Water Savings in Rice in Indo-Gangetic Basin and China

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Introduction

Rice is the most important tropical cereal and supplies a quarter of the entire caloric intake of the human race. Declining availability of water resources is threatening the sustainability of the irrigated rice-based production system. Rice is generally cited as the main culprit for declining groundwater tables in the Indo-Gangetic and Yellow river basins. Therefore, it is an obvious target for water conservation: it is grown on more than 30% of irrigated land and accounts for 50% of irrigation water (Barker et al., 1999). Reducing water input in rice production can have a high societal and environmental impact if the water saved is made available to sectors and locations where benefits are high. A reduction of 10% in water used in irrigated rice would free 150,000 million m^3, corresponding to about 25% of the total fresh water used globally for non-agricultural purposes (Klemm, 1999). However, rice is very sensitive to water stress and ill-suited attempts may drastically impact the productivity and lowland rice ecosystem. Our challenge is to develop socially acceptable, economically viable and environmentally sustainable novel rice-based systems that allow rice production to be maintained or increased in the face of declining water availability (Tuong and Bouman, 2003).

Water Resources in Rice-growing Areas

Globally, more than 75% of rice supply comes from 79 M ha of irrigated lowlands. Rice production in the subtropical regions of north and central China and Indo-Gangetic basin mostly depends upon wet-season (kharif) rainfall, with supplementary irrigation. By overlaying the IWMI water-scarcity atlas with the IRRI rice area maps, it is expected that wet-season irrigated rice area in north China (2.5 M ha) and Indo-Gangetic basin (10.5 M ha) will experience 'physical water scarcity' by 2025 or earlier. In fact, water is always scarce in the dry season (boro rice), when the cropping is impossible without assured water supply. There is growing evidence that water scarcity already prevails in large rice growing areas and groundwater over-exploitation has caused serious problems in Indo-Gangetic basin and in China (Shah et.al., 2000; Shu Geng et. al., 2001). Groundwater tables have declined by 1-3 m/ annum in North China plains and by 0.5-1.0-m/ annum in the Indian and Pakistani states of Indus basin. The situation is comparatively safe in Nepal *terai* and Bangladesh plains due to slow pace of groundwater development and good rainfall for recharge. This has also lead to increased cost of pumping; and salinity, fluoride and arsenic contamination.

Excessive surface water use in the upstream of Indus, Ganges and Yellow river has caused severe water shortages and conflicts in the downstream reaches. Yellow river, which irrigates China's best farmlands, has been running dry in the lower reaches (final 600 km of total 4600km) every year since 1972 (Postel, 1997). Similarly, the Indus has little to no outflow to sea during dry season and thus causing environmental problems. The irrigated rice area in China was reduced by 4 M ha between 1970s and 1990s to free the irrigation water for other competitive sectors.

Major Rice Cultural Systems

Broadly rice culture may be defined as rainfed or irrigated. Rainfed rice is further classified as rainfed upland with standing water, rainfed lowland with 5 to 50 cm standing water and deep-water rice with more than 50 cm standing water. Irrigated rice is generally grown on medium and lowlands. Most upland rice is grown on poor soils with uncertain rainfall (1000-2000 mm) distribution using traditional methods with low or no inputs, which contribute to low average, grain yields. In the rainfed lowlands (eastern India, Bangladesh) and deep-water rice, the crop is established by transplanting or by direct seeding in to dry or moist soil before the onset of the monsoon. Transplanting is increasingly practiced in areas where water regime is somewhat similar that under irrigated conditions. While the crop is grown unirrigated, the soil gets flooded/ submerged for at least a portion of the crop cycle to a water depth of 50 cm or even more.

Relatively high degree of water control through surface and groundwater irrigation in the non-traditional areas and seasons has enabled the use of modern varieties, fertilizers and pesticides to a level that has helped achieve considerable expansion in rice production. Rice-wheat cropping system has emerged the dominant cropping system in Indo-Gangetic basin. There has been a spectacular increase in the yield of rice crop grown in non-traditional areas (Punjab, Haryana, western Uttar Pradesh in Indus basin) and non-traditional seasons (*boro* rice in eastern Gangetic plains) due to assured and regulated water supplies supplemented with assured market prices and subsidies by the governments.

