Moving methodologies to enhance agricultural productivity of rice-based lowland systems in sub-Saharan Africa

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Abstract

The irrigated and rainfed lowland production systems in sub-Saharan Africa offer great potential to improve food security in the region. Rice yields in these systems are presently only at about 40 to 60% of the climate-determined yield potential across agro-ecological zones. To increase agricultural productivity a holistic approach to technology development is needed. This process is called integrated rice management (IRM), which is based on agro-ecological principles and on holistic thinking with wide ranges of technological options that encompass the entire rice cropping cycle. In both irrigated and rainfed lowland systems key factors for raising productivity are soil fertility and weed management. Improved soil fertility and weed management in irrigated systems in Senegal are highly profitable; yields can be raised by 2 t ha^{-1}, closing the yield gap between actual and potential yield by 30%. In inland valley lowlands improving soil fertility and weed management also results in substantial yield increases, depending on water control. We compare approaches used to technology development in Sahelian irrigated systems and in inland valley systems in Côte d'Ivoire. We illustrate that the need for early farmer participation in technology development increases when moving from the relatively uniform high-precision Sahelian irrigated farming systems to the more diverse, low-precision inland valley lowland systems further south. Technologies need to be more flexible and less fine-tuned in the inland valley systems as compared to the Sahelian irrigated systems. More emphasis also needs to be placed on farmer innovations and adaptation according to the prevailing agro-ecological and socio-economic conditions rather than on technology prescriptions, and on farmer-experimentation. Scaling-out of results in the Sahelian irrigated systems was done through change agents of NGOs and national extension authorities and publicity campaigns. Scaling-out of results in the inland valleys relied on the establishment of rural knowledge centers and farmer-to-farmer training. R&D institutions have a much more facilitating role rather than a directing role, when comparing the irrigated Sahelian systems with the inland valley lowlands. In both systems, simple decision support tools, such as a cropping calendar can be extremely valuable to farmers. WARDA and IFDC have developed a participatory learning and action research (PLAR) curriculum for IRM in rice-based inland valley systems. Ultimately IRM needs to move to other aspects of integrated natural resources management (INRM) within a watershed or water basin that are relevant to stakeholders. However, the peoples-orientation, typical for PLAR, will be the leading principle, be it IRM or INRM.

Introduction

Rice (*Oryza sativa* L.) is developing as one of the major staple food crops in sub-Saharan Africa. Rice production increased by about 2.4% year^{-1} in the period 1990–2000, mainly due to an increase in cultivated area. Rice production in sub-Saharan Africa increased from 9.1 Mt in 1990 to 10.7 Mt in 2000,

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with West Africa alone producing 6.9 Mt of rice in 2000 (Nguyen and Van Tran, 2002). Production was not sufficient to meet regional demand. Annual rice imports increased from 2.6 Mt in 1990 to 4 Mt in 2000, mainly to West Africa. Changing consumer preferences and higher consumption levels in urban centers are the main drivers behind this development (Defoer et al., 2003).

Only about 23 to 25 million tons, out of 600 million tons of milled rice produced world-wide, are traded on the world market, mainly from six countries: Thailand, Vietnam, US, India, Pakistan and China. Rapid urbanization and industrialization in Asia means increasing pressure on land and water resources, potentially leading to higher rice prices on the world market. The continued reliance of African consumers on rice imports is, therefore, a potentially precarious situation. Moreover, the cost of importing rice is a heavy burden on trade balances of African countries, with 1 billion US$ spent on rice imports each year. Rice stocks are declining in Asian countries, and it is likely that China will be obliged to import rice in 2004, while it still exported 3 million tons of rice in 2003[1]. Despite trade liberalization and devaluation of the Franc CFA in West African countries, rice remains competitive for most African countries, especially in land locked countries, such as Mali. There is a pressing need to develop production capacity for rice in the region and to improve the quality of domestically produced rice to meet consumer needs and to improve the competitiveness vis-à-vis imported rice.

The three main rice ecologies in West and Central Africa (WCA), found across agro-ecological zones, are the rainfed uplands, the rainfed lowlands, and the irrigated systems. The upland rainfed rice-based systems cover the largest area with 44%, mainly in coastal areas in the humid and sub-humid agro-ecological zone. The rainfed lowland systems are the second most important in terms of surface area with 31% of the total rice cultivated area. The third most important are the irrigated rice-based systems with 12% of the total rice cultivated area. Rainfed lowland systems provide 36% of the production, the irrigated systems account for 28%, followed by rainfed upland with 25% of the production.

Defoer et al. (2003) presented major biophysical and socio-economic constraints, opportunities and challenges related to rice production in the three main ecologies. They point to the important potential for increased rice production in both the irrigated and rainfed lowland systems, and especially in the inland valley lowlands. Inland valleys are defined as flat-floored, relatively shallow valleys that are widespread in the African undulating landscape. They are known as dambos in eastern and central Africa, as fadamas in northern Nigeria and Chad, bas-fonds or marigots in francophone African countries and as inland valley swamps in Sierra Leone (Andriesse, 1986). Inland valleys are characterized by their upstream position relative to a hydrological network. In WCA alone, an estimated 20 to 40 million hectares of inland-valley swamps are found, of which only 10 to 25% is currently used (Windmeijer and Andriesse, 1994). Soils in the valley bottoms can be relatively fertile and may retain residual moisture well after an initial flooded rice crop, permitting two crops per year, or aqua-culture when base flow lasts enough. The hydro-morphic fringes and upland slopes and crests offer potentials for other food and cash crops, and for trees and livestock. Inland valleys constitute an important agricultural and hydrological asset at local and national level, and may provide an opportunity for sustainable agricultural development and thereby contribute to food security and poverty alleviation in sub-Saharan Africa.

In this paper we will present our experience with technology development for enhanced rice productivity in Sahelian irrigated systems and in inland valley lowlands. The transition between irrigated and rainfed lowland ecosystems is often quite fuzzy. A water-management continuum, ranging from strictly rainfed to fully irrigated lowland can be distinguished, which may evolve depending on investments in water control measures (Defoer et al., 2003).

