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VM Chandana
Department of Agronomy
Institute of Agricultural Sciences
Banaras Hindu University
Varanasi, Uttar Pradesh, India

MK Singh
Department of Agronomy
Institute of Agricultural Sciences
Banaras Hindu University
Varanasi, Uttar Pradesh, India

Aakash
Department of Agronomy
Institute of Agricultural Sciences
Banaras Hindu University
Varanasi, Uttar Pradesh, India

Ajay Kumar
PhD research scholar,
Water management
Institute of agricultural sciences
BHU, Varanasi, Uttar Pradesh, India

Corresponding Author:
VM Chandana
Department of Agronomy
Institute of Agricultural Sciences
Banaras Hindu University
Varanasi, Uttar Pradesh, India

Water saving technologies in rice-a review

VM Chandana, MK Singh, Aakash and M Ajay Kumar

Abstract
Gains or losses in grain yield and water-use efficiency of aerobic direct-seeded rice (*Oryza sativa* L.) must be considered before promoting this technology in areas where this is not common. In the northwestern Indo-Gangetic Plains (IGP) of South Asia, irrigation water for rice production is becoming scarce because of depleting surface and groundwater resources. Assessing the scope for gains in water productivity requires an understanding of basic biological and hydrological crop-water relations. How much more water will be needed for agriculture in the future is governed, to a large extent, by links between water, food and changes in die. The amount of water required for field crops and its relation to yield dominates the equation on the need for additional water for food. Exploring ways to produce more rice with less water is essential for food security. Water-saving rice production systems, such as aerobic rice culture, System of Rice Intensification (SRI), raised beds and Alternate Wetting and Drying (AWD), can drastically cut down the unproductive water outflows and increase Water-Use Efficiency (WUE). The water crisis is threatening the sustainability of the irrigated rice system and food security in Asia. Our challenge is to develop novel technologies and production systems that allow rice production to be maintained or increased in the face of declining water availability.

Keywords: Genetic combining ability, specific combining ability, okra, variance, growth, yield and quality

Introduction
Rice is the staple food crop for about 3 billion people, mostly living in Asia (Zhang *et al*., 2009) [65]. Globally rice is cultivated in 161 M ha with annual production of around 496.22 million metric tons. In India, rice occupies 49.86 M ha with a production of 117.47 million tones and productivity of 2.6 thousand kilograms per hectare. (Ministry of Agriculture, 2019-20). It is grown under diverse soil and climatic conditions the productivity level of rice is low compared to the productivity levels of many countries in the world.

Traditional rice production involves submerged conditions with approximately 5 to 10cm deep standing water throughout the crop growth period. This system requires around 4000 to 5000 liters of water for producing one kg of grain which is about twice or even more than that for wheat or maize (Joshi *et al*., 2009) [22]. It is the single largest user of fresh water consuming about 30 per cent and more than 45 per cent of total fresh water used in world and Asia, respectively (Barker *et al.*, 1999) [2]. However, the increasing scarcity of fresh water for agriculture and the competing demand from the non-agricultural sector threaten the sustainability of the irrigated rice ecosystem. By 2025, 15 out of 75 million hectares of Asia's irrigated rice may experience severe water shortage (Tuong and Bouman, 2003) [61]. To cope up with scarcity, several water saving technologies have been developed for rice *viz.*, saturated soil culture (Borell *et al.*, 1997) [6], alternate wetting and drying (Tabbal *et al.*, 2002) [59], system of rice intensification (Stoop *et al.*, 2002) [57] and raised bed system (Choudhury *et al*., 2007) [12] to lower the water requirements of the rice crop. One of the recent developments is to grow rice as an upland crop like wheat or maize called as 'aerobic' cultivation. Aerobic rice cultivation reduces water use the maximum amount as 50 percent compared to lowland rice (Tuong and Bouman, 2003) [61]. Aerobic rice are often rainfed or irrigated to take care of soil water content within the root zone to field capacity and deems to be the foremost feasible alternative to traditional flood irrigated rice. Of late, interest in aerobic rice technology has been enhanced.

