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BEYOND DROPS FOR CROPS: THE SYSTEM APPROACH FOR WATER VALUE ASSESSMENT IN RICE-BASED PRODUCTION SYSTEMS

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Beyond Drops for Crops - The System Approach for Water Value Assessment in Rice-based Production Systems

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Rice beyond the grain and the plant

Rice-based production systems are intimately connected with water development. For hundreds of years, natural selection pressures such as drought, submergence, flooding, nutrient and biotic stresses as well as human intervention have contributed to an increased diversification of rice agro-ecosystems. Whether rainfed lowland or upland, deepwater/flood prone or irrigated - rice cultivation always remains linked to water. The water ponding system of rice cultivation has widely shaped the landscapes of rural areas. In Asia, for example, the typical rural landscape consists of paddy fields on mountain slopes or of the flat plains with abundant ponds and waterways developed over hundreds of years. Water ponding is also advantageous for the natural environment as it allows for an efficient control of weeds without the use of chemical inputs.

The value of paddy field cultivation for local community comes not only from food production but also from the many other aspects such as (i) social capital – the required strong social cohesion to deal with the massive labour required to build and maintain the terrace or canal system as well as to synchronize the cropping pattern, (ii) soil erosion and landslide protections, (iii) flood protection – storage of precipitation within the bunds of the paddy system. In some parts of the world the integration of paddy cultivation into the local cultures has a thousand year old tradition. Religious ceremonies and social structures are closely linked to rice production and to the rice season cycles. In many countries, however, the rice production systems are in crisis due to the widening gap between the incomes they can provide versus the income opportunities provided by other sectors. This crisis is evidenced by symptoms such as aging or feminization of the farming population, part-time farming or decreasing farm sizes.

Since the 1950s, new types of rice systems have emerged: the "modern" medium or large-scale agency-managed systems and the non-voluntarily created man made ecosystems. These systems evolved from supplementary irrigation during the rainy

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season due to double cropping and round-the year irrigation as well as due to current multiple and/or conjunctive use.

Rice ecosystems under submergence are endowed with unique features that influence natural resource management. Soil submergence and its related biochemical processes exercise a great deal of influence on ecosystem sustainability and its vital aspects such as carbon sequestration, nutrient cycling, and water quality. Rice soils under submerged conditions provide environments congenial to soil organic matter build-up, carbon sequestration and biological nitrogen fixation. The organic matter of soil serves as a nutrient reservoir, particularly for nitrogen to plants. Soil submergence under irrigated lowland rice ecosystems is an important contributor to long term sustainability of organic matter resources and nutrients by supplying power to soils. Nevertheless, paddy fields are also a major contributor of greenhouse gases from their methane emissions.

Beyond sustaining crop production, the value of water in rice-based ecosystems plays multiple roles. In the agro-forestry gardens of Asia water also provides an air-cooled environment for people living below the canopy trees, such as for example the coconut trees often fed by water from the neighbouring paddy fields. To the unacquainted rice cultivation may appear as a highly water consuming crop due to spill over and percolation. Yet, once the recycling process and all the various downstream uses of water are considered at the agro-ecosystem level, one can see that rice generates highly productive and efficient water use. The impact of rice cultivation on natural resources and aqua-ecosystems is twofold. On one hand, water withdrawals for paddy systems diminish its availability for natural ecosystems such as wetlands, while on the other hand, rice agro-ecosystems create man-made wetland systems with some of them being considered as such by the Ramsar convention.

In terms of the health dimension, rice production systems have both positive and negative effects. Widely spread standing water in rice systems without a doubt is a factor contributing to the increased vector of water born diseases such as malaria. Nonetheless, the diverse rice systems with natural predators help reduce disease hosts while the economic wealth generated by rice intensification contributes to the wider use of protection against mosquito. Thus, the balance between positive and negative impacts on health is somewhat mixed.

Understanding the value of water in a rice-based system requires to look beyond its use for crops alone and to the introduction of a more holistic system approach. Such holistic approach encompasses various systems as illustrated in Figure 1 (*nutrition system; farmer livelihood system, environmental system and the water management* *system*). The main purpose of this paper is to offer a brief introduction of this holistic system approach to water value assessment in rice-based production systems.