We start this paper with a short description of the irrigated to rainfed lowland continuum in WCA. We then describe approaches used to participatory technology development by WARDA researchers and partners working on improving rice productivity and natural resources during the mid- to late 1990s in irrigated systems in the Sahel. Next, our experience with technology development and diffusion in inland valley systems is described. At first, this approach was building on the experience from the irrigated systems, but after one year of experimentation it was realized that a different approach was needed to respond to the diversity and dynamics of farmer reality in the inland valley systems. We developed a framework for participatory learning and innovation in inland valley systems with 60 farmers working in two neighboring sites in Côte d'Ivoire, one

[1]Source: Jean-Pierre Boris, www.rfi.fr: 'La Chine affole le marché du riz'; 24 mars 2004.

with good and one with poor water control. The differences between the approaches used for technology development and diffusion in the irrigated and rainfed lowland systems are highlighted. Implications for actors, change agents and training institutions involved in agricultural research and development are discussed.

Irrigated to rainfed lowland continuum

Irrigated farming systems can be found throughout WCA, from the desert margins in Mauritania and Niger to the humid forest zone of Sierra Leone and Nigeria. Production systems vary widely between countries and agro-ecological zones. In the Sahel and Sudan savanna agro-ecological zones, water is either pumped from tube wells and major rivers or gravity-fed from rivers and dams. If rice is grown, the crop is either wet-seeded or transplanted and mainly grown during the wet season (July-November), with about 10 to 20% of farmers growing a second crop of rice on the same field during the dry season (February – May). Land preparation is usually done by animal power or tractor-driven. The first irrigated lands in the Sahel, situated in the Office du Niger in Mali (50,000ha) were established by the French colonial administration in the 1920s and thereafter. In the 1970s and 1980s, the World Bank and other donors funded new irrigation schemes, partly as a response to the severe droughts in the 1970s and rising concerns for food security. Such schemes were originally run by parastatal organizations, but with the reduced role of government, are now being turned over for management by farmer cooperatives. In addition to these large schemes, village irrigation schemes (< 20 ha) have been developed in the 1980s, while private initiatives (5–50ha) are common in for example the Senegal River Basin since 1990. New irrigation schemes are still being added, e.g. in Senegal, Mali and Burkina Faso.

Moving south into the Savanna and Humid Forest zones, schemes become smaller (5–200ha) and are mostly associated with inland valley systems. Irrigation schemes with good water control are generally found along major roads and near urban centers. Further away, simple bunding may be the only measure introduced by farmers to retain water on the fields. Water may be supplied from reservoirs and from streams where these have been diverted, while the original water course is used for drainage. Land is usually cultivated manually. If rice is grown, transplanting is the commonest form of crop establishment.

Participatory technology development for Sahelian irrigated systems

The approach taken for technology development in Sahelian irrigated systems is depicted in Figure 1. In the mid- to late 1990s, rice scientists from WARDA, Burkina Faso, Mali, Mauritania and Senegal established country-specific research and development (R&D) task forces to conduct combined agronomic and socio-economic yield gap surveys in key irrigated rice systems in the Sahel to determine reasons behind farmers' decision making and their major constraints and opportunities. These surveys were conducted in collaboration with farmer organizations, extension agencies,

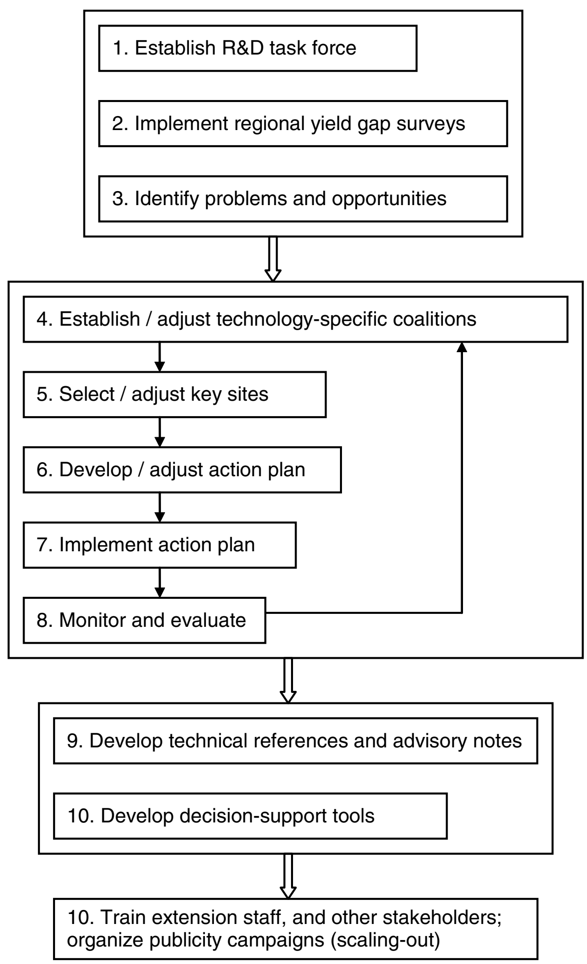

Figure 1. Framework for participatory technology development used in Sahelian irrigated systems

national agricultural research systems (NARS) and non-governmental organizations (NGOs). Technology-specific coalitions addressing the constraints and opportunities identified in the surveys were established, led by the agricultural research institutes. These coalitions resulted into a research action plan that was implemented at representative key sites with volunteer farmers. Results were then scaled-out through training of national extension and NGO staff or other stakeholders using promotion campaigns. The approach is illustrated below with results obtained mainly in irrigated rice systems along the Senegal River in Senegal.

