2. Water for food: Converting inundated rice into dry rice

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Abstract

Over the past years, much public and political attention has been given to current and future water-related problems. Concerning agriculture, the international debate centers around efficient use of water in irrigation systems and on the competition of food and nature for water. The vast challenges ahead concerning water and food necessitate to explore all means, also outside this 'water sector'. The potential to increase food production in rain-fed agricultural systems is huge, as are potential savings of water in inundated rice production systems. This paper gives a concise description of the arguments that urge the need to seriously investigate the conversion of inundated rice cultivation into cultivation practices that use substantially less water. In addition to water saving, other relevant factors and developments are reviewed that govern such transition. Labor scarcity is already pushing transplanting into direct seeding practices, while increasing production pressure on land is stimulating multiple cropping. In addition, human-induced climate change feeds international debates on emission reductions, such as methane from inundated rice systems. Lastly, rice varieties may need to be adjusted to the altered cultivation conditions, but breeding needs to be guided by agronomic and physiologic research.

2.1 International debate on water for food, nature and people

Over the past years, the first and second World Water Conference have catalyzed much political and scientific debate on the use of water to meet the growing needs of the global human population and of natural ecosystems. During the first conference in Marrakech in 1997, the need was felt to create public awareness on this matter. This materialized in the second Conference in The Hague in 2000 and various vision documents. The overall document described the challenges ahead in a 'Global Vision on Water, Life and the Environment for the 21st century' (Cosgrove & Rijsberman, 2000). The international debate was further structured along three vision documents on the themes: water for food and rural development, water for nature, and water for people. The latter theme emphasizes drinking water and sanitation (Anonymous, 2000). The vision on water for nature makes a case for the benefits of freshwater and related ecosystems to humankind, where intrinsic values of these systems are respected and preserved (IUCN, 2000). The vision on water for food and rural development centers on the need to assure adequate nutrition and to secure livelihoods (Van Hofwegen & Svendsen, 2000).

The documents recognize the high priority to improve water use efficiency in agriculture, as this sector is the largest consumer of water. Water scarcity problems are, therefore, primarily a food problem. Two major categories of solutions are advocated to produce 'more crop per drop'. First, through improving agronomic practices by improved crop varieties, substitution of crops and improved cultivation practices. Secondly, through better water management by improving irrigation water management, using more deficit, supplementary and precision irrigation, and reallocation of water from lower- to higher-value uses.

In the past, much emphasis has been placed on increasing food production through irrigated cultivation. Irrigated production indeed provides the bulk of the world cereals (FAO, 1996). Production was boosted to top levels, even in (semi-)arid regions, such as in North India and North

Mexico, where large-scale dams have created reservoirs for irrigation. These wheat, rice and maize baskets of the world have contributed substantially to the total global food production and are likely to maintain that role (Bindraban, 1997; Evans, 1998; FAO, 1996). Currently, irrigation accounts for about three-quarter of global water withdrawals and irrigated agriculture contributes nearly 40% of world food production on 17% of the cultivated land (FAO, 1996). Improper crop irrigation management and inadequate understanding of regional water flow and distribution result, however, in inefficient water use. Over time these inefficiencies may develop into problems that deteriorate soil productivity, such as soil salinity (e.g. Agarwal & Roest, 1996).

In the future, irrigated systems should comply with more sophisticated and responsive irrigation services with more equitable and timely deliveries under specific rights and management by smaller entities, and with charges for deliveries (Evans, 1998). This is needed to improve water use and crop production in irrigated systems. New developments in information technologies, remote sensing and crop modelling and in participatory approaches create powerful tools to assist in increasing regional water use efficiency by improving the temporal and spatial irrigation water distribution to meet crop demand in interaction with farmers (e.g. Bastiaanssen, 1998). Scope for improvement can be found in technical aspects, such as lining or covering canals, but may be beyond the resources of developing countries who use 70% of world's irrigation water. Much gain can be made through a better communication between engineers and farmers to optimize distribution to demand. Progress is made in this area through implementation of approaches such as Integrated and Participatory Irrigation Management (e.g. Mollinga, 1999). The attention to increase water use efficiency in irrigated systems is eminent but has been over-emphasized during the World Water Fora. International debates are dominated by the 'water sector', i.e. actors from the irrigation and drainage arena, who run capital-intensive enterprises.