Rice Water Requirements and Productivity

In the Indo-Gangetic and Yellow river basin areas rice is mostly transplanted or direct seeded into puddle fields. Puddling is mainly done for weed control but it also increases water retention, reduces soil permeability and eases field leveling and transplanting. The field water requirement of rice is composed of three parts: (a) transpiration by rice plants, (b) evaporation from the rice field, and (c) percolation. As transpiration and evaporation occur simultaneously and are inseparable, so in practice these two parts are measured together i.e. evapo-transpiration. Additionally, water is required for land preparation and raising of rice nurseries. The water input in paddy fields depends upon the rates of losses (seepage, percolation, evaporation) and on crop growth duration. Typical ET rates of rice in the Asian region range from 4 –7 mm/day. For a normal high yielding medium duration (100 days) paddy crop, the total water input may vary from 1000-2000 mm depending on soil, climate and other hydrological and management conditions (Table 1). Of this, only 400-500 mm water is lost towards productive evapo-transpiration and the remaining losses are unproductive. Therefore, at the field level water productivity (yield per unit of irrigation water applied) of paddy crop (0.2-0.4 kg/m3) is less than half of the water productivity of wheat (0.8-1.0 kg/m3). However, these differences become less drastic when water productivity is calculated on the basis of evapo-transpiration (grain yield per unit of water evapo-transpired).

Table 1. Irrigation requirement of rice and components of water loss (mm) under continuous submergence in texturally variant soils (from Tripathi, 1990)

Particulars	Clay loam	Silty clay loam	Loam	Sandy loam
Irrigation requirement	1125	1200	1500	1775
Runoff	207	191	193	161
Percolation	893	870	1187	1515
Evapo-transpiration	690	732	808	745
Average annual rainfall	648			

Indus basin has large areas underlain with alkalinity/ sodicity bearing waters and salinity affected soils. Rice is considered a preferred crop for reclamation of such soils and comparatively safe use of poor quality waters. In a study conducted over a period of 6 years, it was found that irrigation with sodic water given after two turns of irrigation with fresh water to rice helped in obtaining yields comparable to those with fresh water. Crop yields even in the case of alternate irrigation with sodic and fresh water were only marginally less than when fresh water alone was used (Table 2).

Table 2. Average grain yield of rice as affected by the use of fresh water and alkaline water over a period of 6 years at Ludhiana, Punjab.

Treatment	Yield, t/ha	Irrigation water productivity, kg/ha/cm
Fresh water	6.7	62
Alkaline water	4.2	39
2 Fresh water- Alkaline water	6.7	62
Alternate fresh and alkaline water	6.3	58

Practices for Water Savings in Rice

Historically, cultivated rice is supposed to have developed in areas where water was abundantly available and thus adoption of submerged rice culture was the natural choice. The practice of land preparation by puddling seems to have evolved to aid soil submergence and was associated with transplanting of rice seedlings. In growing rice under continuous soil submergence, the irrigation water requirements varies a great deal among the different regions It is lowest in the eastern region and highest in the northern region states mainly due to variation in seasonal rainfall and soil types (Table 3). Results of several field studies show percolation loss as percentage of total loss to about 75% (Chaudhary, 1997). However, studies have shown that comparable yields can be achieved through alternative practices of intermittent or rotational submergence.

Table 3. Irrigation requirement of rice under continuous submergence in eastern Gangetic and western Indus region

Region	Seasonal rainfall, mm	Irrigation requirement
Eastern Gangetic	600	1070
Western Indus	200	2030

(i) Intermittent Submergence

Intermittent submergence has been found to be as effective as continuous submergence and has the potential for optimum yield and enhancing water use efficiency. For most locations, a 3-day period appeared to be permissible duration for drainage after which irrigation should be applied to rice (Table 4). Such a schedule (possible with an assured irrigation source) entailed substantial savings in irrigation water, while yield were comparable. In the soils afflicted with high water table conditions even a longer drainage period of 5 days was possible, while in low retentive soils drainage period exceeding one day was not found desirable in view of significant yield reduction. But even with 1-day drainage considerable saving in irrigation water could be obtained.

