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Aerobic rice: Rice for future

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Abstract
Rice production and food security largely depend on the irrigated lowland rice system. But, fresh water scarcity, water pollution, competition for water use, growing population, rising demand for food, climate change and global warming, higher cost of irrigation, and poor availability of labour have threatened the puddled transplanted system of rice. Aerobic rice has been identified as a potential new technology, which can reduce water use in rice production and produce more rice with less water. Water productivity is high and labour requirement is less under aerobic rice production system; it also minimizes greenhouse gas emission rates from rice fields. Aerobic rice is a projected sustainable rice production methodology for the immediate future to address water scarcity and environmental safety in the scenario of global warming. However the hurdles in achieving potential yield under aerobic system has to be overcome by focused research, then only we can make aerobic rice a potentially viable alternative to lowland rice.

Keywords: aerobic rice, green house gas, water requirement, water use efficiency

Introduction

Rice (*Oryza sativa* L.) is the 'staple food crop for more than half of the global population and influences the livelihoods and economies of several billion people. Annual rice production should be increased to meet the demand of ever growing population. This increase in production has to come despite the declining resources like land and water, which is a challenging task. Rice production and food security largely depend on the irrigated lowland rice system, but whose sustainability is threatened by fresh water scarcity, water pollution and competition for water use. In Asia, lowland rice production consumes more than 45 per cent of total fresh water used (Barker *et al.*, 1998) [2]. Water is becoming scare for agriculture at present situation. It is predicted that by 2025, 15 out of 75 million hectare of Asia's flood-irrigated rice crop will experience water shortage (Tuong *et al*., 2005) [32] and 15-20 million hectares of irrigated rice will suffer from some degree of water scarcity (Zeigler, 2012) [38]. The reduction by 10% of water used for rice irrigation would save 150,000 million m^3, which corresponds to about 25% of the total fresh water globally used for non-agricultural purposes (Klemm, 1998) [20]. Transplanted Irrigated rice requires a lot of water for puddling, transplanting and irrigation and significant water losses can occur through seepage, percolation and evaporation, it is estimated that it consumes 3000–5000 liters of water to produce 1 kg of rice (Barker *et al*., 1998) [2]. A growing scarcity of fresh water will pose problems for rice production in future years; therefore there is a need to develop technologies that can reduce these water losses. Promising technologies include water management practices such as intermittent irrigation (e.g., alternate wetting and drying), saturated soil culture (where soil is kept between field capacity and saturation by frequent irrigation, but water is not ponded on the field) and growing rice intensively to increase the 'crop per drop' (Bouman *et al*., 2002) [7]. However, each of these approaches still requires prolonged periods of flooding and/or wet surface soil, and so water losses remain relatively high.

International Rice Research Institute (IRRI) has coined the concept of "aerobic rice", to address the water crisis with a mission of more rice with less water. The concept of aerobic rice holds promise for farmers where water has become too scarce or expensive to grow flooded rice, and in rainfed areas where rainfall is insufficient for flooded rice production but sufficient for upland crops. Climate change as the consequence of global warming and depletion of the ozone layer is already being experienced across the world. Lowland rice cultivation is the major source of methane (CH_4) emissions, contributing 48% of the total greenhouse gases emitted by agricultural sources. However, aerobic rice emits 80-85 percent lesser methane gas into the atmosphere thus keeping the environment safe. Moreover, there is savings of water, along with labour, nutrients, and other inputs in aerobic rice compared with irrigated transplanted rice. Aerobic rice has been identified as a water saving, eco-friendly and economical technology for rice production. Aerobic rice is seen as a as a water saving, eco-friendly and economically feasible alternative to lowland rice.

Aerobic rice production system

Aerobic rice is a new term coined by the International Rice Research Institute (IRRI), for high-yielding rice grown under non-flooded conditions in non-puddled and unsaturated (aerobic) soil, which is responsive to nutrient supply, can be rainfed or irrigated, and tolerates (occasional) flooding (Bouman and Tuong, 2001) [4, 5]. This system has been developed and adopted by farmers in Brazil, China, and other Asian countries (Wang *et al*., 2002; Pinheiro *et al*., 2006) [35, 26]. It is responsive to high inputs, can be rainfed or irrigated, and tolerates occasional flooding Aerobic rice is grown like an upland crop (unsaturated condition) with adequate input and supplemental irrigation when rainfall is insufficient (Bouman, 2001) [4, 5]. The soil is therefore ‘aerobic’ or with oxygen through the growing season, as compared to traditional flooded fields, which are ‘anaerobic’.

