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STRIDING TOWARDS AEROBIC RICE (DIRECT SEEDED) CULTIVATION (A New Way of Growing Rice)

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ABSTRACT

Increasing water scarcity necessitates the development of irrigated rice systems that require less water than traditional flooded rice. In irrigated aerobic rice systems, rice grows in nonflooded and nonsaturated soil under supplemental irrigation. The development of such systems should start with the identification of promising varieties and the quantification of yield potential, water use, field water outflows, and water productivity. In this paper, report has been given on, water input and rice, global fresh water scenario, water consumption in Indian agriculture and on farm performance evaluation of aerobic rice technologies with advantages over conventional flooded rice cultivation. Although aerobic rice cultivation system enjoys some potential advantages like lesser CH_4 emission, reduced Arsenic (As) exposure and more importantly low ammonia volatilization, early crop maturity and high water productivity, over conventional methods of rice cultivation, but, Yield decline penalty is to be considered before promoting this technology as such, new aerobic rice varieties with minimum yield gap compared with flooded rice and crop management strategies that can reverse the yield decline of continuous aerobic rice have to be developed before aerobic rice technology can be adopted in large areas.

Key words: Aerobic rice, water scenario, water use, yield and climate change

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important stable food crops in the world. In Asia, more than two billion people are getting 60-70 per cent of their energy requirement from rice and its derived products. In India, rice occupies an area of 44 million hectare with an average production of 90 million tonnes with productivity of 2.0 tonnes per hectare. Demand for rice is growing every year and it is estimated that in 2010 and 2025 AD the requirement would be 100 and 140 million tonnes respectively. To sustain present food self-sufficiency and to meet future food requirements, India has to increase its rice productivity by 3 per cent per annum.

As we know, rice is a profligate user of water, consuming half of all developed fresh water resources. The increasing scarcity of water threatens the sustainability of the irrigated rice production system and hence the food security and livelihood of rice producers and consumers. In Asia, where ninety percent of the world's rice is produced and consumed, where it accounts for 20%–70% of total caloric intake, 17 million ha of irrigated rice areas may experience "physical water scarcity" and 22 million ha may have "economic water scarcity" by 2025 (Tuong and Bouman, 2001). Therefore, a more efficient use of water is needed in rice production. Although, several strategies are being pursued to reduce rice water requirements, such as saturated soil culture (Borell *et al.*, 1997), alternate wetting and drying (Li 2001; Tabbal *et al.*, 2002), ground cover systems (Lin *et al.*, 2002), system of rice intensification (Stoop *et al.*, 2002) and raised beds (Singh *et al.*, 2002). It is reported that SRI and AWD systems have high water productivity with some amount of saving (approx. 20 per cent) 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. Irrigated rice has very low water-use efficiency as it consumes 3000–5000 liters of water to produce 1 kg of rice. The traditional rice production system not only leads to wastage but also causes environmental degradation and reduces fertilizer use efficiency. Along with high water requirement, the traditional system of transplanted rice production in puddled soil on long run leads to destruction of soil aggregates and reduction in macro pore volumes, and to a large increase in micro pore space which subsequently reduce the yields of post rice crops, e.g. wheat. Added to this, irrigated rice fields will cut off the oxygen supply from the atmosphere resulting in the anaerobic fermentation of soil organic matter. Methane, a major end product of anaerobic fermentation is released from the submerged soil to the atmosphere through roots and stems of rice plants accounting 20-29 % (Chen and Prinn, 2005). Its concentration in the atmosphere has more than doubled during the last 200 years. Continued increase in atmospheric methane concentrations at the current rate of approximately 1 per cent per year is likely to contribute more to future climatic change than any other gas except carbon dioxide. Aerobic rice cultivation will curb methane production and saves water without affecting the productivity. It is the time to save water from the irrigated system of rice cultivation by adopting the aerobic rice cultivation. Varieties or hybrids with enhanced productivity for aerobic cultivation must be bred to address the water scarcity and pollution.