Clearly under-exploited is the option to realize substantial improvements in water use efficiency, which can be obtained in rain-fed production, in inundated rice cultivation and through the use of novel technologies. After all, rain-fed systems account for 60% of the world food production. Though there is much international debate on the use of new technologies in life sciences, only little attention is paid to the use of these techniques for increasing crop production, e.g. by incorporating processes that govern C4 metabolism into C3 crops or incorporating nitrogen fixing characteristics non-leguminous crops. In addition, no attention is given to the possibilities of plant production under marine conditions, which would bring closer the exploitation of the world's largest ecosystem (Bindraban & Roest, 2000; Bindraban, 2000).

An interesting opportunity to reduce water use for food production may come from the current practices of inundated rice cultivation. Rice is the most important contributor to the global food basket and plays a major role in irrigated agriculture. Since approximately 3000 BC, rice in South East Asia has been cultivated under inundated conditions. This production system requires large amounts of water and labor, but has been very successful in feeding large populations for many centuries. More recently, the Green Revolution boosted rice production, but also further increased its dependence on water. Now that water becomes scarcer and labor opportunities are available outside agriculture, traditional rice cultivation practices are being reconsidered. The major rice baskets of China, South India, and Indonesia no longer enjoy unlimited water supply (Table 2.1). Recently, these countries are experimenting with rice production using less water. The objective of this paper is to give a concise overview of the factors and developments that catalyze transition of inundated and transplanted rice cultivation practices.

2.2 Converting inundated rice into dry rice

2.2.1 General

Transplanting rice under wet conditions is the major practice in rice cultivation. Economic factors, such as rising labor costs, and increasing competition for natural resources have enforced the need for less labor-, water-, and land-demanding rice cultivation practices. Advances in rice technology over the past decades have already facilitated transformations of inundated transplanted rice cultivation into direct dry or wet seeding.

Apart from saving water and raising grain yields, any system of non-flooded rice cultivation may bring other advantages such as maintenance of soil structure beneficial to non-rice crops in the rotation. Rice growth in aerated soil will also reduce methane emission, identified as a major contributor to the greenhouse effect. On the other hand, weed problems and hence the need for more labor or herbicides may increase in non-flooded rice cultivation, and may hamper further spreading of this system. The method requires a much larger degree of water control than flooding methods. So, there are technical, economic and social organizational issues to be addressed (Klemm, 1998). In addition, reduced water use at the field and farm level may provide new opportunities for water use in other regions or sectors. However, storage and redistribution of water may be required to make water saved in one area available in other areas. In addition, dramatically changed agronomic conditions may necessitate adaptation of rice varieties.

2.2.2 Labor requirement and direct seeding

Labor requirement in inundated rice systems approximates 1500 hours for a complete crop cycle (Table 2.2). Collier (1979) showed with data from Java that this requirement has not changed over time, also not with the introduction of High Yielding Varieties. Already in the early 1980's the call for reducing labor requirement was present. An analysis in Java showed that introduction of mechanization would reduce labor requirement, but would cause little unemployment because of opportunities outside the agricultural sector (Santoso, 1981).

Table 2.1. Changes in per capita water resources in selected Asian countries.

Country	Per capita available water resources (m^3)		
	1955	1990	2025
China	4597	2427	1818
India	5277	2464	1496
Vietnam	11746	5638	3215
Thailand	7865	3274	2477
Philippines	13507	5173	3077
South Korea	2940	1452	1253
Pakistan	10590	3962	1803
Nepal	19596	8686	4244
Sri Lanka	4930	2498	1738

Source: Hossain & Fischer (1995)

Table 2.2. Labor requirement for various operations in rice cultivation.