Supplementary irrigation is applied in aerobic rice system of cultivation as and when required and can be supplied in the same way as to any upland cereals crops like maize, wheat (Bouman *et al*., 2005) [6]. Irrigation is by surface method (e.g., flush irrigation, furrow irrigation) or by sprinklers and aims at keeping the soil “wet” but not flooded or saturated (Belder *et al*., 2005) [3]. The aerobic rice cultivation involves direct seeding with surface irrigations when required and is characterized by aerated soil environment during the entire period of crop growth. The ecosystem for this type of rice is intermediate between upland and irrigated or favorable shallow rainfed lowlands. The area where water is not sufficiently available to grow lowland transplanted rice, but sufficiently available for upland crops, can be used for aerobic rice. To achieve high yields under aerobic conditions, aerobic rice cultivars should combine the drought-tolerance characteristics of upland cultivars with the high-yielding characteristics of lowland cultivars (Lafitte *et al*., 2002) [21]. The cultivars used are adapted to aerobic soils and have higher yield potential than traditional upland cultivars (Atlin *et al*., 2006) [1]. The labour use is also saved in aerobic rice because more labor is required for land preparation such as puddling, transplanting, and irrigation activities in flooded rice (Wang *et al.*, 2002) [35].

Aerobic rice: A water saving technology

i) Water requirement

Aerobic rice is a new way of cultivating rice that requires less water than lowland rice. The conventional transplanting method of rice used higher quantity of water (16,200 m^3 ha^{-1}) whereas aerobic rice used minimum quantity (9,687 m^3 ha^{-1}) and observed a water saving of 32.9 to 43.9 per cent over transplanted rice (Geethalakshmi *et al.*, 2009) [11]. According to Belder *et al.* (2005) [3] water requirement was less in aerobic rice (842 and 940 mm) as compared to flooded rice (1233 and 1473 mm) in 2002 and 2003. Aerobic way of growing rice saves water by eliminating continuous seepage, percolation and by reducing reducing evaporation (Castaneda *et al.*, 2002) [8]. Flooded rice used three times more irrigation water (358 mm) than aerobic rice (89 mm) for land preparation and twice during the crop growth period (1148 and 481 mm). In aerobic rice production system, continuous seepage, percolation and evaporation losses are greatly reduced; it effectively utilizes the rainfall and help in enhancing the water productivity (Bouman *et al.*, 2005) [6]. Kadiyala *et al.* (2012) [18] reported that the total amount of water applied (including rainfall) in the aerobic plots was 967 and 645 mm compared to 1546 and 1181 mm in flooded rice system, during 2009 and 2010, respectively. This resulted in 37 to 45% water savings with the aerobic method.

Bouman *et al*. (2002) [7] estimated water requirement for aerobic condition by growing two elite aerobic rice genotypes and one popular lowland variety both under flooded and aerobic conditions. The results of their study has shown that compared with lowland rice, water inputs in aerobic rice were more than 50% lower (only 470 mm-650 mm), water productivities 64%-88% higher, and labour use 55% lower. The lower water input, kept at field capacity in direct seeded rice reduced the rates of evapotranspiration (22-31%) and percolation (22-38%) as compared to traditional system (Chaudhary *et al.,* 2008). The direct seeded aerobic rice is a typical technology, wherein an additional 130-150 mm of water input can be saved by foregoing the wet land preparation (Bouman *et al., 2*005) [6]. In experiments at Japan by Kato *et al*. (2006) [19] in aerobic fields, the total amount of water supplied (irrigation plus rainfall) was 800-1300 mm. The aerobic rice cultivation saves 40-50 per cent of water with marginal reduction in grain yield of about 10-20 per cent (Singh and Chinnuswamy, 2006) [29]. Wang *et al*. (2002) [35] reported that in aerobic rice, water use was 60 per cent less than that of flooded rice, requires less labour (55 per cent) and it facilitates mechanization also.