ECONOMIC IMPACT OF DROUGHT STRESS ON RICE PRODUCTION

The global reduction in rice production due to drought averages 18 M t annually

(O'Toole, 2004). This abiotic stress is therefore a major constraint to rice production in water-limited environments. In Asia alone, it is estimated that a total of 23 M ha of rice fields (10 M ha in upland and 13 M ha in lowland) (Pandey *et al.*, 2000) are drought-prone. Drought is a particularly important production constraint in Eastern India, with more than 10 M ha of drought-prone fields, where yield losses due to droughts are reported to cost an average of 250 million US$ per year (Pandey *et al.*, 2000). Drought affects the poorest farmers disproportionately, causing them to reduce their food consumption, withdraw their children from school, migrate for employment or sell assets to meet immediate needs (Pandey *et al.*, 2000). Farmers growing rice in drought-prone environments are well aware of the risks involved and are consequently very reluctant to use expensive agricultural inputs such as fertilizers; this further reduces yield potential in these regions. With diminishing water supplies for agriculture worldwide, the need to improve drought adaptation of rice is becoming increasingly important. Certainly looming water crisis demands to have a look at the flow of water in rice fields and understand where reductions in water use can be achieved without impairing yield.

WATER INPUT AND RICE

Irrigated lowland rice in Asia is transplanted or direct (wet) seeded into puddled lowland fields. Land preparation consists of soaking, plowing, and puddling. Puddling is done not only to control weed, but also to increase water retention, reduce soil permeability, and ease field leveling and transplanting (De-Datta, 1981). Soaking, a one-time operation requires water to bring the topsoil to saturation and to create a ponded water layer. After land preparation, there is an "idle period" until transplanting or direct seeding takes place. The growth period runs from crop establishment to harvest. During the idle period and crop growth, fields are typically flooded with 5–10 cm of water. Under flooded conditions, water is required to match several outflow processes. Because of the standing water, hydrostatic pressure continuously "pushes" water downward through the puddled layer. When this water flows vertically downward below the root zone, it is called percolation (P), and, when it flows laterally underneath bunds, it is called seepage (S). Because they are difficult to separate in the field, S and P are often taken together as one term: SP Water is released into the air by evaporation (E) from the ponded water layer and transpiration (T) by the crop. Again, E and T are difficult to separate in the field and they are mostly considered together as evapotranspiration (ET). However, during land preparation and the idle period, only E takes place, whereas, during crop growth, both E and T occur. Typical ET rates of rice in Asia ranges from 4 to 7 mm day^{-1} (Tuong, 1999). Finally, over-bund flow (or surface runoff) is the spillover when water depths rise above the field bunds.

Table 1, compares the seasonal water requirement between lowland flooded rice and aerobic rice (Lampyan and Bouman, 2005). For a crop growth duration of 100 days (typical of modern high-yielding varieties), total water requirements vary from 675 to 5300 mm, depending on the season and soil characteristics, with 1,500–2,000 mm as a typical value in many lowland areas. Of all outflows of water from a rice field, only T is "productive" water use as it leads directly to crop growth and yield formation. Transpiration is essential to crop growth because it provides cooling and is the driving process for water flow in plants that carries nutrients from the roots to the shoot. Most of the water use in rice, however, is caused by large losses of seepage and percolation. These flows are unproductive as they do not contribute to crop growth and yield formation.

Table 1. Comparison of seasonal water requirement between lowland Flooded rice and aerobic rice

	Seasonal water requirement (mm)	
	Low land flooded rice	Aerobic rice
Land preparation	150-300	100
Evaporation	200	100
Transpiration	400	400
Seepage and percolation	500-1.500	335
Application loss (at 60% efficiency)		335
Total seasonal water requirement	1650-3000	935

Source: (Lampayan and Bouman, 2005)

WHY TRANSPLANTING RICE TO AEROBIC RICE

Global Fresh Water Scenario

Global Freshwater reserves are rapidly depleting and this is expected to significantly impact many densely populated areas of the world. Low to middle income developing regions as well as highly developed countries will face water stress in the future, unless existing water reserves are managed effectively. Although low and middle income developing countries currently have low per capita water consumption, rapid growth in population and inefficient use of water across sectors is expected to lead to a water shortage in the future.