Yield gap surveys

Wopereis et al. (1999) and Donovan et al. (1999) reported in detail on the yield gap surveys conducted in Senegal, Mali, Mauritania and Burkina Faso. Average farmers' yields varied between 3.8 and 7.2 t ha^{-1}, resulting in an overall average of 4.5 t ha^{-1}. Yields of individual farmers were highly variable, ranging from almost complete crop failure (0.3 t ha^{-1}) to very high yields (8.7 t ha^{-1}). High average yields and low yield variability were found in relatively old irrigation schemes, e.g. in the Office du Niger in Mali. Maximum yields reached by farmers were only at 40 to 60% of ten-year-averages of simulated potential yield (limited by climate only). The yield gap between average farmers' yields and highest farmers' yield was between 0.7 and 4.1 t ha^{-1}, with an average of 2.6 t ha^{-1}, indicating considerable scope to improve yields.

Only a few farmers in Mali and Burkina Faso applied organic fertilizer (compost, manure). Without exception, farmers applied N fertilizer, and most farmers also applied P fertilizer. K fertilizer use was mainly restricted to sites where NPK compound fertilizer use is recommended. N was always the most limiting nutrient for rice growth. Average N fertilizer recovery was relatively low and ranged from 18 to 50%, i.e. fertilizer N losses ranged from 50 to 82%. Farmers could, therefore, improve efficiency and profit by improving the recovery rate of N without major increases in investment in fertilizers. Reasons for the low N recovery rates were summarized by Wopereis et al. (1999) as follows: on all sites, timing of N fertilizer application by farmers was extremely variable and often did not coincide with critical growth stages of the rice plant. Farmers did not take into account the soils' nutrient supplying capacity and on a number of sites compound NPK fertilizers were used, which were not specifically designed for rice. Other agronomic constraints included: use of relatively old (> 40 days) seedlings at transplanting (Kou Valley, Office du Niger), P and K deficiency (Office du Niger), unreliable irrigation water supply (Kou valley, dry season), delayed start of the wet growing season resulting in yield losses of up to 20% due to cold-induced spikelet sterility (Kou Valley, Senegal River Middle Valley, Office du Niger), weed problems (Senegal River Delta) and late harvesting (Senegal River Delta).

Haefele et al. (2000 and 2001) reported the following main agronomic constraints for irrigated systems in the Senegal River valley: (*i*) mismatches between timing of N fertilizer application and critical N demanding growth stages of the rice plant; (*ii*) non-use of P fertilizer on P deficient soils; (*iii*) largely neglected or inefficient weed management and (*iv*) late harvesting.

Participatory technology development

Based on the yield gap surveys, scientists from WARDA and the national research institute in Senegal (ISRA) developed new soil fertility and weed management strategies with emphasis on improved timing of urea application, the use of three instead of two nitrogen splits, application of P fertilizer and early and correct application of herbicides. With the Senegal River irrigation and extension authority (SAED), pilot farmers were identified in villages strategically located along the Senegal River. Over a period of two years, pilot farmers evaluated the new soil fertility and weed management recommendations on 'test plots', where farmers managed their own fields as usual, with the exception of soil fertility and weed management, which was carried out jointly by the SAED extension agent and the farmer. Meanwhile, to address the harvest and post-harvest problems, a thresher-cleaner and a stripper-harvester were imported from the Philippines and a consortium of research and development partners and small machinery manufacturers was formed to develop Senegalese prototypes of both machines (Donovan et al., 1998 and Wopereis et al., 1998). SAED extension staff organized regular field days to ensure that a maximum number of farmers profited from these developments, and organized promotion campaigns.

Results

Improved nutrient management (application of 20 kg P ha^{-1} and 150 kg N ha^{-1} in three splits at start tillering, panicle initiation and booting) increased yields by about 1 t ha^{-1}. Improved weed management (application of 6.0 l propanil ha^{-1} and 2.0 l 2,4-D-amine ha^{-1} at 2–3 leaf stage of weeds) also raised yields by about 1 t ha^{-1} as compared to farmers' practice. The combined effect of improved nutrient and weed management was additive: improving both nutrient and weed management raised yields by almost 2 t ha^{-1} over average farmers' yields of 3.9 t ha^{-1}, i.e. an increase of almost 50%. Value/cost ratios were between 2.1 and 4.6 for improved soil fertility and weed management resulting in an increase in net revenues of 40 to 85% compared to farmers' practice. The results of the learning plots were amazingly consistent and were obtained for both small-scale farmers in Senegal (Haefele et al., 2000) and large-scale farmers in Mauritania (Haefele et al., 2001). The yield increases obtained are considerably larger than obtained for similar work on site-specific nutrient management in intensive rice cropping systems in Asia (Dobermann et al., 2002).

The Senegalese version of the thresher-cleaner was baptized ASI and was officially released by the minister of agriculture of Senegal in 1997. The three institutions behind the development of the ASI (WARDA, SAED and ISRA) obtained the *'Grand Prix du Président de la République du Sénégal pour les Sciences'*, out of the hands of President Wade in 2003 for the development and diffusion of the machine. Meanwhile, the project to develop a local version of the stripper-harvester was abandoned. During field tests farmers clearly indicated that they did not appreciate the fact that the machine left rice straw standing in the field.

Development of training materials and decision support tools

During farmer visits to test plots and field tests of the thresher-cleaner, various issues related to rice cropping were debated, including best age to transplant rice seedlings, control of pests and diseases, water management, access to fertilizers, credit, certified seed, etc. Gradually WARDA staff developed a powerful learning tool to facilitate these debates: a cropping calendar depicting timing of key management interventions (i.e. sowing, transplanting, weeding, fertilizer application, harvesting) as a function of rice development stage (Wopereis et al., 2003). The cropping calendars can be easily adjusted to any choice of sowing date x site x cultivar combination along the Senegal River using the RIDEV decision-support tool (Dingkuhn, 1995; Wopereis et al., 2003).

Another direct consequence of the debates in farmers' fields was the development of a manual with technical references on irrigated rice cropping in the Senegal River valley (WARDA and SAED, 2000), as a support for research and extension staff.

Integrated rice management (IRM)

The outcome of the yield gap surveys, the encouraging results on the test plots and the stimulating debates in farmers' fields stimulated WARDA scientists to develop a set of *integrated rice management* (IRM) options that encompass the entire rice growth cycle, from the initial planning phase to the harvest and post-harvest stages (Table 1). IRM is based on agro-ecological principles and holistic thinking; new practices are complementary and not necessary alternatives to conventional management.