ii) Water use efficiency

Patel *et al.* (2010) [24] reported the higher WUE of aerobic rice compared to flooded condition, similar results were also given by Singh *et al*. (2008) [30]. Jinsy *et al.* (2015) [17] found that compared to conventional flooded rice, the average water productivity of aerobic rice (0.68 kg m^3) was 60.7 per cent higher. Gill *et al*. (2006) [13] reported that the irrigation water productivity of rice on beds and furrow system was significantly higher (0.69 g kg^{-1}) than that of paddy raised on puddled flat plots. According to him water productivity in direct seeded rice was 0.34 and 0.76 kg grain m^{-3} in 2002 and 2003, respectively. According to Wang *et al.* (2002) [35] total water productivity of aerobic rice was 1.6 to 1.9 times higher and water use about 60 per cent less than lowland rice. Reddy *et al.* (2010) [27] reported that water productivity was higher under aerobic (0.20 to 0.60 kg m^{-3} of water) than that under transplanted (0.14 to 0.43 kg m^{-3} of water) condition. Under aerobic conditions, the WUE of aerobic rice cultivars was higher (0.65 0.83 g grain kg^{-1} water for HD 502) compared to the WUE of lowland cultivar JD 305,which was 0.26 to 0.66 g grain kg^{-1} water (Xiaoguang *et al.,* 2002) [36]. According to Bouman *et al.* (2002) [7] experiments on aerobic rice have shown that water inputs were more than 50 per cent lesser (only 470-650 mm) and water productivities were 64-88 per cent higher than the lowland rice. From the pertinent literature available, it could be concluded that rice can be grown under aerobic conditions like any other upland crop by developing different agro practices like nutrient management, irrigation methods and schedules for reaping a bountiful yield while saving water.

The water use efficiencies of aerobic varieties under aerobic conditions were 164-188 per cent higher than that of lowland varieties under lowland conditions (Wang and Tang, 2000) [34]. Aerobic rice could be successfully cultivated with 600-700 mm of total water in summer and entirely on rainfall in wet season (Sritharan *et al*., 2010) [31]. A study conducted on farmers field at Chintalapudi, Guntur (Andhra Pradesh) during 2004-05 on clay loam soils with five rice production systems indicated that the water saving through semi-dry rice with rotational irrigation was 20% with a water use efficiency of 6.1 kg ha^{-1} mm^{-1} compared to farmers practice of transplanting with continuous flooding (5.2 kg $ha^{-1}mm^{-1}$) (Jat *et al*., 2009) [15].

Greenhouse gas emissions under aerobic conditions
Globally, anthropogenic sources of methane (CH_4) and nitrous oxide (N_2O) are dominated by agriculture, and agricultural CH_4 and N_2O emissions have increased by approximately 17 per cent from 1990 through 2005 (Forster *et al*., 2007) [10]. Traditional flooded paddy fields have been identified as a major source of increasing atmospheric CH_4 accounting for approximately 5-19% of the annual global CH_4 emissions to the atmosphere (IPCC, 2007). Although most N_2O emissions are produced in uplands, several studies on N_2O emissions from rice fields revealed that substantial N_2O emission results from the mid-season drainage and dry-wet episodes in rice fields (Yao *et al.,* 2010) [37]. Methane is produced by anaerobic (without oxygen) decomposition of organic matter in the soil under flooded rice cultivation. Flooding creates anaerobic conditions a few millimeters beneath the soil surface and leads to the production of methane. The absence of standing water drastically reduces emissions of methane to the atmosphere. Adopting aerobic rice will help to minimize both methane and nitrous oxide emission rates from rice fields without affecting the productivity (Shashidhar, 2008) [28]. Methane flux was almost 10 times more pronounced under continuously flooded conditions than under continuously non-flooded conditions. The significantly lower efflux of methane under aerobic (3.03 mg m^{-2} hr^{-1}) compared to flooded rice (6.16 mg m^{-2} hr^{-1}) was reported by Jinsy (2014) [16]. Vial (2007) [33] reported that approximate 50% reduction in CH_4 emission under aerobic rice system from some trials, were conducted at IRRI. So, we can say that the aerobic rice system is eco-friendly approach and safe for the environment.