	Hours ha^{-1}
Field preparation	660
Planting seeds in seedbed	100
Transplanting	100-400
Weeding	300
Harvesting	300
Drying	100
Total	1560

Various sources: Collier, 1979; Shanthi et al., 1998

Increasing labor scarcity for transplanting caused many farmers during the 1980's en 1990's to shift to direct broadcast seeding of rice under wet or dry conditions. Long-term trends, such as declining real prices of rice and herbicides and increased labor costs for transplanting and weeding, have stimulated the practice of direct seeding. Simultaneous changes that have favored the switch include the release of modern rice varieties with high seedling vigor and tillering ability that increase the crop's ability to compete with weeds, improved water control and increased availability of selective herbicides (De Datta & Nantasomsaran, 1991).

Yield performance and biomass production hardly differs between transplanting and broadcast sowing (e.g. Shanti *et al.*, 1998). Land preparation for broadcast seeding under wet conditions is essentially similar to that for transplanting and does not affect the demand for labor. Direct seeding does, however, aggravate weed problems, resulting in an increase of herbicide use. Depending on the system, direct seeding instead of transplanting can reduce labor requirement by up to 50% (Shanti *et al.*, 1998). Farmers may, however, end up using most of the labor saved to control weeds. Though total labor demand shows no substantial reduction, the demand for labor is spread over a longer period of time than with transplanting. This allows farmers to make full use of family labor and to avoid bottlenecks (Pandey & Velasco, 1999).

2.2.3 Land pressure and multiple cropping

Rice production must increase by more than 40% over the coming 30 years to meet world demand (Hossain & Sombilla, 1999). The production increase should be realized on less land. Much agricultural land, including rice land, is already being lost to urbanization and soil degradation (Brown, 1995; Oldeman, 1999). Productivity can be increased by intensified land use through multiple cropping.

The water constraints may induce policies to relieve marginal lands for rice cultivation and to move from intensive rice-rice to rice-non-rice cropping patterns. Much emphasis is currently placed on rice-wheat cultivation. In India, the area under rice-wheat cropping increased from 4 million ha in 1960 to over 9 million ha in 1990 (Abrol, 1999). Increasing pressure on land pushes the introduction of potato cropping into these systems. Potatoes have become one of the fastest growing commodities in tropical and subtropical regions. India alone has increased its potato production fivefold in the last three decades, and it is the largest potato producer in the Indo-Gangetic Plain.

Cultivation of rice under dry conditions favors the inclusion of non-rice crops in the cropping system. Generally, puddling of soils increases bulk density and decreases hydraulic conductivity. While it facilitates rooting of the rice crop, it jeopardizes root development of consecutive crops. In rice-wheat systems, wheat yields are suppressed by the soil conditions caused by puddling. Bajpai & Tripathi

(2000) found puddling and non-puddling to be equally effective to rice, i.e. rice yields did not decline significantly. Non-pudling of rice produced significantly higher wheat yields than wheat following puddled rice cultivation. They, therefore, conclude that direct drilling of rice instead of puddling, combined with conventional tillage for wheat is beneficial for rice-wheat systems.

2.2.4 Water scarcity and water-saving rice production

Experiments on low water-input rice systems are far from conclusive. Early experiments done at the International Rice Research Institute (IRRI) by De Datta (1981) showed that substantial water savings could be realized (56%) but this resulted in a proportional yield reduction of 57%. Later, using upland varieties, the yield reduction stabilized at 37%. A review of experimental data from the seventies and eighties by Bouman & Tuong (2001) suggests a trade-off between water and yield compromising land requirement for production.

Recent experiments demonstrate that the decline in rice yield under non-flooded conditions is negligible. Bhagat *et al.* (1999) found that saturated soil conditions saved more than 40% water compared to continuos shallow ponding and produced the same rice yield when weeds were controlled by herbicides. They did find increased weed infestation, but argue that proper use of herbicide can substitute the excessive water consumption of continuously submerged rice fields.