Capacity building and scaling-out

The results of the test plots were reported in meetings with ISRA and SAED and on rural radio. The IRM options listed in Table 1 were summarized on A4 leaflets and distributed to thousands of farmers in the Senegal River valley through SAED. Extension agents of SAED and local NGOs were trained in rice cropping and IRM in particular.

Agricultural machinery manufacturers from Senegal, Mauritania, Mali, Mauritania and the Gambia were trained in developing local prototypes of the thresher-cleaner to ensure scaling-out of the technology in the region. There are now hundreds of thresher-cleaners in West Africa, mainly in Senegal, Mauritania, Mali; all slightly different, depending on local settings, such as the need for animal traction.

An independent study by Kebbeh and Miézan (2003) confirmed the potential of IRM to raise rice productivity. They observed that technologies that are of greatest direct interest to farmers and that are within their reach are adopted first, such as improved soil fertility and weed management. Yield increases

Table 1. ICM options for the Senegal River Valley

1. Land preparation: cultivate on soil suitable for irrigated rice (i.e. heavy clay soils, local soil series terminology: Holladé and Faux-Holladé soils), make sure the field is properly tilled and leveled.
2. Varietal choice: use pre-germinated certified seeds; for the dry season (DS): Sahel108 (good grain quality, but salinity sensitive) or I Kong Pao (low grain quality, salinity tolerant); and for the wet season (WS): Sahel108, Jaya, Sahel201, Sahel202.
3. Sowing date: guided by RIDEV to avoid spikelet sterility due to cold or heat
4. Seeding rates: use certified seed and 100 and 40 kg/ha respectively for direct seeding and transplanting.
5. Maximum recommended fertilizer rates: 100 kg/ha Triple Super Phosphate (TSP, 20% P) or Diammonium Phosphate (DAP, 20% P, 18% N) and 250 to 300 kg/ha Urea (46% N), depending on location along the Senegal River. TSP is applied as a base fertilizer, while urea is applied in three splits. The first dose of 40% is applied at the start of tillering, and another dose of 40% at panicle initiation. A final dose of 20% is applied at the booting stage of the crop. Timing is guided by RIDEV.
6. Weed management: a mixture of 6 l/ha of Propanil and 1.5 l/ha of 2,4D applied a few days before first urea application (at 2-3 leaf stage of the weeds), complemented with one manual weeding before the second urea application.
7. Water management: directed at maximizing the efficiency of fertilizers and herbicides, consists of applying herbicides in completely drained fields and reducing water levels in the field to 3 cm for about 4-5 days at each fertilizer application. The rice field is completely drained 15 days after flowering to promote uniform ripening of the grains, but primarily to allow for a timely harvest (Dingkuhn and Le Gal, 1996).
8. Harvest and post-harvest: Harvesting at maturity, i.e. if about 80% of the panicles are yellow. Threshing within 7 days after timely harvest, preferably with the ASI thresher/cleaner prototype developed for Sahelian conditions by WARDA (Wopereis et al., 1998; Donovan et al., 1998).

were positively correlated to the number of IRM options farmers were able to adopt. Clampett (2001) obtained very similar results in irrigated rice systems in Australia.

Inland valley lowlands: yield gains from improved soil fertility and weed management under varying degrees of water control

Building on the experience from the irrigated systems, it was anticipated that soil fertility and weed management would be key factors in improving productivity in inland valleys as well. This hypothesis was tested in two valleys in central Côte d'Ivoire in collaboration with 32 farmers during the 2000 wet season and the 2001 dry season.

Site description

We worked in two inland valleys of varying water control with farmers from the villages of Bamoro and Lokakpli in the Bandama valley in central Côte d'Ivoire. These two villages are about 3km apart and located close to the main road from Bouaké to Katiola (5.04°W, 7.83° N). The Bamoro and Lokakpli inland valley lowlands are very different in terms of social cohesion and crop and water management. Table 2 presents some of their major characteristics. Both sites are mainly managed by autochthon Baoulé, male-headed households.

In Bamoro, water is managed from the central stream, with some diverted canals, that inundate the fields and are also used to drain excess water. There is no infrastructure for irrigation and fields are partially bunded to retain water. Severe flooding at the start of the wet season due to poor drainage is the major problem related to water management. Farmers can only grow rice during the rainy season. The majority of farmers prepare the land manually, while the rest do not cultivate the land before transplanting but simply cut the grass and leave it to decompose. Farmers in Bamoro do not use any fertilizer and hand weed. Harvesting is done manually and half of the farmers thresh rice mechanically.

In Lokakpli, irrigation and drainage facilities were constructed with funding from the Government of Japan in 1998. Irrigation is dam-based and by gravity with two lateral irrigation canals and one central drainage canal. All individual fields are bunded and the risk of flooding is minimal. There are two rice growing seasons per year. Farmers use substantial amounts of mineral fertilizers (composite NPK as basal dressing and 1 or 2 top dressings of urea) and the majority of the farmers control weeds using herbicides. All rice is harvested manually and all farmers use mechanical rice threshers on a contract basis.

Table 2. Major characteristics of two inland valleys in Côte d'Ivoire

Characteristics	Bamoro site	Lokakpli site
Origin of farmers at the site (No. of villages)	1	3
Social cohesion	Strong	Weak
Age of household head	44 year	32 year
Dominant cropping systems		
(area in ha/percentage per farm household)		
- rice	0.34 ha / 39%	0.68 ha / 52%
- yams	0.51 ha / 57%	0.54 ha / 41%
- other	0.04 ha / 4%	0.06 ha / 7%
Water source	Flooding	Gravity irrigation
Irrigation infrastructure	None	Existing
Drainage	Poor	Good
Availability of bunds	Partial	Overall
Risk of flooding	High	Moderate
Rice crops/year	1	2
Land preparation	Manual (64%);	Cultivator (100%)
	None (36%)	
Weeds control	Manual	Herbicides
Fertilizer use	None	NPK and urea
Threshing	Manual (47%)	Mechanical (100%)
	Mechanical (53%)	