Table 4. Effect of irrigation regime on rice yield and requirement of irrigation water in IG basin

Location	Yield (t/ha) in relation to				Savings in irrigation water, %
	Continuous submergence	Irrigation after drainage period			
		1-day	3-day	5-day	
Pusa, Bihar	3.6 (810)	3.47 (600)	3.25 (460)	2.85 (350)	43
Kharagpur, W. Bengal	6.11 (1970)	5.98 (1500)	5.89(1290)	4.99(1080)	34
Pantnagar, UP	8.09(1210)	7.57(1120)	7.38(900)	6.92(600)	44
Ludhiana, Punjab	5.52(1900)	5.44(1450)	5.12(1130)	5.20)960)	40

China has also conducted extensive research work on water saving irrigation for rice and presently studies are underway at more than 150 experimental stations. Experimental results and practices have proved that irrigation of paddy fields with shallow water; periodically keeping soil in wet state and occasional sun drying the field throughout the growing period is a successful method (Zhifang, 2001). This new method of irrigation not only saves a large amount of water but also leads to high yields of rice as compared to the traditional method of deep submergence (Table 5). “Shallow, Wet and Drying” water saving irrigation method was developed and widely popularized in Guangxi Autonomous Region.

Table 5. Irrigation requirements with new method of rice cultivation in China

Method of irrigation	Irrigation requirements, m^3/ha	Rice yield, t/ha
New method	8,918.4	10.56
Deep submergence	12,612.8	7.82

The key technique is keeping wet soil condition for pre-tillering stage, field drying for post tillering stage, again shallow water layer for jointing/ flowering/ grain filling stage, and finally being kept wet for yellow maturity stage. Irrigation by above mentioned water saving method is based on water requirements of growing stages of rice and water is applied just to fulfill that. Meanwhile, a short span of sun-drying the field is applied in the growing season of rice. The general schedule of irrigation and drainage of rice fields is shown in *Figure 1*. Total savings in water consumption and ET and seepage are shown in Figure 2. It may be emphasized that proper irrigation schedules are based on the physiological water requirement of crops, combined with ecological requirements, especially the soil and climatic conditions, which may have large differences at different locations. The Hehai University and Jining Water resources Bureau's many long-term observations show that through these methods the leaf transpiration is reduced by 35%, interplant evaporation is reduced by 22.1%, field seepage by 48.6 % and the total water consumption of paddy rice is reduced by 40.7% in average comparison with the traditional irrigation method. During the last two decades, the area under paddy in China has declined by 2.5 M ha, whereas the total production has increased by 55 M tones and productivity by 2.1 t/ha. This appears to be one of the most potent methods of saving water under agricultural use.