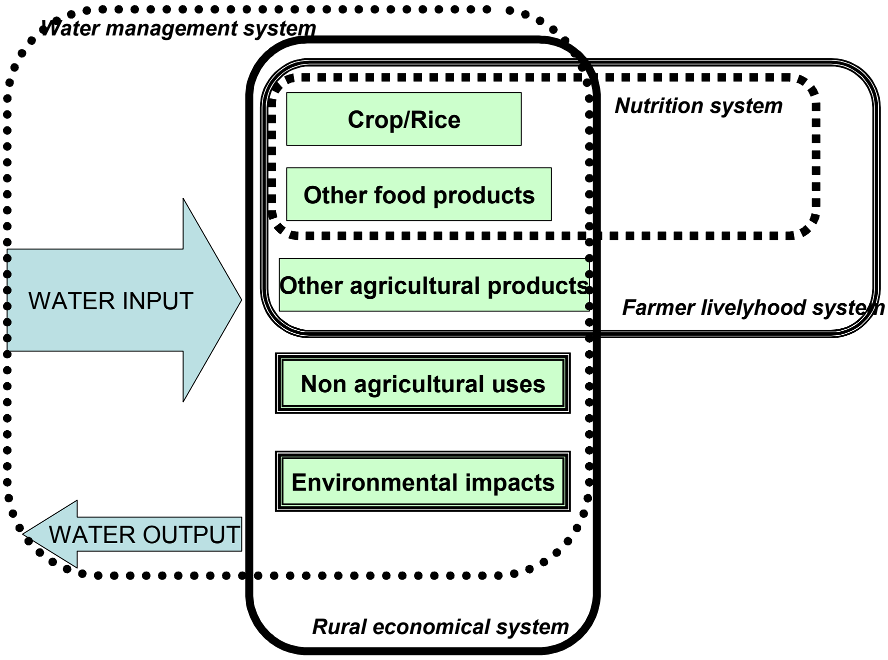

Figure 1. Embedded system approach to tackle rice based systems.

Water under examination

In the globalized world competition for natural resources becomes increasingly acute and each human need and activity needs to be carefully scrutinized in order to improve the efficiency and equity of resource allocation. Use of water for food production is one of the most important human water needs and it remains unaffected by the past and future increases in agricultural productivity. Therefore, in order to promote the most efficient use of water it is necessary to scrutinize water consumption per each agricultural product.

Nevertheless it must be recognized that the evolution of rice systems is not only driven by water-related considerations but also by the socio-economic factors. Therefore, the system approach is not only concerned with the value generated from the effective water management in rice- based systems but in determination of the most environmentally and economically sustainable methods for rice systems' management.

Since quite some time many agricultural and irrigation experts from the arid and western world's areas have been blaming rice cultivation for overly high consumption of water in comparison to other cereals. Simultaneously, the experts and the entire population of Asia where rice has been cultivated since many centuries have praised rice cultivation as the foundation of their life and livelihoods.

It is only recently that we have been able to reconcile these two opposing points of view on how to value rice. Recent investigations from the water management community have documented clearly the grounds on which rice cultivation is felt to be so valuable for Asian societies and that water management performance in rice systems must look beyond the crop and be assessed on the system basis. In practice, recent accurate water balance studies often shows that in rice based systems:

- the beneficial uses of water is much higher that the crop use itself (multiple beneficial uses in the command area);
- there is room for performance improvement (reduction of real losses of water);
- there is often the need to improve water productivity through increased yields.

These last two points may require changes in the traditional water management system. Therefore, one should not confuse the conclusion that the rice system fulfils multiple roles with advocacy for maintaining the rice systems in their present state.

In the contexts where: i) the development of water resources has been made chiefly to develop rice irrigation; ii) new water needs, such as urban or industrial, must be satisfied from the same resource iii) irrigation systems must be managed for multiple use; and iv) water resources as well as irrigation management are moving towards more participatory and decentralized management - it is important to understand what roles or uses the systems are fulfilling at present, what are the opportunities for the systems to fulfil new roles and how can the systems be managed to optimize the total productivity of water.

Beyond crop production, the values of rice agro-systems are numerous and are not always easy to identify and evaluate. Probably the best way to get a quick sense of what these values are is by considering an alternative to rice: what if rice cultivation no longer existed? What would the consequences be for the ecosystems, the economy and the livelihood of people?

Life.....without rice cultivation?