Source: Defoer et al. (2004b)

Experimental design

The study was conducted in the 2000 wet season (2000 WS: irrigated and rainfed site) and in the 2001 dry season (2001 DS: irrigated site only). The profitability of different fertilizer and weed management treatments was compared to farmers' practice, using partial budgeting techniques, and the net benefit of all treatments was estimated. More details are provided by Idinoba et al. (2004). For Lokakpli, alternative fertilizer management included reversing the local fertilizer recommendation (200 kg NPK, containing 18% N, 20% P_2O_5 and 20% K_2O and 100 kg urea ha^{-1}) to 200 kg urea and 100 kg NPK ha^{-1} as it was anticipated that N was a much more limiting factor than P or K, given the results obtained in the irrigated systems. Alternative weed management consisted of an early herbicide application (propanil) at 20 days after transplanting (DAT). For Bamoro, alternative weed management consisted of an early hand weeding at 27 DAT, and alternative soil fertility management consisted of an application of 100 kg urea ha^{-1} in two equal splits, at mid-tillering and panicle initiation of the rice crop.

Results

Yields obtained during the 2000 wet season in Bamoro and Lokakpli were strikingly similar. Farmers' practice resulted in about 4 t ha^{-1}. This is evidence that the soil fertility in Bamoro is much greater than in Lokakpli as these yields were obtained with mineral fertilizer in Lokakpli and without mineral fertilizers in Bamoro.

Yields during the 2001 dry season in Lokakpli were 0.7 to 0.9 t ha^{-1} higher, because of more favourable weather conditions. Results of the trials are given in Table 3. At the rainfed site, alternative fertilizer management, consisting of an application of 100 kg urea ha^{-1}, resulted in a yield increase of 0.6 t ha^{-1} over farmers' practice (no mineral fertilizer). Improved weed management (early hand weeding) increased grain yield only slightly, by 0.3 t ha^{-1}. At the irrigated site, alternative fertilizer management resulted in an average (2000 WS and 2000 DS) yield gain of 0.7 t ha^{-1}. Alternative weed management again only increased yield slightly, i.e. by an average 0.2 t ha^{-1}. The effect of combining the alternative soil fertility and weed management practices was more than additive, i.e. yield

Table 3. Rice grain yields in response to alternative soil fertility and weed management in irrigated and rainfed lowland inland valley systems in Central Côte d'Ivoire. FP: farmers' practice; T1: alternative soil fertility management; T2: alternative weed management; T3: alternative soil fertility and weed management.

	Irrigated lowland				**Rainfed lowland**	
Treatment	**Yield (t ha^{-1})**		**Average (t ha^{-1})**	**S.E. (t ha^{-1})**	**Yield (t ha^{-1})**	**S.E. (t ha^{-1})**
	2000	2001			2000	
FP	3.9	4.6	4.3	0.37	4.1	0.1
T1	4.7	5.3	5.0	0.32	4.7	0.15
T2	4.0	4.9	4.5	0.49	4.4	0.05
T3	5.2	6.1	5.7	0.44	5.1	0.3
Means	4.4	5.2			4.6	
S.E.	0.31	0.31			0.21	

gains of 1.0 t ha^{-1} at the rainfed site, and an average of 1.4 t ha^{-1} for the irrigated site. The value/cost ratios was 5.2 for the rainfed site and could not be calculated for the irrigated site as additional costs were negative as urea is cheaper than NPK fertilizer. Net revenues increased by an average of 25% (rainfed site) and 49% (irrigated site) as compared to farmers' practice. Results, therefore, confirmed the importance of soil fertility and weed management in both the irrigated and rainfed inland valley lowlands.

Moving methodologies to address diversity and dynamics in inland valleys

Although farmers in Bamoro were involved in the design of the experiments, they gradually started to question the use of 100 kg urea ha^{-1}, which they thought was excessive. They also pointed at the risk of fertilizer use, in case of floods as they have no control over water. During the cropping season, many other issues were discussed. We felt sometimes overwhelmed by the large and short-range variability in growing conditions among farmers, especially in Bamoro. Fields located side-by-side could differ in terms of soil type, water control (some experiencing flooding, others drought), problems with iron toxicity (mainly visible on fields near the hydromorphic fringe), and incidence of pests and diseases. There were also tremendous differences in sowing date, age of seedlings used for transplanting and weed control. Varietal choice was remarkably similar, with most farmers growing variety Bouaké189.

Reece et al. (2004) distinguish between low precision farming systems where farmers exercise relatively little control and high precision systems where farmers exercise more control over their resources. Inland valley lowlands without any infrastructure to retain water or drain excess water such as in Bamaro do not allow precise farming, for example in terms of time of rice transplanting, and rice growth and development can be severely disrupted by drought or devastating floods. With increasing control over water and other resources more precise farming becomes possible.

We hypothesized that we could address the diversity and dynamics of farmers' reality in inland valley lowlands by (*i*) the analysis of common practices and knowledge, (*ii*) the introduction of new insights and options for improvement, (*iii*) the use of decision-support tools to assist farmers in making good observations, followed by analysis that motivate them to try out new ideas; and (*iv*) farmer-led innovation and adaptation of improvements. This approach would then gradually lead to a basket of decision-support tools and adapted IRM options for inland valley lowlands. We realized, however, that the degree of water control was a crucial factor for farmers, and we expected that IRM options likely to be innovated and adapted by farmers would greatly differ between Bamoro and Lokakpli. Another important factor, making some options more attractive than others, is access to factor and output markets. However, the two inland valleys did not differ in that respect, as they were both located within 3km distance along the Bouaké – Katiola road.

Our observations in Bamoro prompted us to adopt a much more innovative approach to social learning, called participatory learning and action research (PLAR). PLAR is a farmer education approach, based on adult learning in groups of 20 to 25 farmers, making use of the experiences of the group members (Defoer and Budelman, 2000; Defoer et al., 2004a). PLAR for IRM is captured in a *curriculum* that covers the whole cropping season, following the development stages of the rice crop and the agricultural practices. Farmers analyze their own practices, discover problems and seek the solutions to solve them. Instead of diffusing or transferring the technologies coming from research/extension services, the facilitators incite farmers to find solutions themselves and help them to become better rice crop managers. PLAR seeks to find solutions that are practical, applicable, and adapted to local-specific situations.