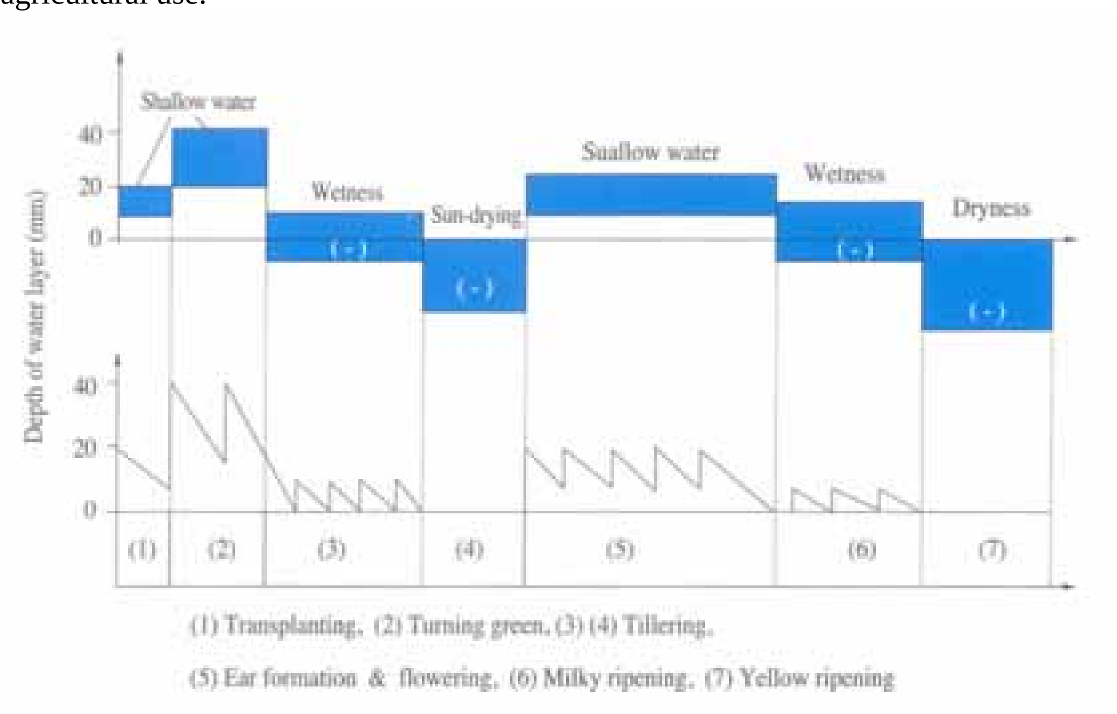
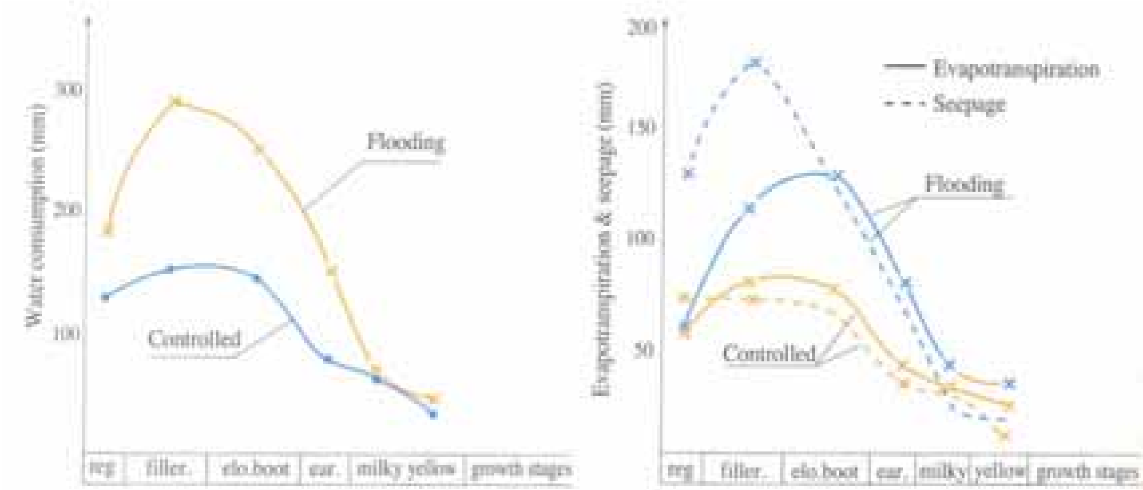


Fig.1. Varying depths of water layer during growing season of rice
(Source: Xu Zhifang, 2001)



(a) (b)

Fig.2 (a &b). Changes in total water consumption, ET and seepage components under flooded and controlled water supply conditions. (Source: Xu Zhifang, 2001)

(ii) Date of transplanting

Farmers, specially with tube well irrigation and free/ subsidized power supply, have the tendency to advance the transplanting date of paddy to make use of cheap labor during the lean season and be early in the market with the produce. Since, temperature during the summers are excessively high (above 43^{o} degree, C), this leads to very high evaporation losses. Date of transplanting of paddy should be planned in such a way that the cropping period matches with the monsoon period to effectively utilize the rainfall in crop production and reduce irrigation requirements. Delay in transplanting from 16th May to 31st May and skipping of high evaporation saved 40 cm of irrigation water (Table 6). Likewise, a further delay in transplanting by 15 days saved considerable amount of water, without any significant differences in yield.

Table 6. Effect of date of transplanting and different irrigation regimes on water requirement of rice crop and yield at Ludhiana, India

Irrigation regime	Yield (t/ha) on three dates of transplanting			Mean
	16 May	31 May	16 June	
Continuous submergence (CS)	7.14 (3100)	7.71 (2700)	6.40 (2380)	7.08 (2720)
CS for 2 weeks + 1 day drainage	6.88 (2140)	7.30 (1890)	6.27 (1720)	6.79 (1910)

New Approaches

On getting confidence that submergence of rice fields was not a prerequisite for getting higher yields, the scientists have come out with several innovative methods of rice cultivation which are high on water and resource conservation. Some of the more recent techniques being widely tried in the IGB include the following:

i. Raised Bed Cultivation

Borell et.al (1997) in Australia experimented with raised beds where water in the furrows (30 cm width and 15 cm depth) kept the beds (120 cm wide) at saturation. Compared with flooded rice, water savings were 34% and yield losses 16-34%. This practice is now being widely tested in IGB and China under the programs of Rice-Wheat Consortium. Initial results are quite encouraging as the practice was able to enhance both field and water course level water productivity. Raised bed system when followed under the cropping system such as rice-wheat helps in improving the drainage conditions for the post rice crop and thus improve the overall system productivity.