Developed countries traditionally have high per capita water consumption and need to focus on reducing their consumption through improved water management techniques and practices. By 2025, India, China and select countries in Europe and Africa will face water scarcity if adequate and sustainable water management initiatives are not implemented. Table 2 clearly shows total global water reserves is ~1400 MM Tr liters, of which Freshwater consists of only about 35 MM Tr liters Groundwater and surface water, which together constitute 30.5% of the freshwater reserves (~0.76% of the total water on the planet), are the most easily accessible and used sources of water. Every year, 0.11 MM Tr liters of precipitation falls on land 92% of this is lost due to surface runoff, evaporation, etc. (Anonymous, 2006). They further stated that, by 2025, an estimated 3 billion people will be living below the water stress threshold (Annual per capita water availability of 1.7 MM liters). Between1995-2025, global population and per capita water consumption are projected to grow at a compound annual growth rate (CAGR) of 1.16% and 0.67% respectively. Densely populated and developing regions of the world, such as Asia and Africa are expected to face the maximum water stress.

Table 2. Showing the global breakdown of fresh water reserves and global population distribution vs. fresh water reserves

Break down of global fresh water reserves (%)			Global population distribution vs. fresh water reserves		
			Continent	Global population (%)	Global available fresh water resources (%)
A)	Salt water	= 97.5	North and Central America	8.0	15.0
B)	Fresh water	= 2.5	South America	6.0	26.0
B_1)	Glacier	= 68.7	Europe	13.0	8.0
B_2)	Ground Water	= 30.1	Asia	60.0	36.0
B_3)	Permafrost	= 0.8	Africa	13.0	11.0
B_4)	Surface and Atmospheric water	= 0.4	Australia and Oceania*	1.0	5.0

Source: Anonymous (2006)

Water Consumption in Indian Agriculture

India is one of the world's leading crop producers. Over the years, this has led to an increase in water consumption in the agricultural sector. The volume of water used for irrigation in India is expected to increase by 68.5 Tr liters between 2000 and 2025. Rice, wheat and sugarcane together constitute 90% of India's crop production and are the most water-consuming crops. India has the highest water footprints (Table 3) among the top rice and wheat producing countries (China, US, Indonesia, etc.). States with the highest production of rice/ wheat are expected to face groundwater depletion of up to 75%, by 2050 due to over exploitation of ground water. Increase in wastewater discharge by agriculturally based industries such as textiles; sugar and fertilizer are among the top producers of wastewater (Anonymous, 2006).

Table 3. Water Footprint ('000 liters/mt). Average values for the period of 1997-2006

Crop	India	Global
Wheat	1,654	1,334
Paddy Rice	2,850	2,291
Sugarcane	159	175

Groundwater depletion has started affecting most of the river basins (Ganges, Krishna, Kaveri and Godavari) which support agriculture in states of Utter Pradesh, Maharashtra, Karnataka, Tamil Nadu and Andhra Pradesh of India by 2050. The above mentioned five states of India are the highest producers of rice, wheat and sugarcane (water-intensive crops) and together produce 70% of the total food crops in India. Subsidies on electricity in these states have led to excessive pumping of groundwater for agriculture. Groundwater level in the Ganges basin (which provides water to UP) is projected to deplete by 50-75%. Groundwater levels in the Krishna, Kaveri and Godavari basins (which provide water to Maharashtra, Tamil Nadu, Karnataka and Andhra Pradesh) are projected to deplete by 50%.

Industrial water consumption is expected quadruple between 2000 and 2050; by 2050 industrial water consumption will reach 18% of total annual water consumption, up from just 6% in 2000. Industrial wastewater discharge causes pollution and reduces available freshwater reserves and 6.2 Bn liters of untreated industrial wastewater is generated every day. Thermal power plants and steel plants are the highest contributors to annual industrial waste water discharge.

Increasing water scarcity necessitates the development of irrigated rice systems that require less water than traditional flooded rice. In irrigated aerobic rice systems, rice grows in non-flooded and non-saturated soil under supplemental irrigation. The development of such systems should start with the identification of promising varieties and the quantification of yield potential, water use, field water outflows, and water productivity. Because of increasing competition for water, water-saving technologies such as alternate wetting and drying and aerobic rice are being developed to reduce water use while maintaining high yield. The components of the water balance of these systems need to be disentangled to extrapolate water savings at the field scale to the irrigation system scale. Simulation modeling is to be used to quantify yield, water productivity, and water balance components of alternate wetting and drying and aerobic rice.