In the PLAR approach, farmers are not considered as potential “recipients” or “adopters” of new technologies; the idea is to create a process which will stimulate the farmers into discovering and innovating themselves. The underlying assumption is that in a given context, the learning, discovering, innovating, adaptation-selection process prompts change and sustainable improvement of the production system. This learning process is facilitated by a team of facilitators, the PLAR-IRM team, often coming from extension services, research or NGOs.

A framework for participatory learning and action-research in inland valleys

Our experience in Bamoro and Lokapli led us to believe that much more emphasis should be put on farmer-led innovation. We also realized that to scale-up and –out our approaches and results we would need to involve local research and extension agencies to a much greater extent. There was also a need for training materials and relevant decision-tools to allow farmers and change agents to make better observations and analyses of problems and opportunities and improve decision-making. We developed a framework (Figure 2) for participatory learning and action research early 2001 and implemented the framework during the wet season of 2001 in both Bamoro and Lokapli. Key concerns were:

1. Involvement of farmers and change agents
2. Farmer innovation
3. Development of training materials to facilitate training of farmer trainers and facilitators to scale-out
4. Development of decision support tools to allow better observations, better analysis and improved decision-making
5. Build institutional capacity to scale-up the approach used within the facilitating research and extension institutions

Application of the PLAR-IRM framework

Establishing PLAR-IRM capacity and selection of key sites

In May 2002 we contacted the national extension agency in Côte d’Ivoire (ANADER) and discussed the PLAR framework with them. We agreed to establish a team of facilitators, consisting of ANADER and WARDA staff that would work at the Bamoro and Lokakpli keysites during one entire growing season. We then discussed the PLAR idea with farmers from Bamoro and Lokakpli. About 30 farmers volunteered to participate in each valley. In a first encounter with the farmers a list was made of problems and opportunities related to rice cropping in the two valleys. A first draft of an agenda was made with issues to be debated during the growing season. This agenda was adjusted as the growing season progressed. Farmers and the PLAR team agreed to meet every week for about 3 to 4 hours, i.e. one morning in Bamoro, under a large tree, near the valley bottom, and one morning in Lokakpli, in a small building near the irrigation scheme. These meeting places were referred to as PLAR-IRM centers. The PLAR team met weekly at the ANADER office in Bouaké to prepare the PLAR sessions and to evaluate progress.

Implementing PLAR-IRM

PLAR sessions usually started in the PLAR-IRM center, but almost always involved a visit to the field to make field observations. Field observations are crucial in the PLAR approach. Farmers are ‘learning’ together how to make good observations, followed by a sound analysis and decision-making. The types of observations that were made were first discussed during plenary sessions at the PLAR-IRM center.

Farmers were encouraged to put into practice any new idea they gained through the PLAR sessions on part of their fields (i.e. ‘IRM learning plots’). In Lokakpli, farmers tried out more than five new practices on average. In order of importance, farmers experimented with improved fertilizer management, weed control,

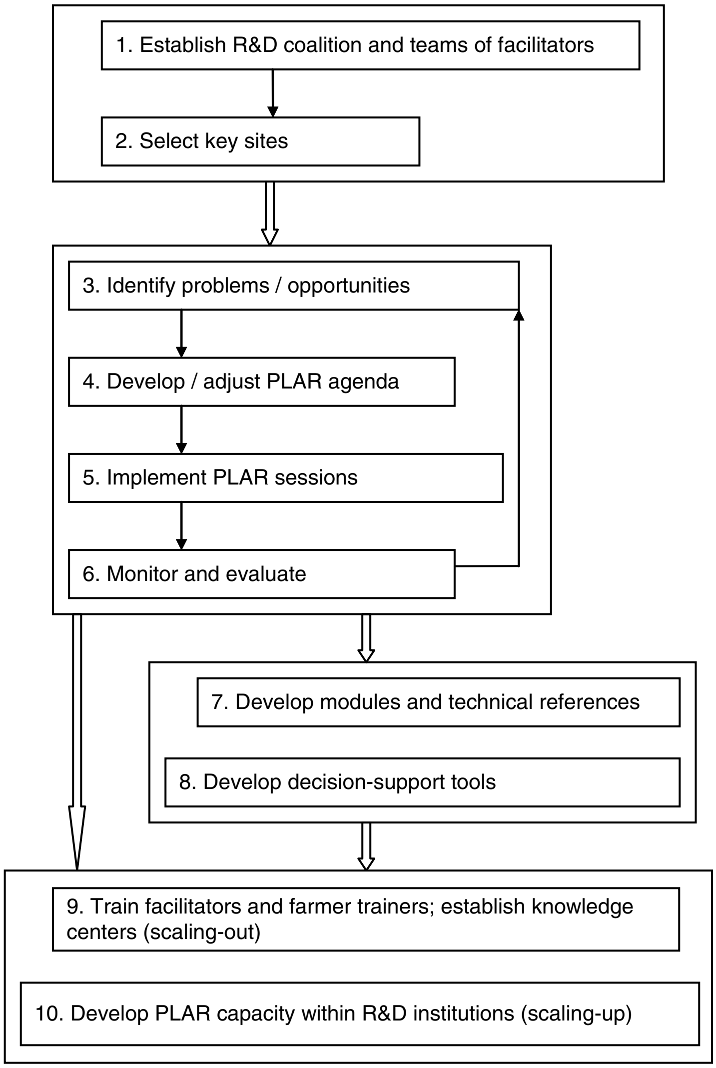

Figure 2. A framework for implementation of PLAR in inland valleys

water management, transplanting of seedlings, harvest management and bund maintenance. In Bamoro, the average number of new practices tried out by farmers was three. The order of importance of the new practices tested was different compared to Lokakpli. Most important was improved transplanting and weed control, followed by improved nursery management, water management and bund maintenance. Improved fertilizer management and harvest management received less of farmers' attention than in Lokapli. More details are found in Defoer et al. (2004b). IRM options increased rice yields by an average of 0.6 t ha^{-1} in both inland valleys. This was, therefore, slightly lower than what was obtained in the researcher-led controlled learning plots during the wet season in the previous year (see section 3).