ii. Aerobic Rice

Efforts have also been made to grow rice crop like any other irrigated upland crop of wheat or maize. The potential water savings when rice can be grown as an upland crop are large, especially on soils with high seepage and percolation losses. Initial studies have shown encouraging results for water savings but require considerable efforts towards weed control, which is a major problem during rainy season and field submergence is apt for control of most of the weeds.

iii. System of Rice Intensification (SRI)

In recent years, there has been a lot of interest towards System of Rice Intensification, which originated in Madagascar. The proponents of the technology claim: “SRI is a methodology for increasing the productivity of irrigated rice by changing the management of plants, soil, water and nutrients. These practices contribute to both healthier soil and plants supported by greater root growth and the nurturing of soil microbial abundance and diversity. It is based on a number of agro-ecological principles with good scientific foundations. SRI concepts and practices have also been successfully adapted to upland rice. As claimed by proponents, SRI *does not require* the purchase of new seeds or the use of new high-yielding varieties, although some of the highest yields with SRI have been obtained from improved varieties. Neither does SRI require the application of chemical fertilizer or pesticides. Increased weeding is required, because rice fields are not kept continuously flooded. But farmers report that with SRI methods, their rice plants are better able to resist damage from pests and diseases, making agrochemicals usually unnecessary. Compost gives even better results than does fertilizer with SRI methods. With SRI there can be **water savings** of around 50%.

SRI *does require* **skillful management** of the factors of production and, at least initially, additional **labor input** - between 25 and 50%, particularly for careful transplanting and for weeding. But since yield increases are 50 to 100%, and possibly by two or three times present levels, returns to labor are very great since no purchased inputs are needed and profitability of rice production is increased. As farmers gain skill and confidence in SRI methods, labor input decreases and can eventually become the same or even less compared with conventional rice-growing methods. Improvements in SRI are continually being made, including better implements and techniques, which farmers are encouraged to consider and further improve upon. Additional information on SRI benefits can be found in the 2005 Uphoff article at http://cifad.cornell.edu/sri/". All these claims have not been widely accepted/ realized by the national institutes, but there appears some merit for consideration and adaptation at the local level.

iv. Biotechnology

The fast pace and advances in genomics, the development of advanced analytical tools at the molecular level and genetic engineering like gene pyramiding for introducing the desired traits provide new avenues for raising the yield potential and enhancing drought/ salinity stress tolerance. For example, the incorporation of the C4 photosynthetic pathway into rice (being a C3 plant) if achieved can potentially increase productivity by 80 % (IRRI). The traditional tools of developing rice hybrids have also met with lot of success in rice growing countries.

Challenges in Adoption of Water Saving Practices

The farmers have been cultivating rice under flooded/submerged conditions since centuries and find it difficult to adapt to the new challenges. However, the looming water crisis and the urgency to produce more from the same or even lesser amount of water is forcing the farmers, researchers, extension agents and policy makers to think differently. Surely, this program has received good appreciation and concerted efforts in China and farmers have started its adoption on a large scale. The following are some of the factors requiring attention at different levels:

1. Water is generally considered a low value input and the government-charged fees for canal/ tank water are very low and do not convey the scarcity or opportunity value of the resource. Farmers have little incentive to adopt water-saving technologies because water conservation does not reduce the cost of cultivation nor does it increase income.
2. Groundwater is generally considered as an easement to the land owned by farmers and as such is entitled to exploit as much groundwater as is humanly possible.
3. Energy policies of the governments (specially subsidized/ free pricing for electricity) also encourage farmers to freely exploit the groundwater.
4. The farmers more readily accept water-saving technologies that improve productivity and income. As such the practices of raised bed cultivation, SRI/ aerobic rice, laser land leveling, dry seeding etc. in the water deficient regions have shown considerable adoption by the farmers.
5. Suitable policies, institutional organization, regulation/ legislation are needed to promote water saving technologies. Similarly, multiple uses of water through integration of rice-cum fish culture and integration of rice with other high value crops have also the potential of increasing the water productivity.

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