Although in Asia and many other parts of the world, rice cultivation has been the way of life since centuries, the current trends in agro-economy favour cultivation of other crops. The real price at the farm gate has dropped significantly during the last decades increasing farmers' temptation to switch, whenever possible, to other crops. The issue of continuing rice cultivation is critical in many rice-based systems and not only in the wealthy Asian countries. In some countries in southern Europe the declining support from the EU has turned the subject of rice cultivation into a rather burning issue. Simultaneously, there is a growing recognition that suppression of rice cultivation can dramatically alter entire water circulation in often very large command areas. The realization of the importance of the external environments linked to rice cultivation is fuelling today's debate. Therefore, the hard way to learn about the real value of rice cultivation is to figure out what would happen to the agro-ecosystem without it.

It can be demonstrated that the consequences for many agro-contexts in Asia would be dramatic because:

- There is little or no alternative for staple food cultivation during the rainy and wet season as other cereals cannot resist heavy rain. Hence, elimination of rice in a monsoon type agro-context would mean significant decrease in food production.
- Rice cultivation and related water management practices are *de facto* sustaining a complex agro-ecosystem that would simply collapse if deprived of an abundant water support for rice.

A diversified system approach for rice cultivation

It must be stated clearly that there exists no single rice system. Rice systems are site specific and although in many areas we can find similar bioclimatic conditions, farming systems can still differ considerably. Therefore, it is crucial at this stage to refrain from considerations of one generic system but to embrace rice agro-ecosystems in their full diversity: from mono-crop industrial farming systems to fully integrated agro-sylvo-pastoral systems.

Another issue related to rice agro-ecosystems is the seasonality of their behaviour: during the rainy season (e.g. monsoon) they are wet systems while during the other cropping seasons they may resemble nearly dry or dry systems which require an external water supply and can lead to very high crop diversification. In addition, the costs for water may be significantly different for the dry and wet seasons.

Therefore, the range of options may vary from traditional rainy season management, which is more or less unchanged, to dry-season management which is drastically changed. This may have a positive impact on rice itself, for other water uses and can lead to bringing significant changes in both the wet and dry season.

Rice one of the main dietary energy supplies

Rice is the staple food for about half of the world population. It has always been vital for fulfilment of human food needs particularly in Asia where population density is high and per capita availability of arable land very low. Rice is the only staple food crop that can stand heavy rains during the wet seasons which is why the growing of rice has spread so much in the tropical countries and specifically in Asia.

The 575 million tons of paddy-rice produced in 2002 was the world's single most important source of dietary energy (21 %). Rice cultivation expanded until 1975, when it virtually stabilized at around 145 million hectares. Although expansion still continues to take place in some areas such as in low income countries where it recently increased from 75 to 92 million hectares, the world average yields have more than doubled since 1961 reaching 3.8 tons/ha in 2001.

In comparison to wheat, rice is more effective for energy supply (Kcal/kg). Yet, it is significantly less effective for supply of protein and much less effective for supply of other micro-nutrients such as iron, magnesium, phosphorus and manganese. Therefore, there exists a need to overcome this nutritional deficiency of rice. There are mainly two ways in how this can be achieved: by improvement of the nutrient content of the product or by diversification of intakes.

Improving the nutrient content

Many diverse aspects within the rice-based system can be considered in order to improve the micronutrient status:

a) selection of varieties with exceptional nutrient content - bio fortification is a sustainable technological tool that can be used to enhance the micronutrient content of the grain and to reduce grain phytate content which inhibits the bodily absorption of these micronutrients;

b) Simple processing techniques such as promotion of less refined milling of the grain and parboiling also preserves available nutrients.

The system response: diversification of products

Diversification of products in a diet has always been the response of communities to compensate for rice nutrition deficiencies. In rural dominated societies rice based systems are usually quite successful in producing complementary food products to rice such as fisheries, fruits, vegetables, meat and milk and this approach should be further encouraged. In modern, large rice cultivation systems the perspectives are different and the main strategic option is to focus on the rice crop only with a view to maximize the rice output (such as in the granary schemes of Malaysia). Specifically in the systems with large holdings or after some form of consolidation, engineering into the systems design and management the level of satisfaction of its different uses and transforming the irrigation schemes into multiple use schemes such as, for example with rice in the wet season, diversified rice, fish, cash crops in other seasons as well as to supply water for the satisfaction of urban needs.

The question is how can we preserve or enhance the value of water in order to fulfil aspirations for an improved and better life?