Farmers in Brazil, China and India are pioneering this technique where water is scarce or costly. Aerobic rice cultivation saves water input and increases water productivity by reducing water use during land preparation and limiting seepage, percolation, and evaporation (Peng *et al*., 2012) [42]. It also reduces labour requirement and greenhouse gaseous emission from the rice field. However, many recent studies have revealed a yield penalty of rice under aerobic cultivation (George *et al*., 2002, Belder *et al*., 2005 and Peng *et al.*, 2006) [18, 3, 40]. The shift from puddled to aerobic soil conditions brings profound changes in soil water status, aeration, soil organic matter turnover, nutrient dynamics, carbon impounding, weed flora and greenhouse emission emissions (Farooq *et al*., 2009 and Prasad, 2011) [16, 44].

To make aerobic rice successful, new varieties and new management practices got to be developed. Optimum irrigation scheduling and nitrogen nutrition are critical for profitable yield realization of irrigated rice ecosystems (Maheswari *et al*., 2008) [28]. Drip irrigation and fertigation methods are proved to be the water and nutrient efficient methods, respectively in most of the crops aside from increasing productivity. Realizing the necessity for increasing water productivity, the govt. of India is providing a 90 percent subsidy to farmers for drip irrigation under Andhra Pradesh Micro Irrigation Project (APMIP). Aerobic rice with micro-irrigation practices results in sustainable rice production for the immediate future to deal with water scarcity with more benefits and environmental safety within the scenario of worldwide warming by reduced methane emission is another advantage (Parthasarathi *et al*., 2012) [36]. Within the aerobic system, the dominant sort of nitrogen is nitrate and comparatively little ammonia volatilization is predicted after fertilizer nitrogen application. The alternate moist and dry soil conditions may stimulate nitrification-denitrification processes in dry sown rice, leading to loss of N through N2 and N2O (Prasad, 2011) [44]. The differences in soil N dynamics and pathways of N losses in dry sown rice system may end in different fertilizer nitrogen recoveries. With even high N applications in aerobic rice, grain filling could also be limited by a coffee contribution of post-anthesis assimilates (Zhang *et al.*, 2009) [65]. additionally, within the absence of transplanting, the roots of aerobic rice are located within the shallow topsoil, which ends up in relatively low uptake of nitrogen (Zhang and Wang, 2002) [64].

Traditionally, rice is mostly grown by puddling the main field and transplanting seedlings into wet and saturated soil. The rice agro-ecosystems occupy areas in the eastern plains and plateaus, sub-Himalayan West Bengal and Indo-Gangetic Plains (IGP), Tripura, Chhattisgarh, western and eastern coastal areas and Assam valley of India11. Water input to rice fields is practised for saturating land, facilitating puddling operation, maintenance of water layer, and to compensate for evaporation, transpiration, and seepage and percolation losses. On average, 2500 litre of water is applied to produce 1 kg of rough rice12, which is 2-3 times more than other cereals 13. This cultivation technique is labour-, water-, and energy-intensive and is becoming less profitable as these resources are becoming increasingly scarce3. However, most of the water applied during crop growth is not used directly for transpiration, and is therefore considered lost from the fields. In the Philippines, water use has been reported at 1300-1500 mm during the dry season and 1400-1900 mm in the wet season 14. It was estimated that seasonal water input for typical puddled transplanted rice was 660-5280mm depending on the growing season, climatic conditions, soil type and hydrological conditions, with 1000-2000mm as a typical value in most cases15. In India, this value ranged from 1566mm in clay loam soil to 2262mm in sandy loam soil. In the IGP, it varied from 1144mm in Bihar to 1560 mm in Haryana16. However, in recent years a major problem is the increasing water scarcity. In fact, water scarcity is threatening Asia’s irrigated rice systems. In Asia, 17 m ha of irrigated rice area may experience physical water scarcity and 22 m ha may have economic water scarcity by 2025. It implies that water needs to be used minimally through water-saving methods or techniques in the future.

