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Review Paper

Aerobic rice, a new approach of rice cultivation

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Abstract

Water shortage is becoming severe in many rice-growing areas in the world, prompting the introduction of water-saving aerobic rice, which is direct-seeded in nonpuddled, nonflooded aerobic soil, aerobic rice systems can reduce water use in rice production by as much as 50% 'Aerobic rice' and 'upland rice' are both grown under aerobic conditions. However, the former is under controlled water management, but the latter is not. Although the technology of growing rice with the new AWD and aerobic rice systems need to be further refined or developed, a broad adoption of these systems is expected to ensure rice production in water-short areas, and result in significant water saving.

Keywords: Aerobic rice, Water management, Water saving.

Introduction

Rice is the staple food of about 3 billion people and demand is expected to continue to grow as population increases [1] .Globally rice is grown over an area of about 149 million ha with an annual production of 600 million tones [2]. In India, rice is cultivated round the year in one or the other part of the country, in diverse ecologies spread over 44.6 M ha with a production of 132 MT of rice and average productivity of 2.96 t ha-1 [3]. Scarcity of freshwater resources, such as in the world´s leading rice-producing countries China and India has threatened the production of the flood-irrigated rice crop [4]. Asia's food security depends largely on irrigated lowland rice fields, which produce three-quarters of all rice harvested. However, the increasing scarcity of fresh water threatens the sustainability of the irrigated rice ecosystem [5]. Irrigated lowland rice in Asia usually has standing water for most of the growing season. In NW-IGP, increasing use of groundwater for rice cultivation has led to declines in water table by 0.1 to 1.0 m yr-1, resulting in water scarcity and increased cost for pumping water [6].

One way to reduce water and labor demand is to grow dry seeded rice (DSR) instead of the puddled transplanted rice [7]. A new development in water-saving technologies is the concept of ''aerobic'' rice. In aerobic rice systems, fields remain unsaturated throughout the season. Rice has been grown under non flooded, aerobic soil conditions in uplands for centuries, but average yields are only 1-2 t ha^{-1}, because of adverse environmental conditions (poor soils, little rainfall, weeds), low use of external inputs, and low yield potential of upland rice cultivars. The new concept of aerobic rice entails the use of nutrient-responsive cultivars that are adapted to aerobic soils [8], aiming at yields of 70–80% of high-input flooded rice. The target environments are irrigated lowlands where water is insufficient to keep lowland (rain fed or irrigated) paddy fields flooded and favorable uplands with access to supplementary irrigation. To keep up with increasing demand for food combined with increasing scarcity of water, several water-saving technologies such as alternate wetting and drying [9] and aerobically grown rice have been developed in order to increase water productivity (i.e. grain yield over water input, WP). Aerobically grown rice may be an option 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 [10].

Origin and History

International Rice Research Institute (IRRI) developed the "aerobic rice technology" to address the water crisis in tropical agriculture. In aerobic rice systems, wherein the crop is established in non-puddled, non-flooded fields and rice is grown like an upland crop (unsaturated condition) with adequate inputs and supplementary irrigation when rainfall is insufficient [11]. The new concept of aerobic rice may be an alternate strategy, which combines the characteristics of rice varieties adopted in upland with less water requirement and irrigated varieties with high response to inputs. In China, the water use for aerobic rice production was 55–56% lower than the flooded rice with 1.6–1.9 times higher water productivity. It indicates that aerobic rice may be a viable option where the shortage of water does not allow the growing of lowland rice.

Effect of aerobic rice on yield attributes

The yield difference between aerobic and flooded rice was attributed more to biomass production than to harvest index. Among yield components, sink size (spikelets m^{-2}) contributed more to the yield gap between aerobic and flooded rice than grain filling percentage and 1000-grain weight. In general, flooded rice produced more panicles with more spikelets per panicle than aerobic rice. Like grain yield, the difference in yield attributes between the first season aerobic rice and flooded rice was small. Rapid yield decline was reported under continuous upland rice cropping [12] and under monocropping of aerobic rice [13] in the Philippines. Studies on bottlenecks in yield formation under aerobic condition analysed using Handao varieties in North China have shown, sink size as the major limitation of aerobic rice yield, because in aerobic rice spikelet number m"2 was too low (20 000-24 000) compared with the lowland rice. So, future research, should focus on effects of water regimes on tiller dynamics to increase yield [14].

