Review Article

Aerobic Rice: Physiological Aspect and Management Techniques – a Review

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Abstract

Rice is an important target for reduction in water use because of its larger water requirement. Aerobic rice is a water-saving rice production system in which potentially high yielding, fertilizer responsive and adapted rice varieties are grown on fertile aerobic soils that are non-puddled and have no standing water. It is grown in an intermediate situation between uplands and shallow lowlands. Aerobic rice is "improved lowland rice" in terms of yield potential and "improved upland rice" in terms of drought tolerance. Nitrate reductase activity and soluble protein content are found to be maximum while Indole acetic acid oxidase activity is found to be minimum in drought tolerant cultivars. Accumulation of proline and total soluble sugar is found to be more under non-submerged conditions than under submerged conditions, more in young leaves than in old leaves, more in leaf sheath than in leaf blade and more in drought tolerant cultivars of rice than in susceptible ones. Careful management of physiological and biochemical traits of aerobic rice is essential for realizing the benefits of aerobic rice technology. Adoption of water saving technologies like aerobic rice will lead to profound changes in rice ecosystem. Some of these changes will be positive while some will be negative. The challenge will be to develop effective integrated natural resource management interventions, which would allow a profitable rice production with increased soil aeration, while maintaining the productivity, environmental safety and sustainability of rice based ecosystem.

Keywords: Aerobic rice, Nitrate reductase, soluble protein, Indole acetic acid oxidase, Proline

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Introduction

Rice (*Oryza sativa* L.) is life for more than half of humanity. It is the grain that has shaped the cultures, diets and economies of billions of people throughout the world. Food security in the world is being challenged by increasing food demand and threatened by declining water availability. More recently, the increasing area under biofuel crops at the cost of food crops is also threatening. Exploring ways to produce more rice with less water is essential for ensuring food security. Rice deserves a special status among cereals as world's most important wetland crop as it provides 35-80% of total calorie uptake to more than 2.7 billion people [1]. Conventional flooded rice cultivation in Asia provides more than 75% of the world's rice supply [2]. About 25% of the world's rice area is under rainfed lowlands and another 13% is under rainfed uplands [3]. Rice, the most common staple food, is an important target for reductions in water use because of its large water requirement compared with that of other crops [4]. Global area under rice is 161 m ha while global paddy production is 678 m t. In India, area under rice is 43.08 m ha while paddy production is 133.7 m t [5]. Although, several strategies are being pursued to reduce rice water requirements, such as saturated soil culture [6], alternate wetting and drying [7], ground cover systems [8], system of rice intensification [9] and raised beds [10]. It is reported that SRI (System of rice intensification) and AWD (Alternate wetting and drying) systems have high water productivity with some amount of saving (approx. 20%) without any compromise on productivity. However, water requirement of these production systems is also very high as land preparation consists of soaking, followed by wet ploughing or puddling of saturated soil. Further, when standing water is kept in the field (5–10 cm) during crop growth, large amount of water (about 10–15 per cent) is lost through seepage and percolation. Every drop of water received at the farmer's field by way of rainfall, surface irrigation or pumped from aquifers, is valuable and needs to be used effectively. Aerobic rice provides for effective use of rain that falls on the farmer's field, as there is no standing water and the farmer can skip irrigation if soil moisture status is sufficient for crop. This is not possible if water is already standing in the field. Aerobic rice is a water-saving rice production system in which potentially high yielding, fertilizer responsive and adapted rice varieties are grown on fertile aerobic soils that are non-puddled and have no standing water. Supplementary irrigation, however, can be supplied in the same way as to any other upland cereal crop [11]. It is grown in an intermediate situation between upland and irrigated/shallow lowland in the areas where water is not sufficiently available to grow irrigated shallow lowland rice, but sufficiently available to grow upland crops (Maize & Wheat). Aerobic rice varieties combine traits of traditional upland rice (drought tolerance) and modern high yielding rice varieties (lodging tolerance, high yield potential). Aerobic rice is "improved lowland rice" in terms of yield potential and "improved upland rice" in terms of drought tolerance. In temperate areas of northern China about 140,000 ha are already cultivated with aerobic rice using "Han Dao" varieties that are especially adapted to the aerobic soil conditions. The yields that can be obtained here range from 4.5 to 6.5 t ha^{-1} [12].

Table 1 Difference Between Eco-Friendly Aerobic rice and Conventional Irrigated rice