Beyond drops for crops: a complex agro-ecosystem

An agro-ecosystem is a complex of air, water, soil, plants, and animals in a defined area that people have modified for the purpose of agricultural production. It develops in an environmental setting which defines resources available in a social setting that conditions how farmers and consumers interact with each other and with the environment.

Rice-based systems exhibit some peculiarities that need to be properly accounted for when sustainability is at stake. More than any other crop, rice agro-ecosystems are profoundly influenced by the scale of water and land management. For hundreds of years, natural selection pressures such as drought, submergence, flooding, nutrient stresses, and biotic stresses have contributed to the diversity of rice agro-ecosystems.

The marriage of rice and water has generated complex patterns of water circulation within the command area of rice-based systems, whether it is rainfed or irrigated. This type of system is often considered in the tradition as well as in modern management as the cascade system where water spills from one field to another, recharges groundwater, supplies near by land and drains from one system to feed another one, recycles drainage water through surface ponds and other open water bodies.

In rice-based systems, the quasi permanent presence of water throughout the command area modifies the environment and the conditions that allow the vegetal and animal life to prosper. It allows for diversification of local production (fisheries, trees, gardening). “Rice is life” not only for itself but also because the mobilisation of resources needed to produce it paves the way to creation of other important products beneficial to human nutrition, wealth, and the environment. In some dry zones of South Asia the coconut trees can only grow if associated with paddy fields. These trees are traditionally called by the communities as the “Tree of life” because they produce almost everything that life requires from additional food to material for house and shadow that create habitats and cooler environment. The symbiosis between rice and other agricultural production is the major feature of rice-based systems that needs to be fully recognised particularly with regard to the livelihoods of small-holders. One should not forget, of course, that some of these rice systems have been created by the drainage of natural wetlands which might have provided some of these services in the past.

In many places water delivery systems required to serve rice production are de facto serving many other purposes which are critical for the rural poor in areas of domestic water supply, fisheries and environment. Therefore, targeting improved water management in rice-based areas may serve the achievement of several Millennium Development Goals such as food security, poverty alleviation and domestic water supply.

This particular eco-system resulting from the marriage of rice and water represents positive and negative externalities that need to be fully considered in order to move towards the goal of sustainable development. Internalizing externalities is both a constraint (cost) and an opportunity for rice-based systems.

Water ponding: a remarkable feature of traditional rice cultivation

Rice is the only cereal that can stand water submergence and this feature is crucial for understanding the long and diversified story of rice and water. The plant’s adaptation strategies include its ability to survive submerged conditions without damage, to elongate stems by several decimetres in one day in order to escape oxygen deficiency due to rising water tables, or to withstand severe drought periods. Based on this agro-ecological diversity ecologists have proposed several classification systems of which the most widely used distinguishes five water related categories. These are: rainfed lowland, deep water, tidal wetlands, rainfed upland and irrigated rice.

For thousands of years paddy has been associated with fields of standing water in various agro-ecological systems. Water use at field level is thus always high due to infiltration, percolation and spill. Therefore, paddy is always blamed for being a high consumer of water (between 900 mm and 2250 mm per season) compared with other cereals (400 to 600 mm).

The mounting water crisis at the global and local level raises questions about the future of paddy. Issues of sustainability force us to reconsider whether paddy should give way to less water-consuming cereals or crops. This requires further scrutiny and an impartial debate. Competition for other uses of water is increasing rapidly and there is no doubt that water consumption will come under increased examination. There is a need for reliable figures on inputs and outputs as well as the advantages and disadvantages associated with paddy cultivation. Hence, a new look at paddy cultivation may review the value of the traditional paddy system as well as technical improvements.

The value of water in rice based systems

Due to the complexity of water flows generated by water ponding, traditional rice-based ecosystems are the natural habitat for a huge variety of living resources including both terrestrial and aquatic organisms. Rural populations rely on the biodiversity associated with rice based ecosystems - including the natural predators of rice pests - and often enhance this biodiversity with cultivated plants, domesticated animals and aquaculture so as to guarantee their daily food supply and income. Fish, frogs, snails, insects and other aquatic organisms derived from these ecosystems are a source of animal protein and essential fatty acids. In Asia, during dry periods, paddy fields are often the only source of water for valuable trees (coconut) and home gardens.