Effect of aerobic rice on Yield

The yield difference between aerobic and flooded rice ranged from 8 to 69% depending on the number of seasons that aerobic rice has been continuously grown. The yield gap between aerobic and flooded rice widened as the number of cropping seasons increased [15]. Peng *et al.* (2006) reported the maximum yield gap in the seventh season when the difference between the aerobic rice and flooded rice reached 69% in 'Apo' [16]. In general, the difference in yield between aerobic and flooded rice was greater in DS than in WS, which was associated with difference in the soil water status of aerobic rice between DS and WS [11]. The soil was wetter in WS because of more frequent rains than in DS. Yield declined by 30–60% in the second season under continuous upland rice cropping for variety 'IR 2061- 464-2-4' [12]. Grain yield decreased by up to 73% in the third season compared to the second season under mono cropping of aerobic rice for variety "UPLRi-5" [13].

Effect of aerobic rice on Nutrient concentration and uptake

Belder *et al.* (2005) 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 [11]. Of the 150 kg N ha^{-1} applied, only an average of 22% was taken up by the crop while 31% was left in the soil and roots after harvest. Since nitrate concentrations in groundwater and soil water were negligible, most of the 47% N unaccounted for must have left the system as gaseous-N losses promoted by rapid nitrification–denitrification processes. A higher recovery of N in aerobic rice (more than the 22%) was desirable to increase N application efficiency, thereby reducing fertilizer costs to farmers, and reduce gaseous-N losses to the environment such as N_2O, which is a potent greenhouse gas. Belder *et al.* (2005) suggested combining water treatments with N treatments to optimize yield and resource-use efficiency. Fertilizer N application as basal just before transplanting showed the lowest N recovery. High N recoveries up to 0.6–0.7 kg kg^{-1} in arable cereal crops show that higher N recoveries in aerobic rice might be possible when N dose and timing better match the N requirement of the crop [11].

Effect of aerobic rice on Changes in soil properties

Peng *et al.* (2006) reported decline in soil organic matter as a possible reason for a decline in yield under aerobic cultivation, because total soil N at physiological maturity in the micro plots was not significantly lower in aerobic than in continuously flooded soil in both 2002 and 2003 [16]. Since soil-extractable NO_3 + NH_4^+ did not constitute more than 0.2% of total N at physiological maturity, almost all N was in organic form. Assuming that C:N ratios were not different between flooded and aerobic soils lead them to conclude that soil organic matter content did not differ between the two water regimes after both seasons. They predicted a decline in soil organic matter under aerobic system as compared with permanent flooding or the rotational flooded rice-aerobic rice.

Effect of aerobic rice on micronutrient status in aerobic rice

For upland rice production, Yoshida (1975) mentioned inadequate water supply as the primary constraint to yield, followed by N when water is sufficient. But also restricted uptake of nutrients other than N may be a limitation for rice in aerobic soils [17]. In flooded soils, the majority of plant nutrients are usually more available, with exceptions for S, Zn, Cu, and P, availability of Fe and Mn is often particularly high in anaerobic soils because of low redox potential [18]. In aerobic soils, however, Fe and Mn may become limiting, especially when the soil pH is high. Moreover, nutrient uptake and supply to plants may be reduced because of lower delivery rates to roots through mass flow and diffusion as both of these processes are influenced by the reduced soil water content.

Effect of aerobic rice on Nematode occurrences in aerobic rice

Soil-borne pests and diseases find different living conditions in aerobic soils and especially root knot nematodes (RKN) have been reported to become problematic when the production system becomes partially or fully aerobic [19]. In experiments under upland or only temporarily submerged conditions, yield increased by 12–80% when control measures against RKN were applied [20]. Inundated soils, on the other hand, can reduce the proportion of root damage as the respective nematode stage (J2) cannot invade new roots under these conditions [19,21]. Kreye *et al.* (2009) reported that average gall rating, an one indicator for infestation with root knot nematodes (Meloidogyne sp.) was 5 (>75% of sampled roots galled) over all treatments at flowering and at harvest in 2004 [22].

Kreye *et al.* (2009) reported different reasons of crop yield failure of aerobic rice under tropical conditions in the Philippines, their primary aim being to establish interaction effects of water and nitrogen on crop growth and development [22]. They found that the experiment suffered from extreme yield failure and it was suggested that other factors besides water and nitrogen also had limited crop growth and development, especially micronutrient deficiencies and/or root knot nematodes. They confirmed these findings in combined experimental-modeling approach including abiotic (water, nitrogen, micronutrients) and biotic causes (root knot nematodes) for the yield failure.