Alternate wetting and drying irrigation method and water productivity

AWD has been normally used as a water-saving practice in many components of the world for more than a decade (Shi. Y.C. *et.al)*. In this system, the soil is allowed to dry for a few days inside irrigation events relying on plant developmental stages (Belder *et al.*). Some success has been suggested as some distance as yield and water demand are concerned 23 however, unproductive water losses ought to not be completely prevented through AWD. Hence, the water consumption is nonetheless high in AWD seeing that the soils need to be submerged at least for the duration of the irrigation period. Savings in irrigation water in the AWD remedies were 53-87mm (13-16%) in contrast with the continually submerged regime (Bueno *et al*.). Rice grain yields ranged from 7.2 to 8.7 t ha-1 and have been not markedly affected by means of the water regimes. Water productivity used to be appreciably greater in the AWD regime than in the always submerged regime. The yield penalty used to be many times observed underneath AWD in contrast with flood-irrigated rice (Belder *et al*.). In general, AWD increased water productiveness with respect to total wat er input due to the fact the yield reduction was once smaller than the amount of water saved. Variety has a large effect on the grain yield of AWD. AWDI objectives to produce the equal yield as paddy rice with plenty much less water consumption (50% water saving in contrast with the regular paddy rice) under irrigated conditions. At the same time, Zhang *et al.* stated that AWD must have the capability of drought tolerance to decrease yield loss underneath water-limited conditions. Several area studies had been performed to determine grain yield, water saving, water productiveness and drought tolerance in AWD.

System of rice intensification: a water-use efficient method

SRI, which was developed in Madagascar, is now spreading to most rice-growing countries. It has become the method of choice for increasing rice production with reduced water demand and increased water productivity 23, 26. Paddy fields are kept moist but not continuously flooded, either by saturated soil culture or by alternately wetting and drying. Under SRI, young seedlings are transplanted with wider spacing26, with active soil aeration using mechanical weeders and the application of available organic manure to stimulate beneficial soil organisms 24, 25. Yield increase (25-50% or more) has been reported by researchers24-26. Such practices should be adapted to local conditions. Studies on the yield and water productivity performance of SRI should be systematically done using drip or sprinkler systems.

Substantial water savings with higher paddy yields using SRI methods have been confirmed in a meta-analysis of 27 published studies across 8 countries, an average 35% reduction in irrigation water per hectare and a 22% reduction in total water (irrigation plus rainfall) (Jagannath *et al*., 2013). But these comparisons were all made with modified regimes of flood irrigation. Possibly there could be even greater savings of irrigation water and more gains in water productivity with employment of drip irrigation technology. And if such benefits are possible, how can the productivity of drip irrigation be optimized? These are important considerations for enhancing both the productivity and sustainability of irrigated rice cultivation, and it is these concerns that gave impetus to the research whose findings are reported here.

Water loss from rice fields and water-saving essentiality

The loss components of a puddle rice field are evaporation, transpiration (combined as evapotranspiration, ET), percolation and seepage. So far as measurements are concerned, ET values are mostly reported. Typically, ET from rice fields is 4-5mm d-1 during wet months and 6-7mm d-1 during dry months; this can be as high as 10-11mm d-1 in subtropical regions. It was estimated that about ~30-40% of ET is due to evaporation14, 18. Losses through seepage and percolation account for 1-5 mm d-1 in heavy clay soils and 25-30mm d-1 in sandy and sandy loam soils14. The combined losses through seepage and percolation may be 25-50% of total water loss in heavy soils with shallow groundwater table (20-50 cm depth); and 50-85% of total water loss in coarse textured soils with groundwater table (1.5 m depth or more) 16, 19, 20. Losses through seepage and deep percolation from one field are recaptured and used in other fields downstream. Therefore, more efficient management of water is needed for rice production. Several strategies are being pursued to reduce rice water requirements, such as saturated soil culture 21, alternate wetting and drying 18, 22, system of rice intensification (SRI) 23-26 and aerobic rice 27-29. In addition, an emerging water-saving technique is the use of micro-irrigation (sprinkler and drip irrigation). This is prevalent in fruit and vegetable cultivation; now researchers have started experiments to understand the feasibility of using micro-irrigation in rice. Hence, it is the need of the hour to elucidate existing information on the use of sprinkler and drip irrigation to rice for future strategies.

