Review Article

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Aerobic rice: water use sustainability

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ABSTRACT

Rice requires approximately 3000-5000 liters of water to grow one kilogram of rice traditionally. About 22 million hectares of irrigated dry season rice experience "economic water scarcity" in South and Southeast Asia. Therefore, it was felt that there is a need to save water in rice cultivation, which led to development of alternative methods of cultivation i.e., alternate wetting and drying(AWD), saturated soil culture (SSC) and aerobic rice. Aerobic rice is the latest technology that reduces water inputs by growing rice as any other irrigated upland crop. Selection of physiological traits of aerobic rice using molecular approaches may help in enhancing water use efficiency sustaining the productivity.

Key words: *Aerobic rice, water stress, upland crop, sustainable agriculture*

Almost 28% of the world's rice is grown under rainfed lowlands (Khush, 1997) and frequently affected by uneven rainfall distribution. Another 13% of the rice area is under upland cultivation, which is always subjected to water stress during the growing season. Besides, about 75% of the total rice production in Asia is from irrigated lowland (Bouman *et al.*, 2007). About 50% of the world rice production area is affected by drought stress. When soil water content drops below saturation, yield losses occur, as rice is susceptible to drought (Bouman and Tuong, 2001; Pantuwan *et al.*, 2002).

It was estimated that 22 million hectares of irrigated dry season rice in South and Southeast Asia was experiencing "economic water scarcity" and 2 million hectares of Asia's irrigated dry season rice and 13 million hectares of its wet season rice would suffer from "physical water scarcity" by 2025 (Tuong and Bouman, 2002). The availability of water for agriculture is declining steadily due to urbanization and rapid increase in population (Xue *et al.*, 2008). Thus farmers are now considering growing rice as an aerobic crop. As moisture stress at any period during growth reduces the crop yield, proper water management is the key for successful cultivation of aerobic rice (Lafitte *et al.*, 2003). Maintaining production, while reducing water use by rice, is a complex task (Lafitte *et al.*, 2006). Two types of irrigation methods i.e., alternate wetting and drying (AWD) and saturated soil culture (SSC) have been developed to reduce water inputs by minimizing outflow.

In alternate wetting and drying (AWD) method, water is applied to obtain a flood water depth of 2-5 cm after passage of a certain number of days (ranging from 2-7) from the day of disappearance of standing water. In this technique, water input, water productivity and rice yield depend mostly on environmental conditions, especially the number of days passed after the disappearance of standing water, soil type and depth of ground water. Generally, by using this technique, water input and rice yield decreases but mostly, decrease in water input is higher than the yield, thus water productivity increases (Bouman and Tuong, 2001).

In saturated soil culture (SSC), the soil is kept as close to saturation as possible by shallow irrigation to obtain about 1 cm floodwater depth a day or so after the disappearance of standing water. This reduces water inputs by 30-60% compared with the conventional practice in the Philippines. The yield reduced from 4-9% resulting in increase in water productivity with respect to total water input of 30-115% (Tabbal *et al.*, 2002). In another experiment rice was grown in raised beds in Australia by using saturated soil culture technique. In this system, rice is grown on beds that are kept at saturation by keeping water in furrows in between the beds. In bed planting the water input is reduced by 42% compared with conventional flooded rice grown in flat fields. Though yield was declined by 17%, the water productivity with respect to total water input was 33% higher than that in conventional flooded system (Tuong, 2003).

There is a need to save water from rice cultivation in future to overcome the problem of water scarcity for which a special rice plant types that requires less of water and a suitable production technology has to be developed. This led to the development of an alternative method of rice cultivation i.e., "Aerobic rice". Aerobic rice is called so because it is grown in a soil environment where oxygen is present in plenty as compared with flooded soil, where the condition is anaerobic. Therefore, the twin benefit of water saving and production increase can be achieved by developing aerobic rice. It was also observed that the average yield was 12% higher in heavy soil than in light soil and 40% less water used under aerobic conditions, whereas in flooded conditions yield was 23% higher in lighter soil, than heavy soil and 35% more water was consumed (Castaneda *et al.*, 2003).

In the United States, studies on lowland rice grown under aerobic conditions were in temperate zones. Depending upon soil type, rainfall and water management, 20-50% less irrigation water was consumed in comparison to flooded conditions. But, 20-30% less yield was observed by growing high yielding cultivars (7-8 t/ha) under aerobic condition. Drought tolerance cultivars produced same yield (5-6 t/ha) under both the conditions. Similar results were also obtained by researchers with sprinkler irrigation in Australia (Blackwell *et al.*, 1985). It was observed later that flooded rice had 20% more panicles per m^2, 15% more spikelets per m^2 and 13% higher grain filling than aerobic rice. Also the harvest index of flooded rice was higher than aerobic rice during dry season (Visperas *et al.*, 2002).