Effect of aerobic rice on Physiological changes under water stress

Drought is undoubtedly one of the most important environmental stresses limiting the productivity of crop plants around the world. Rice is considered a drought sensitive crop species, however, within this species, there are considerable varietal differences in sensitivity to this environmental stress. In aerobic rice crop may face water stress. Drought stress decreases the rate of photosynthesis [23]. Severe drought stress also inhibits the photosynthesis of plants by causing changes in chlorophyll content, by affecting cholorophyll components and by damaging the photosynthetic apparatus [24]. Plants can partly protect themselves against mild drought stress by accumulating osmolytes. Proline is one of the most common compatible osmolytes in drought stressed plants. Proline accumulation can also be observed with other stresses such as high temperature and under starvation. Proline metabolism in plants, however, has mainly been studied in response to osmotic stress. Proline does not interfere with normal biochemical reactions but allows the plants to survive under stress [25]. The accumulation of proline in plant tissues is also a clear marker for environmental stress, particularly in plants under drought stress [26].

The aerobic rice production system has been reported to be less sustainable than irrigated rice systems operated under predominantly flooded soil conditions, especially when aerobic rice is grown in sequence for several years. In a long-term aerobic rice experiment at IRRI, yields of aerobic rice gradually declined over time as compared to a continuously flooded control [16]. In Brazil, yield declined after 2 years of consecutive upland cultivation and rice yields after 5 years of monoculture were only 1.2 t ha^{-1} compared with 4.3 t ha^{-1} after 3 years of soybean [27].

For continuously grown upland rice in the Philippines, yield reductions of 30–60% as well as yield failures [12] and rapid yield loss in repeated cropping of aerobic rice George *et al.,* 2002) were reported. Such a yield decline may be associated with auto toxicity (allelopathy), as assumed for Brazil [27], or the phenomenon of ‘‘soil sickness’’, which comprises the potentially interwoven effects of allelopathy, nutrient depletion, buildup of soil-borne pests and diseases, and soil structural degradation [12].

Effect of aerobic rice on Water saving and water productivity

Water requirement of low land rice varies from 1,650 to 3000mm. Aerobic rice production system eliminates continuous seepage and percolation losses, greatly reduces evaporation as no standing water is present at any time during the cropping season, and effectively uses the rainfall and thus helps in enhancing water productivity, concomitant loss of soil sediments, silt and fertility from the soil. A comparison of water requirement of lowland flooded rice and aerobic rice system clearly shows that aerobic rice system can save about 45 per cent of water [28]. Water saving in the aerobic rice system compared with the conventionally irrigated lowland rice results mainly from (1) no water losses during land preparation, (2) less percolation and seepage due to the elimination of the ‘pressure head’ of the ponded water layer normally maintained in an irrigated field, and (3) less evaporation [11].

Weed problems in aerobic rice

In traditional irrigated lowland rice systems, rice has a two- to three-week ‘head start’ over weeds, which favors rice in competition against weeds that have not emerged yet at transplanting, and the water layer after transplanting effectively suppresses the emergence and growth of most weed flora, including upland and semi-aquatic weeds. Among rice ecosystems, therefore, the greatest weed pressure and competition occurs in upland and aerobic rice, and the least in transplanted irrigated and rainfed lowland rice. Mahajan et al. (2011) 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 [29]. In conventional transplanted system, weeds are suppressed by standing water and by transplanted rice seedlings, which have a “head start” over germinating weed seedlings. On the other hand, aerobic soil dry-tillage and alternate wetting and drying conditions are conducive for germination and growth of weeds causing grain yield loss of 50 to 91% [30]. 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.

Conclusion

Over the centuries, lowland rice has proven to be a remarkably sustainable system for rice production mostly because of its luxurious water availability. But the present day water crisis threatens the sustainability of lowland rice production and necessitates the adoption of water saving irrigation technologies. Technologies like saturated soil culture and alternate wetting and drying are receiving renewed attention by researchers. These technologies reduce water inputs only at the expense of yield. Aerobic rice is a new concept to decrease water requirements in rice production and is highly suitable for irrigated lowland rice with insufficient rainfall and favourable uplands with access to Experiments on aerobic rice have shown that water requirement in aerobic rice were more than 50 per cent lower (only 470-650 mm) and water productivities were 64-88 per cent higher than the lowland rice.

Rapid degradation of rice ecologies due to imbalanced use of fertilizers and unscientific water management has put tremendous pressure on the rice growers to make rice farming economically viable and ecologically sustainable. The concept of aerobic rice holds promise for farmers in water-short irrigated rice environments where water availability at the farm level is too low or where water is too expensive to grow flooded lowland rice.In India, aerobic rice systems are still very much in the research and development phase and varieties developed for another environment are evaluated under aerobic system. However, more varieties need to be evaluated and their nitrogen requirement should be assessed. From the review, it is unambiguous that, aerobic ricecultivation has been identified as a potential new technology, which can reduce water use in rice production and also recognized as an economically attractive crop. But, the major hurdle of mounting weed pressure has to be removed so as to make aerobic rice cultivation more efficient in terms of returns on farmer investments and use of water resources.

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