Performance of Rice in Aerobic vs Puddled Condition

One of the primary reports came from Bouman (2001) demonstrating that rice might be grown aerobically under irrigated conditions a bit like upland crops, like wheat and maize. Later in 2003, research began on aerobic rice in rainfed lowlands within the Philippines (Lampayan *et al*., 2004) [25]. Aerobic rice is grown under non-flooded conditions in non-puddled and unsaturated (aerobic) soil with supplemental irrigation. Irrigation is applied to bring the soil water content within the root zone up to volume unit after it's reached a particular lower intensity, like halfway between volume unit and wilting point (Doorenbos and Pruit, 1984) [15]. the quantity of irrigation water should match evaporation from the soil and transpiration by the crop plus any application inefficiency losses (Bouman *et al*., 2005) [5].

Growth

Qing *et al*. (2004) [45] reported increased above-ground dry weight of rice plants under aerobic conditions compared to flooding. But at Los Banos, the Philippines, flooded rice produced more above-ground total biomass than aerobic rice as was reported by Belder *et al*. (2005) [3] and Peng *et al*. (2006) [40]. In another experiment, Bouman *et al*. (2005) [5] at IRRI, Philippines found that the biomass accumulation was similar in flooded and aerobic plots within the first year of experimentation, but differences appeared within the second year and have become gradually more pronounced under aerobic than under flooded conditions. The leaf area index (LAI) of rice was more or less identical in flooded likewise as aerobic condition. However, the entire chlorophyll content was found to decrease under aerobic conditions compared to the flooded condition as was reported by Reddy *et al*. (2007) [46] in an experiment conducted at Hyderabad. Rai and Kushwaha (2008) from Pantnagar reported that the number of days taken for 50 percent flowering in rice was significantly more in rainfed condition compared to continuous submergence with 5.0±2.5cm ponded water and seven .5 cm irrigation water in some unspecified time in the future after the disappearance of ponded water. Nguyen *et al*. (2009) [34] from Brisbane, Australia observed that the difference in tiller number in rice among flooded (FL), aerated (AR) and saturated soil conditions (SSC) wasn't significant. Katsura *et al*. (2010) [24] observed that the above-ground biomass of rice was significantly higher in aerobic culture (17.2-18.5 t ha-1) than in flooded culture (14.7-15.8 t ha-l) in Japan. Kadiyala *et al*. (2012) [23] from Hyderabad, Andhra Pradesh reported that LAI and dry-matter production at harvest was the very best in flooded rice compared to aerobic rice. In contrary to the above authors, Sridhara *et al*. (2012) [55] from Shivamogga, Karnataka found a better number of tillers m-2 (237), leaf area (1379 cm2 plant-1), root volume (67 cc plant-1) and root dry weight (9.1 g plant-l) of aerobic rice compared to puddled rice.

Yield attributes and yield

Lafitte and Courtois (2000) found increased sterility of spikelets with a lower test weight of grains in sprinkler irrigated or furrow-irrigated aerobic rice compared to lowland rice. Belder *et al*. (2005) [3] recorded a better percentage of filled spikelets per panicle in flooded conditions (86) as compared to aerobic conditions (75) at Los Banos, Philippines. Bouman *et al*. (2006) [10] also reported a better percentage of filled spikelets with the increased frequency of irrigation in aerobic rice in China. Peng *et al*. (2006) [40] conducted an experiment at Los Banos, Philippines and located a significantly higher number of panicles, spikelet number per panicle and test weight of rice in flooded compared to aerobic conditions. At Fukuoka, Japan, Matsuo, and Mochizuki (2009) [31] observed that the panicles and spikelet number per panicle, filled spikelets and test weight markedly decreased under aerobic plots relative to it of continuous flooding and alternate wetting and drying. At Brisbane, Nguyen *et al*. (2009) [34] observed shorter panicles in saturated soil condition systems than in flooded and aerated systems. In an experiment conducted at Hyderabad, Andhra Pradesh, although the aerobic method had significantly higher panicles m-2, the other yield attributing characters like spikelet number per panicle and 1000-grain weight were significantly higher in flooded method (Kadiyala *et al*., 2012) [23]. Sridhara *et al*. (2012) [55] in red sandy loam soils of Shimoga recorded a better number of productive tillers hill-1 with more length and number of grains panicle-1 and test weight of rice in aerobic condition compared to flooded condition.