To reduce evaporation, the easy method is to reduce land preparation period (Tuong, 1999). After crop establishment, canopy closing earlier will reduce evaporation. This can be achieved by using rice varieties with good seedling vigour and maintaining proper plant density. Thus, rice plants can compete more efficiently with weeds and reduce non beneficial transpiration resulting in increase in yield (Tuong *et al.*, 2000). Hydrostatic water pressure that forces water movement through the soil causes higher amount of outflow in flooded rice. This can be reduced by reducing the duration of flooding in the fields or decreasing the rate of outflow. To reduce the rate of outflow there is need to reduce hydrostatic pressure or increase resistance to water flow (Tuong *et al.*, 1994). Puddling increases the hydraulic resistance for vertical water movement and thus reduces percolation. Puddling in clay soil is very efficient to fill the gap formed by cracks. This technique is not much effective in coarse soil due to lack of fine particles to migrate downward. But it does not reduce total water requirement for rice (Tabbal *et al.*, 2002). Yield of 3–6 t ha^{1} was reported at soil moisture tensions of 10–12 kPa or in ''low-stress environments'' in aerobic cultivars (Bouman *et al.*, 2005; Atlin *et al.*, 2006).

An alternate method to reduce water inputs is to grow it like an irrigated upland crop such as wheat or maize, i.e. on non-puddled, aerobic soil without standing water. Some tropical rice varieties have a relatively high yield under aerobic soil conditions. Some new high yielding varieties which are responsive to inputs in aerobic conditions must be developed through the concept of growing rice like an irrigated upland crop. Evidences of aerobic rice came from Brazil and Northern China where it is now growing commercially under about 140,000 ha. In Northern China, however, breeding efforts have produced temperate aerobic rice cultivars such as HD297, Han Dao 277, Han Dao 502, Handao 65, Han 946, Han 58, Wushi Handao, Xiahan 51, Danjing 5 and Danjing 8, Danhandao 1 with reported yield potential of up to 6 t/ha under supplementary irrigation (Bouman and Tuong, 2001; Bouman *et al.*, 2005, 2006; Peng *et al.*, 2006). Water use was observed to be about 60% less than that of lowland rice and total water productivity was 1.6-1.9 times higher (Wang *et al.*, 2002; Guang-hui *et al.*, 2008).

In Brazil the impact of improved varieties and associated technologies in the more favorable parts of the savanna region pioneered a new concept of upland rice known as ''sequeiro'' which means ''dry conditions''. Later these varieties are classified in the nomenclature of ''aerobic rice'' proposed by IRRI and aerobic rice is recognized as an economically attractive crop. Now the main research challenge is to integrate aerobic rice as a regular component of cropping systems (Pinheiro *et al.*, 2006). Yields of 4-6 t/ha were obtained using extremely little water (450-650 mm, in place of 1300-1500 mm in lowland rice), resulting in much drier soil condition. It was also demonstrated that besides water use efficiency, the nitrogen use efficiency of aerobic rice was also higher than that of lowland rice (George *et al.*, 2001).

It was noticed that changing from saturated to aerobic conditions, affected the soil form, availability and uptake of zinc, phosphorus and nitrogen (Willett, 1982; Muirhead *et al.*, 1989). Reduced Zn shoot concentrations, partly below deficiency level, in aerobic compared with flooded rice were observed in North China at a site with a soil pH of 8 (Gao *et al.*, 2006). Continuous submergence of soil under flooded rice promotes the production of methane, which is an important greenhouse gas, whereas saturated soil culture and alternate wetting and drying method or the aerobic rice reduces the methane emission. Reports on increased level of NO and N_2O emissions in aerobic rice system are seen and it was varying with soil type, ground water depth, fertilizer application rate and soil water content. In China it was observed that by the application of fertilizer in fields the total N_2O fluxes in aerobic condition was 5-6 times higher than that in paddy soil, while the total emission of CH_4 in paddy soil was 18-19 times higher than that in aerobic condition (Li *et al.*, 2003). It was suggested that both methane and nitrous oxide emissions are minimized by maintaining the soil redox potential within a range of -100 to +200 mV (Hou *et al.*, 2000). Occasionally, yield failures were also noticed which may be related to soil health problems (Nie *et al.*, 2008; Kreye *et al.*, 2009).

Further yield improvements in aerobic conditions can be achieved by identifying secondary traits contributing for tolerance against water stress and selecting for those traits in a breeding programme. The efficiency of selection for secondary traits for yield improvement has been demonstrated in sorghum (*Sorghum bicolor* {L.}Moench.) (Tuinstra *et al.*, 1998) and maize (*Zea mays* L.) (Chapman and Edmeades, 1999).

In the process of drought avoidance rice root characteristics like thickness, depth of rooting, root length density, root pulling force and root penetration ability have been associated (Nguyen *et al.*, 1997). Osmotic adjustment, the active accumulation of solutes during the development of water stress in plants helps in maintaining leaf water potential. It delays leaf rolling, tissue death and leaf senescence under water stress in rice (Hsiao *et al.*, 1984) and enhance grain yield in other crops (Zhang *et al.*, 1999). Quantitative Trait Loci (QTLs) have been detected for several root related traits and osmotic adjustment in rice (Ali *et al.*, 2000; Price *et al.*, 2000; Zheng *et al.*, 2000; Zhang *et al.*, 2001; Mu *et al.*, 2003; Thanh *et al.*, 2006; Zheng *et al.*, 2006; Uga *et al.*, 2008; Suryapriya *et al.*, 2009).

By comparing the coincidence of QTLs for specific traits and QTLs for plant production under drought, it is possible to test whether a particular constitutive or adaptive response to drought stress is of significance in improving field level drought resistance (Lebreton *et al.*, 1995). A total of 47 QTLs have already been identified for various plant water stresses and comparing the coincidence of QTLs with specific traits it was observed that root traits have positive correlation with yield components under water stress. This can be further used for marker-assisted selection for rice improvement (Babu *et al.*, 2003).

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