW/CPE ratio in dry sown rice (Haindavi *et al*., 2018). Irrigation scheduling of three days' disappearance of ponded water produced the highest grain yield compared to seven days' disappearance of ponded water in aerobic rice (Kumari, 2018). Among the drip irrigation trials for rice, 100 per cent CPE at two day intervals recorded a 45 per cent higher yield than conventional irrigation in direct seeded basmati rice (Bhardwaj *et al*., 2018). Irrigation scheduling at IW/CPE 1.5 increased the grain yield by 37.3% (Singh *et al*., 2019). Irrigation at 150 per cent PE on a daily basis recorded the highest rice grain yield under aerobic conditions (Natarajan *et al*., 2020) and 125 per cent PE (Mondal *et al*., 2020).

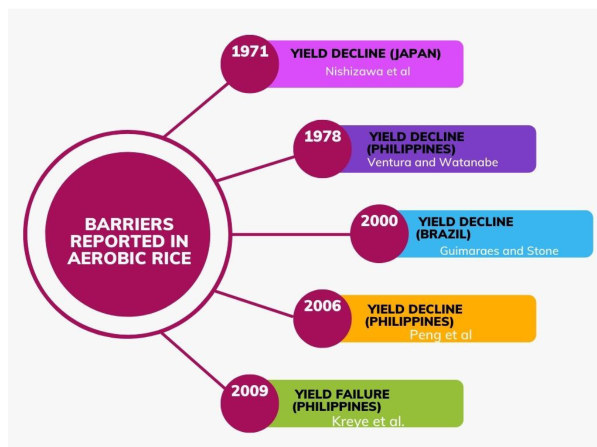

Fig. 3. Barriers Reported in Aerobic Rice

Irrigation scheduling (IW/CPE) and root growth of aerobic rice

The root length was highly restricted with severe stress compared with mild stress (Kondo *et al*., 2000). The three days of intermittent irrigation increased the root volume as compared to the rainfed condition (Shi *et al*., 2002). In raised beds, alternate wetting and drying registered increased root activity in the deeper soil layer in aerobic rice (Ramamoorthy *et al*., 2005). The highest root number per plant^{-1}, root hair density, and root volume with a three-day interval of irrigation in aerobic rice (Girish *et al*., 2006).

The root length is higher and deeper in aerobic rice than in flooded rice (Biswas and Yamauchi, 2007). Increase in plant root volume with irrigation at a 1.2 IW/CPE ratio as compared to 0.8 and 1.0 IW/CPE ratio (Maheswari *et al*., 2007). The inability of roots to adapt to changes in soil water regimes is a result of reduced root growth and function of roots in aerobic rice (Suralta and Yamauchi, 2008). Upland rice cultivars required a deeper rooting system and higher root length density than lowland rice cultivars due to the increased frequency of irrigation intervals (Matsuo *et al*., 2010). The lowest root biomass was found in direct seeded rice with a three-day irrigation interval than in puddled transplanted rice, owing to a reduction in root biomass in the surface soil (Kato and Okami, 2010).

Aerobic rice culture might promote lateral root branching with a lower frequency of irrigation intervals as compared to transplanted rice (Kato and Okami, 2011). When a 2.0 IW/CPE irrigation regime was followed by a 1.5 IW/CPE irrigation regime, the longest root length and root volume were measured (Devi *et al*., 2014). The highest root volume was recorded in aerobic conditions with a high moisture regime compared to the low moisture regime of rice (Kannan *et al*., 2015). The highest root length was observed with a 5 day irrigation regime compared to a 3 day irrigation regime in aerobic rice (Limouchi *et al*., 2017). Irrigation every 7 days during active tillering, every 3 to 4 days during flowering, and every 7 days during maturity period resulted in the highest root volume and root shoot ratio of aerobic rice (Mohamed, 2018).

Irrigation scheduling (IW/CPE) and nutrient uptake of aerobic rice

The highest N, P, and K uptake were recorded three days after the disappearance of ponded water with irrigation at 2.5 cm depth (Balasubramanian and Krishnarajan, 2001). It was concluded that higher nitrogen uptake was associated with the irrigation scheduling at 3 and 5 days after infiltration of applied water; P uptake at 1, 3 and 5 after infiltration of applied water; and K uptake at 1 and 3 after infiltration of applied water (Parihar, 2004). In basmati rice, the irrigation schedule of 1.6 IW/CPE ratio registered the highest uptake of nitrogen (Jadhav and Dahiphale, 2005).