Yield

Xiaoguang *et al*. (2001) [62] reported that the normal lowland varieties yielded less under aerobic conditions than flooded conditions, but aerobic varieties yielded higher under aerobic conditions in China. In another study, Belder *et al*. (2005) [3] obtained higher grain yield in flooded conditions (5.45 t ha-1) than in aerobic conditions (4.35 t ha-1) at Los Banos, Philippines. Peng *et al*. (2006) [40] stated that aerobic rice produced significantly lower grain yield than flooded rice in an experiment conducted within the Philippines. Similarly, the harvest index was lower under aerobic than in flooded conditions. Rice yields at Delhi on raised beds that were kept around field capacity were 32-42% less than under flooded transplanting conditions and 21 percent less than under flooded wet-seeded conditions (Choudhury *et al*., 2007) [12]. At Brisbane, Nguyen *et al*. (2009) [34] recorded a 30 percent higher mean grain yield within the flooded system than with saturated soil condition systems. In a study conducted on sandy loam soils at Hyderabad, Andhra Pradesh, grain yields in aerobic rice plots were significantly less than those in flooded rice (Kadiyala *et al*., 2012) [23]. Similarly, aerobic adaptation under water stress environment caused a big reduction in overall grain yield, producing 3.52 t ha-1, which was significantly enhanced to 4.26 t ha-1 under semi-aerobic conditions (Ghosh *et al*., 2012) [19]. Yield at Coimbatore, irrigating semi-dry rice with a water depth of 5 cm at weekly interval up to 45 and 60 days after emergence (DAE) resulted in significantly superior yield compared to fortnightly irrigations. (Thyagarajan and Selvaraju, 2001) [60]. At Los Banos, the Philippines, keeping the rice in aerobic conditions at vegetative and reproductive stages and flooding at grain filling didn't end in any yield increase over that of keeping the soil aerobic throughout crop growth (Nieuwenhuis *et al*., 2002) [35]. The yield reduction was only 12% with the aerobic conditions throughout crop growth as compared thereto to continuously flooded condition. Bouman *et al*. (2005) found that the rice yields and harvest index under aerobic conditions were higher in relatively wet soil with a soil moisture tension of -10 to -12 kPa within the root zone than in dry soil of -40 kPa at IRRI, Philippines. The yield of aerobic rice obtained with an irrigation schedule of 1.2 IW/CPE ratio (4916 kg ha-1) was 13 percent above that obtained at 0.8 IW/CPE ratio but quite double thereupon obtained under micro-irrigation treatment (Maheshwari *et al*., 2008). Ghosh and Singh (2010) [10] at Cuttack, Odisha conducted a study to work out the critical soil moisture regime at the root-zone depth (30 cm) for sustaining optimum growth and grain yield of aerobic rice and located that irrigation at 0, -20 and-40 kPa soil moisture tension resulted in similar grain yields but declined significantly at -60 kPa. In contrast, (Pasha, 2010) [38] observed a significantly higher yield of aerobic when irrigated at 7 days interval at vegetative stage and 4 days interval at the reproductive stage compared to frequent irrigation at two days interval throughout the crop growth period. Shekara *et al*. (2010) could realize a yield of 6.4 t ha-1 of aerobic rice with the irrigation regime of IW/CPE ratio of two .5 which was 26 to the next than that of IW/CPE ratio of 1.5.Grain yield of dry seeded rice observed with daily irrigation and at -20 kPa was similar and declined because the irrigation threshold increased to-40 and-70 kPa (Sudhir *et al*., 2011) [58]. Significantly higher grain (3350kg ha-1) and straw yield (5530 kg ha-1) of aerobic rice was related to irrigation scheduled at IW/CPE ratio of 1.5 upto panicle initiation and a couple of .0 for the remaining period in sandy clay loam soils of Hyderabad, Andhra Pradesh (Balamani *et al*., 2012) [1].