In Madagascar, the 'System of Rice Intensification' (SRI) was developed where fields are kept un-flooded and the soil well aerated throughout the entire vegetative growth, while only a little water is kept on the field during the reproductive growth phase. While this may seem extreme, dramatic yield increases have been witnessed in Madagascar and some other countries. SRI prescribes a set of additional practices, including application of large amounts of organic matter, wide plant spacing, and the transplanting of very young seedlings. Yield increase is tentatively attributed to additive effects of water management, fertilization and timing of transplanting and by unexplained interactions. Experimental yield levels tripled from a starting point of approximately 2 t ha^{-1} (Uphoff, this volume). These results are encouraging but need further investigation, in particular to explore whether the advantages would also apply to higher yield levels, e.g. above 6-7 t ha^{-1}.

2.2.5 Global climate change and methane emission in rice fields

Methane is one of the principal greenhouse gasses with an estimated contribution to the greenhouse effect varying from 15 to 20%. The atmospheric methane concentration has more than doubled over the last century and shows strong correlation with global population growth, suggesting anthropogenic causes. It is estimated that wetland rice account for approximately 20% of the anthropogenic emissions (Denier van der Gon, 1996), but the uncertainty range runs from 4 to 20% (Van Bodegom, 2000). Wassmann *et al.* (2000a,b) report emissions from rainfed rice to correspond to only 20-40% of the emissions from irrigated rice. Based on the global distribution of the rice area, they assessed irrigated rice to account for 70-80% of total global methane emissions from rice cultivation, and the most promising target for mitigation strategies. Accurate assessments of regional emissions are however difficult, as management practices have a large impact on emission rates, and emission rates show non-linear responses to many factors (Van Bodegom, 2000).

The fact that management practices in inundated rice cultivation have a large impact on emissions creates, at the same time, a large number of options to make interesting contributions to reduce methane emissions. Factors that affect emissions are varieties, fertilizer type (sulphate containing), fallow, mulching, organic matter content, and water etc. (Wassmann *et al.*, 2000b; Minami & Takata, 1997; Husin *et al.*, 1995; Denier van der Gon, 1996).

Various experiments have been carried out to study the impact of water management on methane emission. In an experiment with intermittently flooding of paddy fields, Miyata *et al.* (2000) found increased fluxes of methane for drained paddies, compared to flooded conditions. This result is in line with findings of Denier van der Gon (1996), who shows an increased release of methane during 2-4 days after the soil fell dry. He estimated these emissions at 10-15% of the seasonal emission. These findings are also in line with results from Byrnes *et al.* (1995). Still, many studies report that introduction of midseason drainage and alternate flooding/drying reduces emissions by 30 up to 50% without compromising on yield (Lu *et al.*, 2000; Wang *et al.*, 2000). Adhya *et al.* (2000) found that conversion of rice-rice production systems into rice-non-rice could reduce emissions to one third only.

Singh *et al.* (1999) showed that the seasonal balances of methane emissions in dry land cultivation are not a source but a potential net sink of methane. The sink strength is potentially affected by the rice variety due to differential plant characteristics, length of period of soil saturation, and fertilization. Methane consumption showed a significant negative correlation to soil moisture content, for both control and fertilized conditions.

2.2.6 Changing practices, changing cultivars

Success in breeding for yield increase in rice during the 1960's and 1970's has been great for rice grown under inundated conditions, with effective irrigation facilities. Less successful was the development of varieties resistant to prolonged moisture stress and temporary submergence from heavy rainfalls (Hossain & Fischer, 1995).

Some scientists expect that genetic crop modifications may be needed to compensate observed yield declines when transforming inundated cultivation (Dat Van Tran, pers. comm.). Rice yield levels in upland cultivation may, however, be as high as in inundated cultivation. This suggests that sufficient genetic material is available to adjust current rice cultivars to cultivation practices with less water. In addition, better physiological understanding is needed before running into genetic adjustments.