Eco-Friendly Aerobic Rice	**Conventional Irrigated Rice**
No need of puddling and land levelling	It is necessary
Direct seeding	Nursery raising is needed
Reduced seed rate	Higher seed rate (25 kg per ac)
40–50% water saving; no constant maintenance of water	Constant maintenance of water level
No need for trimming bunds and plugging holes	Requires constant attention by way of plugging holes and trimming of bunds
Labour requirement is 55% lesser (Wang *et al.*, 2002)	More
Intercropping of any other arable crop is possible	Not possible
Crop rotation can be practiced (with pulses for balanced nutrition)	Not common
Aerobic condition in soil	Anaerobic condition prevails
Soil structure is maintained	Destroyed. Subsurface hard pan is made by repeated ploughing
Faster organic matter decomposition	Slower
Oxygenated rhizosphere is found	Not found
Nitrogen use efficiency is more	Less
Nitrous oxide is not produced	Produced
Better water use efficiency	Low
Very low mosquito population	Severe mosquito incidence
Efficient utilization of rain water	Less efficient utilization of rain water
No occurrence of methanogenesis	Methanogenesis occurs
Lower yields (20-30% lesser)	Higher yields
Production of toxins like ethanol and lactate absent	Toxins are produced
Energy efficiency is more – efficient glycolysis	Less
Reduced humidity in microclimate; healthy crop	High humidity
Incidence of diseases and pests is significantly low	High
Cost of cultivation is significantly low	High

On-farm evaluation of performance of Aerobic rice

Various experiments carried out at various locations under different conditions on the physiological and management aspects of aerobic rice have revealed following results;

Physiological aspect
Proline content

An experiment carried out at Isfahan [13], Iran to study the effect of submergence, plant part, its age and cultivar on the proline content and total soluble sugar content of aerobic rice revealed that the Proline content was higher in young leaves as compared to old leaves. It might have been due to higher physiological activity of younger leaves. Further more, the Proline content was found to be higher under non-submerged conditions as compared to submerged conditions which might have been due to water stress under non-submerged conditions which lead to accumulation of more and more proline in leaf sheath or leaf blade of rice. Leaf sheath accumulated more proline than blade under both submerged and non-submerged conditions, in both young and old leaves and in all the cultivars. It might have been due to two reasons. First, leaf sheath is the zone of meristematic division. Second, leaf blade draws water from sheath causing more and more water stress in sheath. Among the cultivars, zayande rood accumulated maximum proline while the cultivar 216 accumulated minimum proline both in young and older leaves, in sheath and blade and under both submerged and non-submerged conditions. Lower proline content of 216 might have been due to higher drought susceptibility (**Tables 2** and **3**).

Table 2 Proline content (μmol lit^{-1}) of sheath under submerged and non-submerged conditions [14]

	Young leaves			Old leaves		
Rice cultivars	Submerged	Non-submerged	Change (%)	Submerged	Non-submerged	Change (%)
Zayande-Rood	112	155	0.384	58	73	0.258
829	84	102	0.214	48	52	0.083
216	97	120	0.237	54	61	0.129
Average	97.67	125.67	0.286	53.3	62	0.163

Table 3 Proline content (μmol lit^{-1}) of blade under submerged and non-submerged conditions

	Young leaves			Old leaves		
Rice cultivars	Submerged	Non-submerged	Change (%)	Submerged	Non-submerged	Change (%)
Zayande-Rood	116	129	0.112	58	60	0.034
829	82	85	0.036	45	45	0.00
216	100	104	0.040	51	53	0.039
Average	99.3	106	0.067	51.3	52.7	0.026

Total soluble sugar content

In the same experiment the total soluble sugar content was found to be higher in younger leaves as compared to older leaves, higher under non-submerged conditions as compared to submerged conditions, maximum in cultivar zayande rood and minimum in 216 and higher in leaf sheath as compared to leaf blade. The reasons being the same as in case of proline content [15] (**Tables 4** and **5**).

Table 4 Total soluble sugar content (mg g^{-1}DW) of sheath under submerged and non-submerged conditions

	Young leaves			Old leaves		
Rice cultivars	Submerged	Non-submerged	Change (%)	Submerged	Non-submerged	Change (%)
Zayande-Rood	239	310	0.297	180	205	0.138
829	225	276	0.226	181	203	0.121
216	208	237	0.139	173	193	0.115
Average	224	274	0.223	178	200.3	0.123

Management Techniques
Yield attributes and yield

Field experiments during summer and kharif, at Wetland farm, Tamil Nadu Agricultural University, Coimbatore, to study the performance of different rice cultivation methods on productivity and water usage using hybrid CORH - 3 as test crop. The influence of different rice cultivation methods on the yield attributes and grain yield are presented in

(**Table 6**). SRI registered significantly more number of productive tillers/m^2 (383 and 416) than other rice cultivation methods in both the seasons. Transplanted rice and wet seeded rice were comparable to each other in recording productive tillers/m^2. Significantly lower number of productive tillers/m^2 was observed under aerobic rice cultivation. With regard to panicle length, all the systems of rice cultivation were comparable except aerobic rice. Higher number of filled grains per panicle was observed with system of rice intensification (117.8 and 130.8), followed by transplanted rice and alternate wetting and drying method. Among the different rice production methods, SRI produced significantly higher grain yield (6014 and 6682 kg/ha), followed by transplanted rice (5732 and 6262 kg/ha). Under SRI, 5 and 6.7 % increase in grain yield was noticed compared to transplanted rice. Increased grain yield under SRI is mainly due to the synergistic effects of modification in the cultivation practices such as use of young and single seedlings per hill, limited irrigation, and frequent loosening of the top soil to stimulate aerobic soil conditions. Transplanting of very young seedlings usually 8-12 days old, preserves its potential for tillering and rooting which was reduced if transplanted after the occurrence of fourth phyllochron. Further, combination of plant, soil, water and nutrient management practices followed in SRI increased the root growth, along with increase in productive tillers, grain filling and higher grain weight that ultimately resulted in maximum grain yield. The lowest grain yield of 3582 and 3933 kg/ha was recorded under aerobic rice cultivation. Competition from weeds during early stage of growth and less soil moisture under aerobic rice might have been the reasons for poor yield [15] .