AEROBIC RICE SYSTEM

Aerobic rice is a new way of growing rice that needs less water than lowland rice. It is grown like an upland crop such as wheat, in soil that is not puddled, flooded, or saturated. The soil is therefore "aerobic" or with oxygen throughout the growing season, as compared to traditional flooded fields, which are "anaerobic." The difference, however, between aerobic rice and upland rice is that aerobic rice produces higher yields, 4–6 tonns per hectare and perhaps beyond. This is possible because the crop is grown in aerobic soil but cared for with external inputs such as supplementary irrigation (if rainfall is insufficient) and fertilizers. This new way of growing rice started as early as the mid-1980s in China. To differentiate it from traditional upland rice, the International Rice Research Institute (IRRI) coined the term "aerobic rice." Aerobic rice has been considered a mature technology in temperate countries such as northern China and Brazil, where aerobic rice area is estimated at 80,000 and 250,000 hectares, respectively. In both countries, breeding programs since the 1980s have resulted in the release of several high-yielding aerobic rice varieties by crossing high-yielding lowland rice varieties with traditional upland types. In northern China, new high-yielding aerobic varieties such as Han Dao 277, Han Dao 297, and Han Dao 502 were released in the late 1990s with yield potential of up to 6.5 tons per hectare. After a 20-year breeding program in Brazil, aerobic rice varieties have yielded 5–7 tons per hectare under sprinkler irrigation in farmers' fields.

In the tropics, aerobic rice systems are still very much in the research and development phase. IRRI started to develop varieties for the Asian tropics in 2001. The first generation of tropical aerobic rice varieties consists of IR55423-01 (Apo) and UPLRI-5 from the Philippines, B6144-MR-6-0-0 from Indonesia, and CT6510-24-1-2 from Colombia. These varieties were mostly derived from crosses between indica and tropical japonica parents. Under southern Indian conditions (Martin *et al.*, 2007) has found an upland land rice variety 'PMK 3' produced the highest grain yield of (3684 kg ha^{-1}) with highest water productivity of (7.06 kg) per ha mm of water, followed by 'ASD 16' produced (3138 kg ha^{-1}) under aerobic conditions. Current research focuses on the development of improved management systems and on breeding further improved varieties.

On-farm Performance Evaluation of Aerobic Rice Technologies

Effect on Growth and Yield

Yield penalty and yield stability of aerobic rice have to be considered before promoting this water-saving technology in the tropics and temperate. In an eight season experiment conducted by Peng *et al.*, (2006) at International Rice Research Institute (IRRI). Grain yield and its components were compared between aerobic and flooded rice continuously for eight seasons from 2001 to 2004 using the best available aerobic rice varieties in the tropics. 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, dry and wet seasons, and varieties. When the first-season aerobic rice was compared with flooded rice, the yield difference was 8–21%. The yield difference between aerobic and flooded rice was attributed more to difference in biomass production than to harvest index. Among the yield components, sink size (spike lets per m^2) contributed more to the yield gap between aerobic and flooded rice than grain filling percentage and 1000-grain weight. Yield decline was observed when aerobic rice was continuously grown and the decline was greater in the dry season than in the wet season. The yield decline of aerobic rice was attributed more to changes in biomass production than in harvest index. Our data suggest that new aerobic rice varieties with minimum yield gap compared with flooded rice and crop management strategies that can reverse the yield decline of continuous aerobic rice have to be developed before aerobic rice technology can be adopted in large areas in the tropics. In an another field experiments conducted by Geethalakshmi *et al.* (2009) during summer and kharif, 2008 at Wetland farm, Tamil Nadu Agricultural University, Coimbatore, India to study the performance of different rice cultivation methods on productivity and water usage using hybrid CORH -3 as test crop. The results (Table 4) revealed that the system of rice intensification (SRI) registered significantly more number of productive tillers/m^2 (383 and 416) than other rice cultivation methods in both the seasons. Transplanted rice (TR) and wet seeded (WS) 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 (AWD). Grain yield of rice was significantly influenced by different methods of rice cultivation. Among the different rice production methods, system of rice cultivation (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 (Stoop *et al.*, 2002).