The relatively lower uptake of nitrogen under aerobic conditions with low soil available soil moisture over flooded rice cultivation was reflected by the relatively low nitrogen recovery under aerobic conditions (Belder *et al*., 2005). Ramakrishna *et al*. (2007) found the highest N, P, and K uptake in rice with irrigation at five cm depth one day after the disappearance of water (Ramakrishna *et al*., 2007; Edwin and Anal, 2008).

Irrigating aerobic rice at an IW/CPE ratio of 2.5 resulted in greater nitrogen uptake than IW/CPE ratios of 1.0 and 0.8 (Shekara and Krishnamurthy, 2010). The highest nitrogen uptake was recorded with irrigation at seven-day intervals during the vegetative stage and four-day intervals during the reproductive stage (Pasha *et al*., 2011). The nitrogen, phosphorus, and potassium uptake of upland rice was recorded at the lowest at an irrigation threshold of -20 kPa rather than at -10 kPa (Mahajan *et al*., 2012). Nitrogen uptake of grain and straw in aerobic rice increased gradually with irrigation at 100% PE to soil saturation (Reddy *et al*., 2013).

Nitrogen, phosphorus, and potassium uptake by grain and straw of aerobic rice tended to be increased with an increased irrigation schedule from IW/CPE ratio of 0.8 to 1.2 (Murthy and Reddy, 2013). The uptake of nitrogen, phosphorus, and potassium was found to be very slightly affected by water potential of as low as -1.2 Mpa (Roy *et al*., 2018). The highest nitrogen uptake was recorded with energy controlled irrigation (drip irrigation) compared to alternate wetting and drying irrigation in rice (Zheng *et al*., 2018). The highest nitrogen uptake was recorded with irrigating the crop up to 100 per cent saturation (lower limit) rather than at 70 per cent saturation in aerobic rice (Hamoud *et al*., 2019).

Irrigation scheduling (IW/CPE) and post harvest soil nutrient status of aerobic rice

The highest soil available N, P, and K status of post harvest soil in aerobic rice was recorded with irrigation scheduling at 7 day intervals during vegetative and 4 day intervals during reproductive stages, as compared to irrigation scheduling at 2 day intervals throughout the crop duration (Pasha *et al*., 2011). The lowest post harvest soil available nitrogen with irrigation scheduling of -20 kPa rather than -10 kPa in aerobic rice (Mahajan *et al*., 2012). The highest nutrient uptake occurred with a high moisture regime of 1.5 IW/CPE ratio (Kannan *et al*., 2015). Singh *et al*. (2017) stated that rice crops irrigated with 30 mm CPE scheduled registered the highest grain yield and lowest post-harvest soil N, P, and K compared to those irrigated at 45, 60, and 75 mm CPE (Singh *et al*., 2017).

Irrigation scheduling (IW/CPE) and water use efficiency / water productivity

Intermittent irrigation with 48 mm (27%) of irrigation increased yield and had the highest WUE compared to flooded irrigation (Xiaoguang *et al*., 2002). The highest water use efficiency was registered with irrigation scheduling of 2.0 IW/CPE ratio or 8 to 10 days' interval in aerobic rice (Bhale *et al*., 2003). With a three-day irrigation interval, an aerobic rice system saves 73 percent of water in land preparation (Castaneda *et al*., 2004). Aerobic rice saved water by around 56 per cent during the crop growth stage and also effectively used rainfall during the dry period (Ambrocio *et al*., 2004). It was concluded that the positive influence of intermittent irrigation on flooded rice for getting higher water use efficiency and water productivity and also that continuous flooding may not be the best option for rice in irrigated conditions (Lin *et al*., 2005; Horie *et al*., 2005).

The total water use of aerobic rice was 27 to 51 per cent lower than that of flooded rice (Bouman *et al*., 2005; Belder *et al*., 2005). In aerobic rice, irrigating the crop at four-day intervals resulted in the highest water use efficiency (4.58 kg grain ha mm^{-1}) than irrigating the crop daily (2.99 kg grain ha mm^{-1}) or once every two days (3.22 kg grain ha mm^{-1}) (Kumar *et al*., 2006). Higher yield and WUE were obtained with 566 mm of total water in aerobic rice (Bouman *et al*., 2006). The highest water saving was recorded with aerobic rice (43.9 per cent) (Geethalakshmi *et al*., 2009). There were significant differences in water productivity with different water regimes along with various nitrogen rates in aerobic rice. The alternate wetting and drying and raised bed irrigation increased water productivity by 28.9 per cent and 32.2 per cent, respectively, over flooded rice cultivation (Pan *et al*., 2009).