The control of water layers at field level for submerged rice growth has led over the ages to the development of specific water management and cultivation practices that produce some specifically beneficial outcomes. The terrace system in mountainous areas is a typical product of the ponding technique which has allowed for cultivation on steep slopes. This technique is instrumental in preventing soil erosion and landslides. Another advantage of this technique is its capacity for flood control: the field bunds generate a significant capacity of water storage which reduces peak flows under heavy rains. The permanent presence of water on the field also generates percolation of water and groundwater recharge which is often beneficial for other water uses.

One major advantage of water ponding in rice cultivation is the fact that it prevents weed development leading to avoidance of herbicide use and to the reduction of the amount of labour required.

Clearly, switching from paddy to other dry cereals implies making decisions that will have profound consequences on many aspects of rural livelihood.

The paddy ecological environment is based on the peculiarity of water submergence and anaerobic root zones. Submerged rice soils create environments congenial to organic matter build-up, carbon sequestration and nitrogen fixation. Rice ecosystems are important contributors to long-term sustainability of organic resources and nutrients supplying power to soils. However, anaerobic conditions also favour the release of methane into the atmosphere which constitutes the main global ecological issue related to the greenhouse effect. The traditional irrigated paddy fields are one of the main methane contributors but improvements in field techniques can drastically reduce emissions by drying the field and aerating the soil (intermittent irrigation; drainage once per season). The varietal improvements can also add on to the emissions' reduction.

Social capital and rice water management

Historically rice cultivation has been the result of a collective enterprise requiring investment and management of rice that was dependent on development of social capital. Investment in infrastructure and the shaping of landscape for the ponding system (terraces) required collective organization within the community. Water management also relies on a high sense of collective interest: crop and water calendars must be organized per large blocks of fields in order to efficiently manage water and organize work from land preparation and transplantation to drying up for harvesting.

Rice systems as wetlands

Many rice systems are classified as wetlands and they fall into one of the major categories of the RAMSAR classification, namely the man-made wetlands sub-category agriculture. For example, this is the case of the Kirindi Oya project presented in Figure 3 & 4. Investigating the value of water in these rice systems is therefore similar to performing an economic valuation of wetlands (their functions, products and attributes) according to the guidelines developed by IUCN and other conservation agencies (Barbier et al, 1996). As this paper illustrates, rice systems do perform a variety of services generally attributed to wetlands which vary according to the type of rice agro-ecology.

Field water management for rice cultivation in rice systems

Water takes on the prominent role in rice production. Unlike many other cropping systems where water is mainly used for production purposes (transpiration), the rice cropping system uses water in numerous ways, which can be both beneficial and non-beneficial. Estimates of the water needs for productive and beneficial use in rice systems can be divided into three categories: (1) crop water requirement for evapotranspiration (evaporation and transpiration), (2) seepage & percolation and (3) needs for specific water management practices such as land preparation and drainage of water prior to the tillering stage.

Figure2. Land preparation requires a huge amount of water for puddling (Nepal- Sunsari Morang)

The range of daily dry season evapotranspiration rates is given as 5-12 mm/day, adding up to 500-1200 mm on the basis of 100 irrigation days. Evapotranspiration needs include two components: 1) transpiration for maintaining physiological processes that lead to plant development and growth, and 2), water needs to compensate for evaporation from the soil or water layer. Land preparation needs are in the order of 150-250 mm.

Seepage and percolation needs of 2-7 mm/day are required if the moisture is to be kept at saturation (200-700 mm) level or if submerged conditions are to be maintained. If the drainage of water prior to the tillering stage (panicle initiation) is practised another 50-100 mm are to be added. Based on these calculations, the total water requirements of irrigated rice ranges from 900 to 2,250 mm.

The actual water demand of farmers is often much higher in order to account for conventional application efficiencies of less than 50 percent.

The importance of the multiple uses of water in a rice-based system

In many rice-based systems, a great part of water enters the field as precipitation, surface irrigation, or spills/percolates from adjacent fields. This is the well known "cascade" system applied at field or sub-system levels. Therefore, it is critical that the water budget should be made at an appropriate scale and that it should not be limited to that of the field alone. In some systems in Asia water consumption at the field level can go hand in hand with many other important uses of water as shown in the example presented in Figure 3. Here the crop consumption (evapotranspiration at field level) accounts only for 23 % of the total inflow in the command areas, while fisheries are taking advantage of the multi streams and water bodies in the system in the same example leading to about 19 % of economical activities of rice.