Table 5 Total soluble sugar content (mg g^{-1}DW) of blade under submerged and non-submerged conditions

	Young leaves			Old leaves		
Rice cultivars	Submerged	Non-submerged	Change (%)	Submerged	Non-submerged	Change (%)
Zayande-Rood	248	268	0.080	187	185	-0.010
829	231	243	0.052	183	180	-0.016
216	222	235	0.058	178	178	0.000
Average	233.4	248.6	0.064	182.6	181	-0.009

Source: Mostajeran *et al.*, 2009

Table 6 Yield parameters and grain yield of rice as influenced by different systems of rice cultivation

Year	**Summer, 2008**				**Kharif, 2008**			
Treatment	**Productive Tillers (m^2)**	**Panicle length (cm)**	**Filled grains (No./Panicle)**	**Grain yield (kg ha^{-1})**	**Productive Tillers (m^2)**	**Panicle length (cm)**	**Filled grains (No./Panicle)**	**Grain yield (kg ha^{-1})**
TR	354	23.2	110.8	5732	374	23.3	121.9	6262
SRI	383	23.7	117.8	6014	416	23.3	130.8	6682
AWD	336	22.9	106.5	5376	381	23.3	126.4	5796
WS	361	23.1	102.5	5175	402	23.8	94.8	5500
Aerobic	302	20.9	85.2	3582	347	21.6	86.7	3933
CD (0.05)	**21.1**	**1.1**	**7.3**	**276**	**26.7**	**1.3**	**8.9**	**311**

Water usage and water productivity

Variation in water usage, water saving and water productivity of rice under different cultivation systems are presented in (**Table 7**). In summer and Kharif seasons, wet seeded rice required more number of irrigations (37 and 39), followed by transplanted rice (32 and 33). Under SRI, there was a saving of 3 and 6 irrigations respectively during summer and kharif seasons compared to transplanted rice. Minimum number of irrigations were recorded under alternate wetting and drying method of rice cultivation (24 and 23), followed by aerobic rice (26 and 24) in both the seasons [18]. Conventional rice cultivation used higher amount of water (16120 and 16802 m^3), followed by wet seeded rice and SRI. Aerobic rice used minimum quantity of water (9687 and 9425 m3 respectively) during both the seasons compared to other methods. Maximum water saving was recorded with aerobic rice (39.9 and 43.9 %), followed by alternate wetting and drying method (15.4 and 18.0 % respectively) over transplanted rice in both the experiments. Water saving under SRI was 12.6 and 14.8 % respectively during summer and kharif seasons. Impounding of 2.5 cm of irrigation water, irrigation after formation of hairline cracks showed considerable water saving besides better root environment in SRI. With respect to water productivity, SRI method of rice cultivation registered the higher water productivity (0.43 and 0.47 kg/m^3), followed by AWD and aerobic rice cultivation during both the seasons. The conventional rice cultivation (0.36 and 0.37kg/m^3 in summer and Kharif respectively), and direct sown rice produced lower grain yield per unit quantity of water used. The cultivation of rice through system of rice intensification increased the grain yield by 5 to 7 % besides saving of water by 12 to 15 % over conventional method of rice cultivation under wetland ecosystem.

Table 7 Water usage and water productivity (WP) of rice as influenced by different systems of rice cultivation [16]

Treatment	No. of irrigations	Total water used m^3 ha^{-1}	% water saving over transplanted	Water productivity kg/ m^3	No. of irrigations	Total water used m^3 ha^{-1}	% water saving over transplanted	Water productivity kg/ m^3
TR	32	16120	-	0.36	33	16802	-	0.37
SRI	29	14085	12.6	0.43	27	14322	14.8	0.47
AWD	24	13636	15.2	0.39	23	13773	18.0	0.42
WS	37	15763	2.2	0.33	39	15683	6.7	0.35
Aerobic	26	9687	39.9	0.37	24	9425	43.9	0.42

Conclusion

A water saving technology such as aerobic rice can drastically cut down the unproductive water outflows and increase water use efficiency. Through the adoption of water saving technologies, rice land will shift away from being continuously anaerobic to being partly or completely aerobic. These shifts will produce profound changes in water conservation, rice yield, nutrient dynamics, greenhouse gas emissions and weed flora. Some of these changes will be positive like water conservation and decreased methane gas emission while some will be negative like low rice yield and low organic matter content in the soil. The challenge will be to develop effective integrated natural resource management interventions, which would allow a profitable rice production with increased soil aeration, while maintaining the productivity, environmental safety and sustainability of rice based ecosystem.

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