Water Requirement and Water Use Efficiency (WUE)

Qing *et al*. (2004) [45] reported less water use efficiency with low water inputs in aerobic rice compared to flooded conditions in China. At Los Banos, Philippines, higher water productivity was obtained in aerobic condition (0.57 and 0.42 kg m-3 in 2002 and 2003, respectively) than in flooded condition i.e., 0.45 and 0.37 kg m-3 in 2002 and 2003, respectively (Belder *et al*., 2005) [3]. Water requirement was reduced by 34 percent in aerobic compared to flooded rice. Similarly, water productivity of rice (with reference to rainfall and irrigation water input) under aerobic conditions was 32-88% above under flooded conditions at IRRI, Philippines (Bouman *et al*., 2005). Choudhury *et al*. (2007) [12] from Delhi reported that reduced water inputs and yield reductions balanced one another in order that water productivity was comparable among the aerobic (raised beds or flat) and flooded transplanted conditions. In an experiment conducted by Geethalakshmi *et al*. (2009) [17], the traditional transplanting method of rice used more quantity of water (16,200 m3 ha-1) whereas, aerobic rice used minimum quantity (9,687 m3 ha-1) leading to a water-saving of 32.9 - 43.9%. Matsuo and Mochizuki (2009) [31] measured the water productivity of rice cultivars in aerobic plots in Japan and located that it had been 2.2 to 3.6 times above that in continuously flooded paddy. At Brisbane, Nguyen *et al*. (2009) [34] found similar WUE values in aerated and flooded treatments which were significantly less than those observed for saturated soil conditions. Ghosh *et al*. (2012) [19] reported that despite requiring 20% more water following supplementary irrigation, water productivity (23 g grain L-1 water) remained almost equal in semi-aerobic and aerobic conditions of rice at CRRI, Cuttack. An experiment conducted by Kadiyala *et al*. (2012) [23] at Hyderabad revealed that flooded rice treatment used 1364 mm of water as compared to 806 mm in aerobic rice but water productivity was also suppressed in aerobic rice because of lower yields.

Nitrogen Uptake

Belder *et al*. (2005) [3] recorded higher total plant nitrogen in flooded conditions (102.5 kg ha-1) as compared to that in aerobic conditions (74.3 kg ha-1). In contrast, Katsura *et al*. (2010) [24] found that the N accumulation at maturity was significantly higher in aerobic culture (193-233 kg N ha-1) than in flooded culture (142-173 kg N ha-1) in Japan.

Kadiyala *et al*. (2012) [23] found that nitrogen uptake in aerobic rice was 20-40% but that of the flooded system.

Economics

Kadiyala *et al*. (2012) [23] reported that gross returns and benefit: cost ratio was higher in flooded rice compared to aerobic rice, especially in dry years.

Influence of Irrigation Schedules on Aerobic Rice Growth

Panicle number and weight, filled spikelets panicle-1 were found to be higher but test weight remained unaffected in aerobic rice irrigated at 7 days interval during the vegetative stage and 4 days interval during reproductive stage compared to irrigations given at 2 days interval throughout the growth period at Kampasagar, Andhra Pradesh (Pasha, 2010) [38]. Shekara *et al*. (2010 b) in Bengaluru, Karnataka noticed a significant number of productive tillers hill-1, filled spikelets panicle-1, 1000-grain weight of aerobic rice when irrigated at an IW/CPE ratio of two .5 compared to lower levels of IW/CPE ratio. Balamani *et al*. (2012) [1] from Hyderabad, Andhra Pradesh found that irrigating the aerobic rice at an IW/CPE ratio of 1.5 at panicle stage and 2.0 for the remaining period produced significantly higher number of panicles m-2 compared to other schedules while panicle length, grains panicle-1 and test weight was unaffected by the irrigation schedules. In an experiment conducted at CRRI, Cuttack, Ghosh *et al*. (2012) [19] observed a reduction of twenty-two.6% in panicle number m-2, 3.6 to 23.5% in panicle length because of water stress caused at-40 kPa of soil water potential than at -20 kPa while the test weight wasn't stricken by the water management treatments. Mahajan *et al*. (2012)