Table 1. Estimated consumptive use of water for evapotranspiration and other uses

Purpose of water use	**Consumptive use** (in mm)		**Remarks**
	Low	High	
Land preparation	150	250	Refilling soil moisture, ploughing, and puddling
Evapotranspiration	500	1200	
Seepage and percolation	200	700	To maintain water layer
Mid-season drainage	50	100	Refill of water basin after drainage
Total	900	2,250	

Figure 3. Example of water balance in a rice based system - Sri Lanka (After Renault et al, 2001)

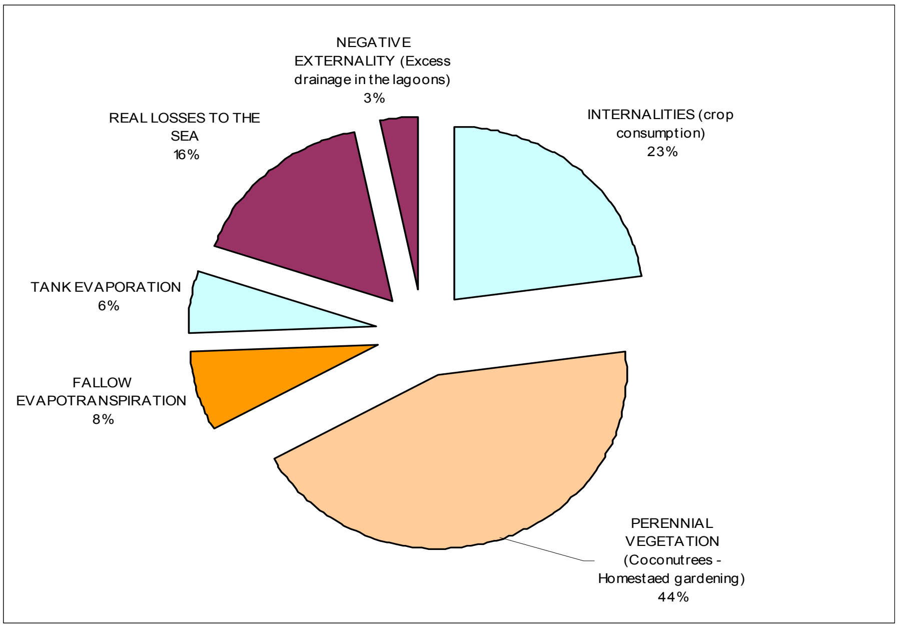

Figure 4. A typical association of Rice between paddy field and homestead garden fed by surplus water from the paddy field and providing materials for housing, additional food nutrients, and medicinal plants.

The importance of re-circulation in rice based systems

The flow of water in many rice systems is characterized by a lot of re-circulation at various levels: from field to fields or from subcommand area to another subcommand area. The inference of poor efficiency is often due to the confusion of scales and mis-understanding of water circulation. For example, adding conveyance losses at various levels to field losses to estimate overall efficiency instead of adopting a proper water balance approach with spatial and time boundaries will lead to abnormally low values for efficiency.

In traditional rice systems a lot of services are provided by this recirculation or storage and circulation of losses. In many modern systems these services are generated due to accident or as a result of poor management and sometimes may even lead to negative rather than positive externalities e.g. rise of salted groundwater.

Lessons from rice-based systems for water management improvement

In the irrigation domain, enhancement of management performance has for a long time been sought for through water efficiency improvements in mobilizing, conveying, distributing and ultimately making water available to crops.

Efficiency *vs* productivity

The focus in irrigation systems performance has mostly been on efficiency in water delivery and application with the goal to minimize the costs borne and the water losses generated by water transport and application. The rationale of efficiency can be captured by the following formulae:

$$\text{Efficiency} = \frac{\text{Water consumed by crops}}{\text{Water input}}$$

However, using only the previous indicator for the rice-based system has led to many misleading judgments and in the past paddy field cultivation has often been wrongly accused of very poor water management performance on the basis of low efficiency at field level.

The performance of rice-based systems cannot be looked at considering the role of water supply to crops alone. In rice systems the focus should be on productivity and on accounting for beneficial outputs (Molden, 1997) as expressed in the following formulae:

$$\text{Productivity} = \frac{\text{Beneficial outputs}}{\text{Water input}}$$

For example, in Asia water duties are often computed as the sum of the precipitation and the total irrigation supply divided by the net command area (irrigated fields) and it is very common in the humid tropics to record very high water duties, i.e. greater than 4000 mm/year. With regard to efficiency, this high water input value would lead to a very low performance indicator. However, when we consider that the entire gross command area of a rice-based system benefits from water through crops and other uses its real performance increases abundantly. In the Kirindi Oya project (South-East of Sri Lanka) the net command area is only 40% of the gross command area. Accordingly, water duties when referring to the gross command area are reduced in this project to more realistic figures, i.e. 1360 mm/year (Renault et al. 2001).