Table 4. Yield parameters and grain yield of rice as influenced by different systems of rice cultivation under Southern Indian Conditions of Asia

Year	Summer, 2008				Kharif, 2008			
Treatment	Productive tillers (m^2)	Panicle length (cm)	Filled grains (No./ Panicle)	Grain yield kg/ha	Productive tillers (m^2)	Panicle length (cm)	Filled grains(No/ Panicle)	Grain yield (kg/ha)
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

Source: Geethalakshmi *et al.* (2009)

In a long term experiment, Nie *et al.* (2009) at International Rice Research Institute (IRRI) has realized severe yield decline when aerobic rice has been grown continuously. Therefore, monocropping system of aerobic rice should be avoided and crop rotation should be encouraged. Their experiments suggest that crop rotation and fallow could be used to reverse the yield decline of continuous aerobic rice.

Effect on Water Usage and Water Productivity

Total seasonal water input to rice fields (rainfall plus irrigation, but excluding capillary rise, which is rarely quantified) is up to 2–3 times more than that for other cereals (Tuong *et al.*, 2005). It varies from as little as 400 mm per field in heavy clay soils with shallow groundwater tables that supply water for crop transpiration by capillary rise, to more than 2,000 mm in coarse-textured (sandy or loamy) soils with deep groundwater tables (Bouman and Tuong, 2001). About 1,300 millimeters (mm) seems to be a typical average value for irrigated rice in Asia. Nonproductive outflows of water by runoff, seepage, and percolation are about 25%–50% of all water input in heavy soils with shallow water tables of 20–50 cm depth and 50%–85% in coarse-textured soils with deep water tables of 1.5 meter depth or more.

Geethalakshmi *et al.* (2009) under Indian conditions has observed variation in water usage, water saving and water productivity of rice under different cultivation systems, presented in (Table 5). 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 is 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. 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 m^3 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.

Table 5. Water usage and water productivity of rice as influenced by different systems of rice cultivation under Southern Indian conditions of Asia

Treatments	Summer, 2008				Kharif, 2008			
	No. of irrigations	Total water used (m^3/ha)	% water saving over transplanted	Water productivity (kg/m^3)	No. of irrigations	Total water used (m^3/ha)	% water saving over transplanted	Water productivity (kg/m^3)
Transplanted rice	32	16120	-	0.36	33	16802	-	0.37
SRI	29	14085	12.6	0.43	27	14322	14.8	0.47
AWD	24	13636	15.4	0.39	23	13773	18.0	0.42
Wet seeded	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

Source: Geethalakshmi *et al.* (2009)

Economics Returns

Sah *et al.* (2007) conducted on-farm performance evaluations of aerobic rice technologies during kharif seasons, 2003/04, 2004/05, and 2005/06. Direct Seeded Rice by Power-Tiller Drill (T_1) was the most profitable among the treatments. In all the years, the Net Returns by (T_1) were higher compared to Farmer's Practice (T_3) and Direct Seeded Rice by Zero-tiller Drill (T_2). As the establishment costs were lower and productions were higher, the Net Returns were higher with (T_1) compared to (T_2), and (T_3). Over the years, the mean establishment cost of 3162 Rs/ha, 3978 Rs/ha and 6304 Rs/ha were found with treatments T_1, T_2, and T_3, respectively. Similarly, the mean total production costs of 17165 Rs/ha, 20380 Rs/ha and 19594 Rs/ha were observed with T_1, T_2, and T_3, respectively, over the years. Therefore, the mean Net Returns of 30263 Rs/ha, 20282 Rs/ha, and 18863 Rs/ha were observed with T_1, T_2 and T_3, respectively (Table 6).

Thus, Direct Seeded Rice by Power Tiller Drill (T_1) showed 60% and 49% higher Net Return compared to Farmer's Practice (T_3) and Direct Seeded Rice by Zero-till Drill (T_2), respectively. Though, not much, Direct Seeded Rice by ZTD (T_2) showed 7% higher Net Return than Farmer's Practice (T_3) (Table 6).