Development of PLAR Modules

From May to November 2001, a PLAR curriculum composed of 28 learning modules was developed with farmers (Figure 3). Each learning module comprises an introduction, learning objectives, a procedure for implementation, time and materials required. The introduction presents the issue(s) treated in the module and the learning objectives generally relate to specific skills and capacities farmers are likely to acquire through

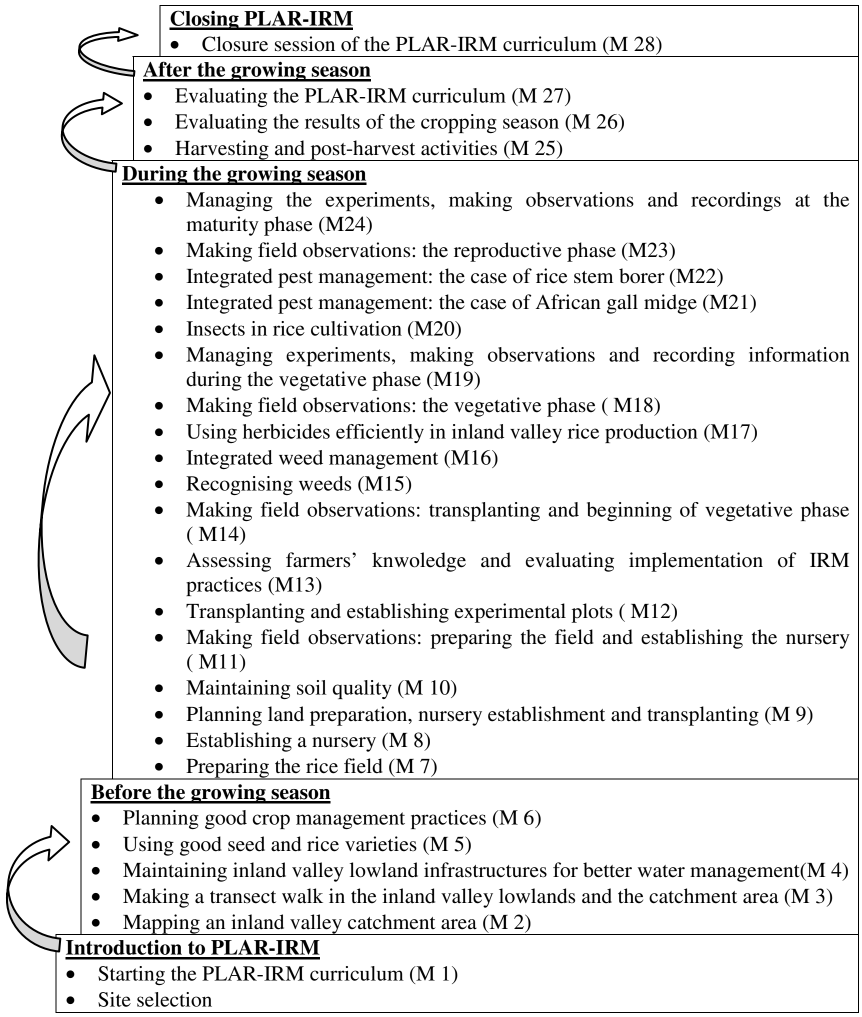

Figure 3. Modules of the PLAR curriculum

the implementation of the module. For most of the modules, the procedure for implementation includes: a short review of the previous module, presentation of the learning objectives, exchange of farmers' experiences, introduction of new ideas using learning tools, field observations in sub-groups, plenary session and evaluation of the module. The full set of learning modules is given by Defoer et al. (2004a).

Development of IRM technical references

During the same period, a list of technical references was developed, parallel with the development of the modules (Table 4). The references deal with agronomic issues related to rice cropping in inland valleys and provide technical backstopping to change agents in the PLAR teams. The full set of technical references is given by Wopereis et al. (2004).

Decision support tools

A very important aspect of the PLAR sessions was the use of simple decision-support tools and the emphasis on agro-ecological and socio-economic principles. The most important decision-support tool was the cropping calendar, which was also used with success in the Sahelian irrigated systems. The cropping calendar was 'constructed' by the farmers themselves using pre-conceived symbols for rice development stage and management interventions depicted on small cards

Table 4. Technical references for inland valley development

1.	Selecting PLAR-IRM sites
2.	Hydrological network, inland valley catchments and lowlands
3.	Different types of soil
4.	Iron toxicity
5.	Water control structures for inland valley lowlands
6.	The seasonal work plan
7.	Field water management
8.	Knowing the rice plant
9.	Seed production
10.	Selecting a variety
11.	Effects of temperature on rice development
12.	Field preparation before the start of the rice growing season
13.	The seedling nursery
14.	Plant nutrients
15.	Integrated soil fertility management
16.	Transplanting
17.	Farmers' experimentation
18.	Getting acquainted with weeds of rice
19.	Integrated weed management
20.	Safe and correct use of herbicides
21.	Insects in rice cropping
22.	African rice gall midge
23.	Rice stem borers
24.	Major diseases in rice
25.	Integrated rice disease management
26.	Harvest and post-harvest
27.	End-of-season evaluation

which were fixed on a white cloth, below a time-line subdivided into weeks. The cropping calendar allowed farmers to obtain a global picture of all the development stages of the rice plant, assisting them in planning agricultural practices. Discussions around the cropping calendar allowed farmers to identify options to improve time-management, such as timely transplanting, fertilizer application or weeding. The improved time-management options were then visualized by depicting the cards with corresponding symbols on a line above the lines representing farmers' current management practices. Farmers then discussed necessary conditions to implement the improved time-management options.