Over the past decade, IRRI launched a program on 'super rice', to boost yield potential of rice. Success can unfortunately not be reported up to date. In designing this rice, much emphasis was placed on the morphological and photosynthetic characteristics (Peng *et al.*, 1994). While a large panicle was needed as sink, grains failed to fill adequately (Pulver & Nguyen, 1998). Earlier, Bindraban (1996; 1997) showed the eminent importance of a strong sink and hypotheses that the transport capacity of wheat could be limiting yield potentials in wheat. Simultaneously, research suggested that similar problems could apply to the super rice (Sheehy, pers. comm.). Emphasis in crop improvement may need to shift from increasing the source to increasing the sink and improving the vascular transport system. In the SRI system, Uphoff (this volume) found that early transplanting increased yield, with a positive association between tillering and grain filling, contrary to common finding. On the one hand, these positive relations are not uncommon at lower levels of production. On the other hand, this may point to the importance of the formation of the panicle and the transport system. In wheat, the double ridge stage, i.e. the transition of the apex from vegetative to generative, can occur already in 20 to 30 days after sowing (Slafer & Rawson, 1996; Gómez-Macpherson & Richards, 1997). The importance of the early days after emergence on yield formation is demonstrated by Jitla *et al.* (1997). Doubled CO_2 concentration from sowing onwards increased tiller number and yield. Delayed exposure to doubled CO_2 to 15 days after sowing still affected yield through enhanced sink while tiller number remained unchanged to control. They conclude that the results indicate that the generation of the sink in the floral apex plays an important role in determining grain yield. The above, shows that transplanting at 3-4 weeks after emergence can coincide with a critical phase of sink formation. This could mean that the transplanting shock may have a long-term damaging effect on the formation of the sink capacity and, therefore, on grain yield.

2.3 Discussion

Over the past decades, global and national developments have initiated research for alternative practices of inundated and transplanted rice cultivation. Increased labor scarcity has encouraged direct seeding, which does not cause reductions in yield and even increases return on investment.

Pressure on land for production causes cropping intensity to increase. Multiple cropping is of high value to many farmers as diversification reduces income risk and generates additional income. Conversion of inundated rice cultivation into cultivation practices with less water facilitates and enhances the production of other crops in the rotation.

The need to increase water use efficiency in rice production is pressing. Production loss in rice experiments with reduced water use in the past was substantial, but the need for detailed research was absent, because of a lacking pressure on more efficient water use. Recent results indicate that yield losses can be modest to non-existing and that new approaches, such as the SRI system, could even improve yield.

Cultivating rice under dry conditions reduces emissions of methane. Reducing methane emissions from rice fields through the introduction of dry cultivation practices cannot be the driving force for introducing the change. Ensuring food availability has priority over reducing methane emissions. However, simultaneous reduction in methane emissions in rice production systems using less water, could become an additional source of income for nations through emission trading.

Weed control has been one of the major driving forces behind inundated cultivation. Experiments on reducing water use for rice production all reveal increased weed competition. Although weeds can be controlled effectively by herbicides, the reliance on chemical aids reduces the sustainability of the production system, because of development of resistance, health hazards and environmental pollution. In the end, weed problems are also common for other crops, and ways should be found to sufficiently control its occurrence in rice.

Altered agronomic practices may necessitate adjusted rice varieties. Careful agronomic and crop physiological knowledge is, however, required to effectively guide the breeding efforts, either through conventional breeding or genetic modification.

Overall, it can be concluded that there is an increasing need to transfer inundated and transplanted rice production systems into less water- and labor-demanding systems, thereby facilitating multiple cropping and as a side-effect reducing methane emissions. Such systems may reduce income risks and increase farm household income, while water savings may increase total regional production. Clearly, much research is needed to overcome agronomic and crop-related problems.

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