Table 6. Economic returns of direct seeded rice technologies in farmer's fields

Particulars	Direct seeded rice by PTD				Direct seeded rice by ZTD				Farmer's Practice			
	2003-04	2004-05	2005-06	Mean	2003-04	2004-05	2005-06	Mean	2003-04	2004-05	2005-06	Mean
Gross return from grain and straw yield (Rs./ha)	51323	43662	47301	47429	38975	42348	-	40661	42027	34847	38498	38457
Land preparation cost (Rs./ha)	2646	2250	2250	2382	2646	2250	-	2448	3850	4125	4125	4033
Seeding/Transplanting cost (Rs./ha)	717	769	853	780	1481	1579	-	1530	2271	2271	2271	2271
Total production cost (Rs./ha)	18067	18478	14950	17165	21651	19108	-	20380	20071	21080	17632	19594
Net returns (Rs./ha)	33255	25184	32351	30263	17323	23240	-	20282	21956	13767	20867	18863
Change in net returns over Farmer's practice (%)	51	15	55	60	21(-)	59	-	7	-	-	-	-

Source: Sah *et al.* (2007)

ADVANTAGES OF SHIFTING FROM FLOODED RICE TO AEROBIC

Transplanted rice has deleterious effects on the soil environment for the succeeding wheat and other upland crops. Direct seeded rice which removes puddling and drudgery of transplanting the young rice seedlings provides an option to resolve the adaphic conflict and enhance the sustainability of rice-wheat cropping system. Puddling requires lots of scarce water at a time when there is little water in the reservoirs, destroys soil structure and adversely affects soil productivity. DSR overcomes the problem of seasonality in labor requirement for rice nursery rising and transplanting operations. Non-development of ground water in kharif, late onset of monsoon and drudgery of operations often delays rice transplanting which leads to late vacation of fields, forcing farmers to plant wheat after the optimum sowing time. DSR facilitates timely establishment of rice and succeeding winter crops. Unlike puddle fields, DSR fields do not crack and thus help save irrigation water. Surface retained residue serve as physical barrier to emergence of weeds, moderate the soil temperature in summers and winters, conserve soil moisture, add organic matter and nutrients to the soil on decomposition (Govaerts *et al.*, 2005).

Datta and Nantasomsaran (1990) have concluded that ammonia volatilization loss of nitrogen was 28 percent higher in transplanted rice as compared to direct seeded aerobic rice (Fig. 1), while in tropical transplanted rice nitrogen losses from ammonia volatilization can be 50% or higher, while in direct-seeded rice in temperate regions losses are generally negligible. This may be due to the presence of anaerobic conditions in transplanted flooded rice due to which ammonium ions do not readily gets converted to nitrite and nitrate and volatilization losses remains high. Ammonia-nitrogen volatilizations from lowland rice fields are estimated at 3.6 teragrams (Tg) a year (compared with 9 Tg a year emitted from all agricultural fields worldwide), which is some 5%–8% of the estimated 45–75 Tg of globally emitted ammonia-nitrogen each year (Kirk, 2004).

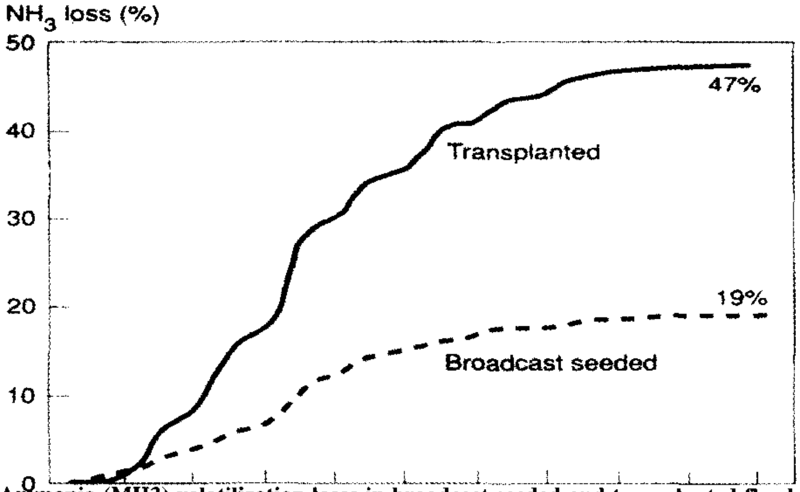

Fig. 1. **Ammonia (MH3) volatilization loses in broadcast seeded and transplanted flooded rice**

Source: Datta and Nantasomsaran (1990

Irrigated rice ecosystems are also an important source in the global budget of the green house gas methane (CH_4). Methane emission pattern can be quite different at different sites, seasons, management schemes and so forth (Wassmann *et al.*, 2000). The most important variables that control CH_4 emission include soil type, rice variety, temperature, soil redox potential, water management and fertilization with organic carbon and nitrogen (Aulakh *et al.*, 2001; Kimura *et al.*, 2004; Yan *et al.*, 2005). When rice fields are flooded, production of CH_4 starts after a lag phase, then proceeds with maximum rate (methanogenic phase) and eventually slows down (steady state phase). These events are observed in all rice field soils, but duration and magnitude differ among the various soils (Yao *et al.*, 1999).