[27] from Ludhiana, Punjab reported that the quantity of grains panicle-l and 1000-grain weight increased at an irrigation threshold of -10 kPa than at -20 kPa in aerobic rice. Productive tillers m-2 and number of filled grains panicle-1 increased significantly with irrigation schedule once in three days in aerobic rice as compared to other irrigation schedules while the test weight didn't differ due to the different amounts of water applied (Prabhakar *et al*., 2012) [43]. Sridharan and Vijayalakshmi (2012) [56] from Coimbatore reported that on clay loam soils, the number of panicles m-2 and test weight of aerobic rice was significantly increased from the irrigation schedule of IW/CPE ratio 0.8 to 1.2 and it had been on a par therewith of micro-sprinkler irrigation given at three days interval. Yield attributes viz., number of panicles m-2, the total number of grains panicle-1 and number of filled grains panicle-1 were found to be the very best in aerobic rice with irrigation scheduled at IW/CPE ratio of 1.2 compared to 1.0 or 0.8 (Murthy and Reddy, 2013) [33] at Naira, Andhra Pradesh. Maintenance of soil under saturated condition throughout the crop growth period in aerobic rice at Warangal, Andhra Pradesh resulted in higher number and longer panicles, the number of filled grains panicle-1, with the corresponding decrease in chaffyness but was on a par with drip irrigation at 150% PE (Mallareddy *et al*., 2013) [30]. However, test weight didn't vary with the irrigation schedules.

Yield

At Coimbatore, irrigating semi-dry rice with a water depth of 5 cm at weekly interval up to 45 and 60 days after emergence (DAE) resulted in significantly superior yield compared to fortnightly irrigations (Thyagarajan and Selvaraju, 2001) [60]. At Los Banos, the Philippines, keeping the rice in aerobic conditions at vegetative and reproductive stages and flooding at grain filling didn't end in any yield increase over that of keeping the soil aerobic throughout crop growth (Nieuwenhuis *et al*., 2002) [35]. The yield reduction was only 12% with the aerobic conditions throughout crop growth as compared thereto to continuously flooded condition. Bouman *et al*. (2005) found that the rice yields and harvest index under aerobic conditions were higher in relatively wet soil with a soil moisture tension of -10 to -12 kPa within the root zone than in dry soil of -40 kPa at IRRI, Philippines. The yield of aerobic rice obtained with an irrigation schedule of 1.2 IW/CPE ratio (4916 kg ha-1) was 13 percent above that obtained at 0.8 IW/CPE ratio but quite double thereupon obtained under micro-irrigation treatment (Maheshwari *et al*., 2008). Ghosh and Singh (2010) [20] at Cuttack, Odisha conducted a study to work out the critical soil moisture regime at the root-zone depth (30 cm) for sustaining optimum growth and grain yield of aerobic rice and located that irrigation at 0, -20 and -40 kPa soil moisture tension resulted in similar grain yields but declined significantly at -60 kPa. In contrast, (Pasha, 2010) [38] observed a significantly higher yield of aerobic when irrigated at 7 days interval at vegetative stage and 4 days interval at the reproductive stage compared to frequent irrigation at two days interval throughout the crop growth period. Shekara *et al*. (2010 b) could realize a yield of 6.4 t ha-1 of aerobic rice with the irrigation regime of IW/CPE ratio of two .5 which was 26 to the next than that of IW/CPE ratio of 1.5. Grain yield of dry seeded rice observed with daily irrigation and at -20 kPa was similar and declined because the irrigation threshold increased to-40 and-70 kPa (Sudhir *et al*., 2011) [58]. Significantly higher grain (3350 kg ha-1) and straw yield (5530 kg ha-1) of aerobic rice was related to irrigation scheduled at IW/CPE ratio of 1.5 up to panicle initiation and a couple of .0 for the remaining period in sandy clay loam soils of Hyderabad, Andhra Pradesh (Balamani *et al*., 2012) [1]. Mahajan *et al*. (2012) [27] obtained higher grain yields of aerobic rice at an irrigation regime of -10 kPa compared to -20 kPa in sandy loam soils of Ludhiana. Irrigation given to aerobic rice scheduled once in three days interval registered higher grain and straw yield of aerobic rice compared to other schedules at Utukuru, Andhra Pradesh (Prabhakar *et al*., 2012) [43]. In a study conducted by Mallareddy *et al*. (2013) [30] scheduling of irrigation to aerobic rice aimed toward maintaining the soil moisture at saturation throughout the season led to the many increase within the grain and straw yield compared to drip irrigation at 100 or 150% of PE. Similarly, Murthy and Reddy (2013) [33] from Naira, Andhra Pradesh also reported that grain and straw yield of aerobic rice increased significantly with a rise in irrigation schedule from 0.8 to 1.2 IW/CPE ratio.