Water management

Whether applied to traditional systems or to new-technical paddy systems, improved water management is required to supply users with an appropriate and reliable water service. This is of particular relevance to those who are practising new water-saving techniques and promoting stakeholder governance arrangements as well as economic and environmentally-sustainable management at scheme level.

DIRECTIONS FOR THE FUTURE DEVELOPMENT OF RICE SYSTEMS

At field level: rice emancipation from water ponding or rice as an ordinary cereal

Rice has traditionally been largely developed in monsoon Asia in the areas and at the time when water was quite abundant. The more recent developments of rice cultivation have occurred more in areas or in periods of the year that are much dryer than in the past. Furthermore, water abundance in some parts of monsoon Asia is a concept that has eroded with the huge increase of water requirements for other uses (domestic-industrial-environmental). Consequently, there is the general trend to develop water savings irrigation techniques for rice.

Besides the development of new high yielding varieties with classical field practices, there are many worldwide attempts to experiment with new types of rice practices at field level. Many of them are specifically motivated by water savings. Water consumption for paddy rice is higher than for any other cereals, even if a great part of the field losses are recycled. The increasingly acute competition for water leads many rice growing countries to seek ways to reduce water consumption per grain. During the last decades, various new techniques of rice have been tested by international and national rice institutes. All these techniques tend to suppress, either partially or completely, water ponding at field level: aerobic rice, alternate wet and dry, System Rice Intensification.

Table 2. Opportunities and challenges related to drier rice cultivation

	Traditional permanent water ponding techniques	Intermittent wet-ponding and dry techniques	Dry cultivation (rain-fed and irrigated) – no ponding
Favourable feature +	• Generate multiple uses of water • Share of management cost among many uses of water • Weed control	• Water savings to crop only • Flexibility of the cropping calendar	• No additional supply of water, or supplementary only • Water savings at field level (no ponding)
Non favourable feature -	• High water withdrawal • Potential risks of pollution by chemicals leaching out • Low flexibility in crop calendar (per block organization)	• High quality of service of water required • High cost of water management to be born by farmers only • Weeding required	• Water conservation technique (mulch) • Weeding required

Somehow these new techniques revolutionise the age old idea that rice is an aquatic crop. This idea stems from the fact that rice can develop well in water and this property gives rice the great advantage for weed control. However, recent developments tend to demonstrate that rice can be grown also in dry soils just like other classic cereals (see Figure 5). These less water consuming techniques are much more sensitive to water stress and they strongly depend on a reliable water supply during the wet season to compensate for dry spells and the dry season. This can only be achieved through highly performant irrigated infrastructure.

If these techniques confirm their potential in improving water productivity, more grain per drop, then rice will become much more water efficient even if in some instances to the detriment of other uses of water in the command area. Therefore, the choice between increasing crop water efficiency and maintaining water productivity of various uses must be properly taken into consideration.

Figure 5. A field of rainfed rice with mulch in Tanzania (improved hybrid TXD 306 "Saro") which has not received water for the last 30 days. Under normal rainfall conditions yields of 5 tons/ha are obtained under this system, which equals those obtained under irrigated paddy.

Environmental protection and improvement.

There are a growing number of environmental concerns that challenge sustainable rice production. Indiscriminate use of pesticides and inefficient use of fertilizers, clearing of flooded forests and destructive fishing gear need to be confronted together with the problem of emissions of carbon dioxide, methane, nitrous oxide and ammonia. Environmental protection is not only of increased public concern but efforts to increase protection must comply with a growing number of international agreements such as those negotiated at the WTO, within the Framework Convention on Climate Change and in the Convention on Biological Diversity. Rice development will only be sustainable if it is approached as an ecosystem that provides the habitat with a variety of organisms such as fish and insects used by the indigenous people. Yet, these important rice-based resources are generally undervalued by governments and the international community despite the fact that consideration of *all* rice-based resources presents an important future opportunity to alleviate rural malnutrition and poverty. Adequate approaches have to be taken to protect the environment and the people who are directly depending on it.