The current atmospheric CH_4 concentration of 1.7 ppm by volume, up from 0.7 ppm in the pre industrial times, is much lower than the 360 ppm of carbon dioxide, up from 275 ppm. The global annual emission of methane is estimated to be 500 Tg (1 Tg=1 million tonnes), (Wahlen *et al.*, 1989) with an apparent net flux of 40 Tg/yr (Cicerone and Oremland, 1988). The current burden of methane in the atmosphere is approximately 4700 Tg. But one molecule of methane traps approximately 30 times as much heat as does a molecule of carbon dioxide. The heating effect of the atmospheric methane increase is approximately half that of the carbon dioxide increase.

Crop growth simulation models provide a good means to quantify the effects of climate, soil and management on crop growth and biogeochemical processes in soil. The Denitrification and Decomposition (DNDC) model was evaluated for its ability to simulate methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions from Indian rice fields with various management practices (Pathak *et al.*, 2005). The model was calibrated and validated for field experiments in New Delhi, India. Green House Gas (GHG) emissions were in good agreement with the values predicted by the model. The model was then applied for estimation of GHG emissions from rice fields in India using a newly compiled soil/climate/land use database. Continuous flooding of rice fields (42.25 million ha) resulted in annual net emissions of 1.07–1.10, 0.038–0.048 and 21.16–60.96 Tg of CH_4-C, N_2O-N and CO_2-C, respectively, with a cumulated global warming potential (GWP) of 130.93–272.83 Tg CO_2 equivalent. Intermittent flooding of rice fields reduced annual net emissions to 0.12–0.13 Tg CH_4-C and 16.66–48.80 Tg CO_2-C while N_2O emission increased to 0.056–0.060 Tg N_2O-N. The GWP, however, reduced to 91.73–211.80 Tg CO_2 equivalent (Table 7). The study suggests that the model can be applied for studying the GHG related issues in rice cropping systems of Asia.

Table 7. Annual green house gas (GHG) emissions from Indian rice fields under continuous flooding and mid-season drainage practices

Parameter	Continuous flooding		Mid-season drainage	
	[a] Minimum	[b] Maximum	Minimum	Maximum
CH_4 emission (Tg C Yr^{-1})	1.07	1.10	0.12	0.13
N_2O emission (Tg N Yr^{-1})	0.048	0.038	0.060	0.056
CO_2 emission (Tg Yr^{-1})	21.16	60.96	16.66	48.80
GWP (Tg CO_2 equiv.Yr^{-1})	130.93	272.83	91.73	211.80

[a] Scenarios for minimum emission: Minimum of SOC, pH and bulk density and maximum of clay content of soil.
[b] Scenarios for maximum emission: Maximum of SOC, pH and bulk density and minimum of clay content of soil.
Source: Pathak *et al.* (2005) (Unit of Simulation and Informatics, Indian Agricultural Research Institute, New Delhi, India)

Water management is probably the most efficient mitigation option. Mid-season drainage or frequent intermittent drainage or managing rice cultivation aerobically generally results in a drastic reduction of CH_4 production and emission (Yue *et al.*, 2005).