Crop Evapotranspiration

Shekara *et al*. (2010 b) observed higher consumptive use of aerobic rice at the IW/CPE ratio of two .5 over 2.0 ratio.

Water Requirement and Water Use Efficiency (WUE)

Singh and Chinnusamy (2006) [51] reported that irrigation scheduled at-20 kPa soil moisture tension in aerobic rice system helped in saving of 35% percent water. In aerobic rice, quantity of water utilized in irrigation scheduling with IW/CPE ratio of 0.8, 1.2 and micro-sprinkler was 498, 618 and 659 mm, respectively, but the water productivity was found to be higher with 0.8 IW/CPE ratio (8.61 kg ha-mm-1) compared to other schedules (Maheswari *et al*., 2008) [28]. Ghosh and Singh (2010) [20] found that irrigation to aerobic rice at -40 kPa soil moisture tension ensured the utmost water productivity of 0.90, 0.47 and 0.53 g grain kg-1 of water with reference to evapotranspiration, irrigation plus rainfall and irrigation alone, respectively. Pasha (2010) [38] found that water input was higher with the irrigation scheduled once in two days, while the water productivity was higher with irrigation scheduled at 7 days interval during the vegetative stage and 4 days interval during the reproductive stage. From an experiment conducted by Shekara *et al*. (2010b), supported the 2 years mean, irrigation scheduled at IW/CPE ratio of two .5 took more water (154.8 cm) resulting in lower WUE (41.3 kg ha-cm-1), whereas, irrigation scheduled at IW/CPE ratio of 1.0 needing all-time low total water (91.8 cm) had higher WUE (52.1kg ha-cm-1). In another trial, the entire water utilized in different irrigation schedules was within the range of 675-775mm including an efficient rainfall of 325 mm, while the very best water use efficiency was observed with irrigation scheduling supported soil moisture tension of -20 kPa to-30 kPa up to panicle initiation stage and -10 kPa to -20 kPa for the remaining period compared to other schedules which were supported IW/CPE ratio (Balamani *et al*., 2012) [1]. Mahajan *et al*. (2012) [27] observed that the WUE of aerobic rice was greater at -20 kPa than irrigating at soil water potential of -10 kPa at Ludhiana. Similarly, scheduling irrigation through the drip system at 100% PE resulted during a 25 and 42 percent increase in water use efficiency over 150% PE and soil saturation, respectively at Warangal, Andhra Pradesh (Mallareddy *et al*., 2013) [30].

Nitrogen Uptake

Pasha (2010) [38] observed higher N uptake in aerobic rice, with the irrigation regime of seven days interval during the vegetative stage and 4 days interval during the reproductive stage compared to it of two days interval throughout the growth. At Bengaluru, irrigating the aerobic rice at 2.5 IW/CPE ratio registered higher nitrogen uptake than at lower levels of the IW/CPE ratio (Shekara *et al*., 2010 b). The N-uptake of aerobic rice was found to be lower at an irrigation threshold of -20 kPa than at-10 kPa at Ludhiana (Mahajan *et al*., 2012) [27]. Nitrogen uptake by the grain also as straw in aerobic rice gradually increased with the water input from 100% PE to soil saturation treatment at Warangal, Andhra Pradesh (Mallareddy *et al*., 2013) [30]. Murthy and Reddy (2013) [33] also found that nitrogen uptake by both grain and straw of aerobic rice attended increase with the increasing levels of IW/CPE ratio from 0.8 to 1.2 at Naira, Andhra Pradesh.

Nitrogen Use Efficiency

Improved N-use efficiency in aerobic rice was reported by Mahajan *et al*. (2012) [27] at -20 kPa irrigation regime than in -10 kPa regime in sandy loam soils of Ludhiana.

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