Irrigation scheduling with a 1.5 IW/CPE ratio resulted in the highest water productivity (0.43 kg m^{-3}) in aerobic rice over flooded rice (0.33 kg m^{-3}) and alternate wetting and drying (Matsuo and Mochizuki, 2009). The irrigation schedule of 1.0 IW/CPE ratio recorded the highest water use efficiency (52.09 kg grain ha cm^{-1}) in aerobic rice (Shekara and Krishnamurthy, 2010).

The irrigation schedule at 2.5 IW/CPE ratio noted the highest water use of 154.79 cm with a lower water use efficiency of 41.31 kg/ha. whereas the irrigation schedule at 1.0 IW/CPE ratio recorded the lowest total water use of 91.84 cm with a higher water use efficiency of 52.09 kg/ha^{-1} cm (Sudhir *et al*., 2011). There was no irrigation water saving in direct seeded rice as compared to puddled transplanted rice when the crop was irrigated daily. However, the irrigation input to direct seeded rice was lower than that to puddled transplanted rice with respect to irrigation scheduling (Kanwar, 2011). In aerobic rice, direct seeded rice irrigated at -20 kPa soil water tension reduced irrigation input by 30 to 35 percent when compared to puddled rice irrigated at -20 kPa soil water tension with 120 kg N ha^{-1} (Tan *et al*., 2013).

Intermittent irrigation based on soil water status would significantly reduce deep percolation and improve irrigation use efficiency. A large saving in input water was achieved due to reduced irrigation applications with a nominal yield penalty (Hatiye *et al*., 2015). Water productivity with respect to irrigation was influenced by the irrigation schedules in drip irrigation and the highest water productivity was obtained with irrigation scheduling at 100 percent Epan (Rao *et al*., 2016). Kombali *et al*. (2016) found that drip irrigation at 1.5 PE up to maturity with 100 per cent RDF through water soluble fertiliser recorded the highest water use efficiency and water productivity of aerobic rice.

Water use efficiency was highest with crops irrigated at 30 CPE compared to 45, 60, and 75 CPE and also resulted in a higher grain yield (Singh *et al*., 2017). The highest water use efficiency was noticed with the application of 125 kg of nitrogen ha-1 with four equal splits of 25% N at basal dose, 25% N at tillering, 25% N at PI stage, and 25% N (Djaman *et al*., 2018). Subsurface drip irrigation combined with nitrogen application at 75 kg ha^{-1} saved 22% of the water in aerobic rice (Rajwade *et al*., 2018). Different irrigation water regimes of -10 kPa and -40 kPa saved water by 25% and 58% in non-puddled rice cultivation, respectively (Kar *et al*., 2018). Alternate wetting and drying at 10 cm of depletion of water below the soil surface recorded the highest water use efficiency and water productivity in aerobic rice (Sangavi and Porpavai, 2018). Irrigation scheduling based on IW/CPE of 1.50 recorded the highest water use efficiency and water productivity (0.61 kg/m^3) (Jagadish *et al*., 2019; Sathisha *et al*., 2022). The highest water use efficiency (80.4 kg m^3) was recorded with IW/CPE 1.0 up to maturity (Maharajan *et al*., 2020).

Conclusion

Based on different IW/CPE ratios (0.6, 0.8, 1.0, 1.2, 1.4, 1.5, 2, and 2.5), scheduling of irrigation for aerobic rice produces the highest yield, uptake of nutrients, and water use efficiency even though there are more constraints in rice production under aerobic conditions, viz., all the soil is not suitable for rice cultivation in aerobic rice cultivars, severe weed problems, nematode issues, less nutrient and standing water availability because of unpuddled condition, micro-nutrient deficiency, and mono-cropping system. The increase in the average temperature of the earth's surface stresses the reduced usage of fresh water for irrigation purposes and all other domestic needs too. The last 20 years of research reviewed 5 cm depth of irrigation water along with scheduled number of irrigations and interval between two successive irrigations according to daily evaporation rate results in good economic yield and water use of aerobic rice in different countries. Strategies to overcome this sever water shortage in future, the researchers necessary to do many advance research on scheduling of irrigation in surface and sub-surface micro-irrigation also without declining of optimum yield of rice.

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