Major challenges and future prospects of aerobic rice
Aerobic rice system inquire lesser water inputs (50%), labour (55%) and higher water productivities (66 to 88 %), than that of flooded rice cultivation. However, in the present case widespread adoption of aerobic rice is limited due to several constraints. Yield reduction in compared to traditional system is the visible factor inhibits the spread of aerobic rice technology, Patel *et al.* (2010) [24] reported that the yield difference between aerobic (average yield, 1.67 Mg ha^{-1}) and flooded rice (average yield, 2.31 Mg ha^{-1}) ranged from 18.4 to 37.8 per cent. Bouman *et al.* (2005) [6] reported that the mean yield was 32% lower under aerobic conditions than under flooded conditions. Neiuwenhuis *et al.* (2002) [23] observed 12 per cent reduction in yield of aerobic rice when compared to continuous submergence. Moreover, most of the varieties that farmers currently cultivate are not suitable for cultivation in aerobic conditions. Achieving high yields under irrigated but aerobic soil conditions requires new varieties of aerobic rice that combine the drought-tolerance characteristics of upland cultivars with the high-yielding characteristics of lowland cultivars (Lafitte *et al*., 2002) [21]. Weeds perceived to be the most severe constraint to aerobic rice production. Found almost double weed density and biomass in aerobic rice field than those of conventional transplanted rice at 35 and 75 days after sowing /transplanting. Although flooding has beneficial effects on soil acidity (pH), soil organic matter buildup, availability of phosphorus, iron, and biological nitrogen fixation, etc., these beneficial effects may decrease with aerobic rice cultivation. Major nutrient and micronutrient dynamics and their bioavailability are expected to change due to a shift to aerobic cultivation. Belder *et al.* (2005) [3] reported relatively low uptake of nitrogen under aerobic conditions as compared to flooded conditions which was reflected by the relatively low fertilizer-N recovery under aerobic conditions
As aerobic system of rice cultivation is a new approach, detailed research in the area can refine the limiting factors and thereby we can achieve yield comparable with that of traditional system. The increased water saving and fertilizer responsiveness combine with the inherent yield potential of aerobic rice could realize an estimated yield potential of 6-7 t ha^{-1} (Peng *et al*., 2006) [25]. In Brazil, aerobic rice cultivars with high grain yields of 5-7 t ha^{-1} have been developed (Castaneda *et al*., 2002) [8]. By developing aerobic rice varieties with an efficient root system that enables increased uptake of water and nutrients, rice yield under aerobic conditions can be further increased. In northern China, the grain yields of 8 tha^{-1} and even higher have been achieved using high-yielding aerobic rice cultivars under appropriate management practices (Wang *et al*., 2002) [35]. Kato *et al.* (2006) [19] reported that the super-high-yielding cultivar Takanari achieved yields greater than 10 t ha-1 with no yield penalty under aerobic conditions in three out of four experiments. Similarly higher yields under aerobic conditions were obtained with improved upland variety Apo (Bouman *et al*., 2005) [6]. Since the concept of aerobic rice is new, relatively few insights exist into water, N, P, Fe, and Zn dynamics and their interactions. There are reports of soil sickness after some years of aerobic rice cultivation. Hence, a thorough understanding of these processes would lead to the development of sustainable management of irrigation and nutrients to optimize yield and resource-use efficiency. Weeds, however, are the major constraints in aerobic rice production. The adoption of weed-competitive cultivars will decrease environmental pollution and the development of herbicide-resistant biotypes by reducing herbicide application. Weed-competitive cultivars are reported to be a low-cost and safe tool for integrated weed management (Gibson and Fischer, 2004) [12]. Thus, it appears that weed is the major constraint to aerobic rice production and therefore, success of this technology mostly depends on effective weed management. To achieve effective, long-term, and sustainable weed management in aerobic rice, there is a need to integrate different weed management strategies, such as cultural, physical and biological weed management strategies and judiciously using herbicides as last resort rather than as only resort.

Conclusion
Water is undoubtedly one of the most precious resources; however water is becoming increasingly scarce globally. Rice production and food security largely depend on the irrigated lowland rice system, but whose sustainability is threatened by fresh water scarcity, water pollution and competition for water use. From the review, it is unambiguous that, aerobic rice is a potentially viable alternative to lowland rice when water scarcity is a limiting factor. Above all, adopting aerobic rice will help to minimize greenhouse gas emission rates from rice fields without affecting the productivity. However the

sustainability of aerobic rice cultivation is questioned by yield decline, weeds, lack of varieties and less nutrient availability. Since it is a new system constant and focused research on the hurdles can make aerobic rice a potentially viable alternative to lowland rice

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