Another constraint with irrigated rice ecosystem can be had from As (Arsenic exposure) by consumption of rice, particularly for the population on a subsistence rice diet in South Asia. More than 40 million people worldwide are at risk from drinking As-contaminated water Nordstrom (2002). A large portion (>36 million) live in Bangladesh and West Bengal, India, where water from shallow tube-wells containing elevated levels of As has been used for drinking over the last two to three decades. Long-term exposure to As has caused serious health problems among the population in the affected areas (Chakraborti *et al.*, 2002). Furthermore, As-contaminated tube-well water is also widely used for irrigating crops during dry (boro) season rice production in Bangladesh and West Bengal (Duxbury and Panaullah, 2007). It has been estimated that irrigation water from shallow aquifers adds more than 1000 t of As per year to the arable soils of Bangladesh (Ali *et al.*, 2003). This has resulted in an accumulation of As in soils and elevated uptake of As by crops (Mehraj and Rahman, 2003), thus further increasing exposure of the local population to As. Recent studies have shown that human As intake from consumption of rice can be substantial, and in some cases exceeds that from drinking water (Williams *et al.*, 2005). Arsenic is present in rice grain both as inorganic As (mainly arsenite) and dimethylarsinic acid (DMA), with inorganic As representing between 20% and 90% of the total As (Williams *et al.*, 2006).

Xu *et al.* (2008) investigated the dynamics of As speciation in the soil solution under both flooded and aerobic conditions and compared As accumulation in rice shoot and grain in a greenhouse experiment. Flooding of soil led to a rapid mobilization of As, mainly as arsenite, in the soil solution. Arsenic concentrations in the soil solution were 7-16 and 4-13 times higher under the flooded than under the aerobic conditions in the control without As addition and in the +As treatments (10 mg As kg-1 as arsenite or arsenate), respectively. Arsenate was the main As species in the aerobic soil. Arsenic accumulation in rice shoots and grain was markedly increased under flooded conditions; grain As concentrations were 10-15-fold higher in flooded than in aerobically grown rice (Fig. 2).

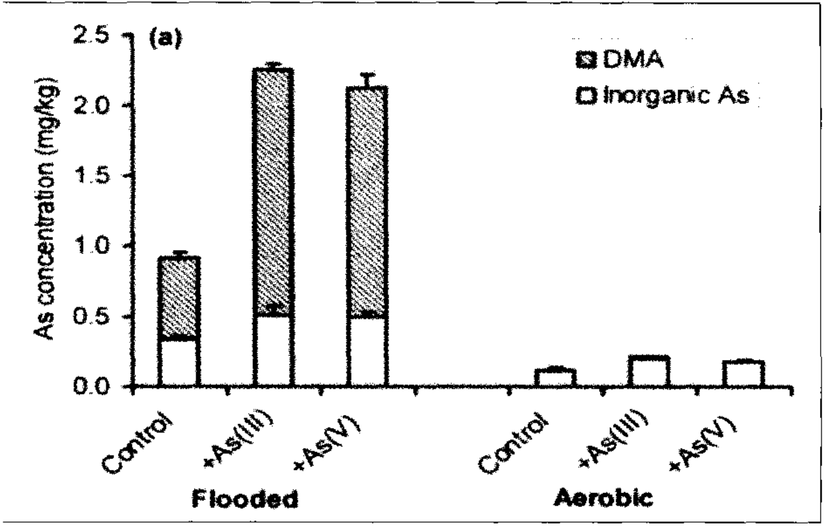

Fig. 2. Arsenic speciation in rice grain as influenced by water management regimes and as treatments. Data are means +SE (n=4)

Source: Xu *et al.* (2008)

Aerobic rice cultivation system certainly aims to reduce the emission of green house gases (CH_4), reduces the ammonia volatilization and more importantly exposure from harmful arsenic substances.

CONCLUSIONS AND FUTURE STRATEGIES

Food and water are two of the most important necessities for survival, but, with an increasing demand for food and a looming water crisis, a shortage of both may be on the horizon unless innovative technologies are developed. Water, especially, is fast becoming a precious commodity, as more and more people continue using water for the household, industry, and agriculture. One technology that enables rice to be grown in dry land without flooding, and help farmers cope with water scarcity is the aerobic rice system. Aerobic rice systems are still very much in the research and development phase as such potential high yielding varietal development is much needed. Current research focuses on determining the causes of yield decline under continuous cropping, and on developing resistant varieties, suitable management options such as crop rotation, and integrated weed management practices. Participatory testing of aerobic rice by farmers should be done more and often to identify promising varieties. Aerobic rice concepts are to be circulated through national extension networks. With predictions suggesting that many Asian countries will have severe water problems by 2025, aerobic rice gives hope to farmers who do not have accessto enough water to grow flooded lowland rice.

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