Paths for water management improvements in rice-based systems

The discovery and recognition of the diversified values of rice ecosystems is not at all a good reason for complacency. There is room for improving water management in technical terms as well as in economic terms. In fact, this is the very important chance for most rice-based systems to seize the opportunity to find various ways of valuing water and to come up with acceptable solutions for bearing the cost of operation and maintenance of water management.

As we mentioned previously, the systems of rice cultivation are very much diversified and thus would not required the same path of modernization.

In simple terms a modern water management service is one adapted to the user's demand and to their willingness to pay. More fundamentally, the thinking process behind modern water management consists of defining the management objectives as the basis for defining operation requirements for design of both infrastructure and management systems.

Therefore, the first approach is to acknowledge or identify the various functions or services that the rice system already provides or is expected to provide. Second, the capacity of stakeholders should be improved by: valuing and planning techniques in defining the management objectives related to the various roles and values of water, setting water management strategies, operating rules, as well as management arrangements (including contributions by various stakeholders) and design features.

In a sense, the recognition of these different values of water in the rice systems is the major requirement for moving towards integrated water resources management.

In large holding, modern systems such as in those found in the developed countries the general path for modernization is focused on efficiency in providing water to the crops only, i.e. minimizing other uses of water and focussing on yield increases alone. In that way only crop/farmers will bear the responsibility and cost of maintaining and operating the water management infrastructure. Through this part of the productivity gains and yield increases bear the cost of management. However, the modernization of the systems is also often motivated by the preservation of environmental value in application of stricter ecological standards. For example, in irrigation districts in California modernization of operation is motivated by the need to keep water ponded in the fields to allow for a sufficient time for the degradation of chemical pesticides. At the same time, the value of storage ponds and drainage discharges for wildlife habitat has been recognized and therefore these systems are requested to maintain them.

In large, modern systems in developing countries there are also opportunities for enhancing the multiple roles of water in rice systems by engineering them into the system design and operation. For instance, the typical design of irrigation schemes can be improved by the introduction of intermediate storage (generally ignored in design standards) in the form of ponds at one or various levels in the system. This, as illustrated by the "melon on the grape-vine" concept in China, provides opportunities not only to significantly improve the reliability and flexibility of the systems but also to decentralize their management for fisheries, habitat, etc. Another example is the introduction of constructed wetlands at the drainage outlets to both improve water quality and provide habitat.

In traditional, small holding rice systems representing many other uses of water within the command area, the modernization path should consider all uses and all users of water and promote a much more efficient service of water with its cost shared among different categories of users (Renault and Montginoul, 2002). This is an important chance for the traditional systems which most of the time cannot be economically sustainable when relying only on farmers to pay for their operating costs. Here again, the improvements considering diversified uses go along with improving productivity for each use (e.g. increased rice and fish yields). This is where a good compromise must be found in order not to undermine the gains recorded for one use by adverse side effects on other sides (i.e. pesticides leaching impacting fisheries).

There is also an opportunity for engineering into these systems measures that enhance the multiple roles or mitigate the impact of intensification of rice systems. For instance, it is possible to introduce into the system ponds as dry season refuges for fish. From the institutional point of view, the water user's associations or similar arrangements created by participatory irrigation management reforms should include all stakeholders that compromise not only farmers especially when users are a different group. Such arrangements should by specified in the statutes delimitating various roles of the system. In Japan, for example, many land development districts (the equivalent of WUAs) are evolving towards service providers for integrated water resources management.

For traditional systems it can also be noted that evolution towards conjunctive use of shallow groundwater during the dry season appears to preserve the desirable features of the traditional systems while allowing for intensification and diversification of crops.

Conclusions

Rice-based systems prove that performance is about productivity and efficiency and that usage of only one criterion is not sufficient to capture the wealth of some complex agro-ecosystems. The diversified value of water in rice-based systems is the critical asset for many systems in order to improve performance and promote economically sound management in addition to accounting for their negative externalities.

Rice cultivation and water must be tackled within the system approach leading to diverse options for modernization of the management and for a proper integration of the rice systems into integrated land and water resources management.

Finally, it is very important to revise our concepts of rice systems management not only for existing command areas but also for the development of new systems in other contexts such as in Africa. Only through the use of such system approach we can value the full potential of the agro-climatic context and prevent disappointments resulting from technical as well as economic project failures.

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