Farmers also produced a large (about 3 x 1 m) map of the inland valley itself, highlighting different soil types, the extent of the lowland, hydromorphic zone, and upland areas, and drainage and irrigation infrastructure (in the case of Lokakpli). This map proved useful, especially in Bamoro, where the PLAR sessions and the map motivated farmers to work together for a period of 3 days to build a central drainage canal to improve water control in their valley lowlands. Other decision support tools used where pictures of symptoms of diseases, life cycles of insect pests and nutrient deficiency symptoms.

A large amount of time was devoted to soils and soil fertility management. Farmers were keen to learn about simple decision-support tools to analyze soil texture and soil organic matter content. They realized the importance of these soil characteristics for the efficiency of mineral fertilizer use, especially after conducting percolation experiments with different soil types. Much time was devoted to improved understanding of the importance of the major nutrients to rice growth and development, and what nutrients are found in fertilizer bags and in what quantity. The use of 'nutrient-omission trials' was also discussed, where one nutrient is deliberately omitted, and others applied in sufficient quantities to evaluate to what extent the missing nutrient limits growth (e.g. Dobermann et al., 2002). The outcome of such trials may be used to develop site-specific soil fertility management options within the inland valley lowland area. This particular method is extremely powerful and very illustrative. Farmers debated access to organic and mineral fertilizers, their costs and potential benefits and financial returns from their (combined) use.

Particular attention was also paid to weed management. Farmers developed a herbarium of weeds occurring in the two valleys and ranked these in terms of competitiveness vis-à-vis the rice crop. Farmers were able to distinguish and name (using local nomenclature) more than 30 weed species in each valley and rank these in terms of competitiveness. Lokakpli farmers were using herbicides to control weeds, so in this village we paid attention to safe and correct use of herbicides, in terms of: (i) choice of product as related to weed flora in the field; (ii) timing of the treatment; (iii) water management; (iv) equipment inspection and maintenance; (v) calculation of dose to apply; (vi) application techniques and (vii) safety.

Calculating what dosage to apply is often a problem for rice-growers and for extension agents. We have tried to simplify calculations by using a measuring unit that is easy to find in most West African markets: the small tomato can, containing 50 to 60 ml of tomato paste. For a sprayer capacity of 15 liters per hectare and a normal application rate of 300 l ha^{-1} a farmer needs to use x small tomato cans filled with herbicide per sprayer to apply x liters of herbicide per hectare. For example, to control grasses, it is recommended to apply 5 litre ha^{-1} of a particular herbicide. This dosage corresponds to 5 small tomato cans of the herbicide per

15 liter sprayer. This particular simple and practical decision support tool was very much appreciated by farmers in Lokakpli. More details on these and many other decision-support tools can be found in Defoer et al. (2004a) and Wopereis et al. (2004).

Scaling-out: training of facilitators and farmer trainers

In 2002, 40 researchers, extension agents and NGOs from Benin, Burkina Faso, Côte d'Ivoire, Guinea, Mall, Togo and Senegal were trained at a workshop in the PLAR-IRM approach. Four farmers from Bamoro and Lokakpli also attended the workshop. In 2002 PLAR-IRM testing was extended to five additional sites in Côte d'Ivoire and new sites in Benin, Burkina Faso, Guinea, Mali and Togo.

Keysites need to gradually become veritable 'knowledge centers' on IRM. It is anticipated that some farmers in such IRM knowledge centers will train colleague farmers from neighboring valleys. In 2002, publicity tours were made to neighboring villages around Bamoro and Lokakpli to create awareness of the existence and competences of these two new rural knowledge centers. Four demands for training were received. Members of the PLAR-IRM team assisted four farmer trainers to prepare training sessions and provide on-the-job guidance during implementation. We compensated the farmer trainers using a system of 'learning-coupons' valued at CFA 2000 (about 3 euros) for one training session. After receiving training, a farmer group pays the farmer-trainer one learning-coupon who claims the value of the ticket from ANADER/WARDA. Such a system needs to be phased out gradually. This is, however, only one possibility of a reward system that requires further experimentation and adaptation. Experiences in 'knowledge centers' will provide valuable feedback to research. It will be important to determine the optimal density of 'knowledge centers' that an extension service can handle and that will allow for sufficient coverage of the inland-valley rice-based systems through farmer-to-farmer exchange and learning.

Scaling-up: building PLAR-IRM capacity

PLAR is often a relatively new approach for R&D change agents and for it to be accepted will need time and capacity building at all levels within the R&D organizations. R&D change agents play a facilitating role, whereas they are often used to a much more directing role.

Conclusions

The classic scenario for technology transfer in agricultural research has been for researchers to develop technology on research stations. They then hand over a final product to extension agents for delivery to end-users. This 'assembly line' approach has been able to generate improved technologies, such as modern, high-yielding rice varieties, but adoption rates have often been disappointing.

For the Sahelian irrigated systems, which are relatively uniform and enjoy relatively high crop management precision, identification of constraints and opportunities was conducted at a regional level through a R&D task force. Technology-specific coalitions were then established, one for improved weed and soil fertility management and one for the development of appropriate agricultural machinery. These coalitions developed an action plan and worked with farmers and manufacturers to evaluate and adapt technologies at key sites, often through test plots, and regular field visits. Gradually a basket of IRM options was developed. The cropping calendar decision support tool was frequently used in farmer meetings to introduce the concept of IRM. Given the relatively uniformity of these conditions, scaling-out was done through training of extension staff and promotional campaigns, and relatively 'fixed' technologies were released.

For the inland valley lowlands, a peoples-oriented approach (in contrast with the technology-oriented approach in irrigated systems) was needed given the diversity and dynamics of farmer reality and growing conditions encountered in the field. A coalition of R&D organizations established teams of facilitators that worked in two inland valleys differing in terms of water control and social cohesion. In this approach, identification of constraints and opportunities was done at the village level and an action plan was elaborated with the farmers. PLAR sessions stimulated farmer-led innovation. Much emphasis was placed on observation skills and sound analysis to improve decision-making. PLAR sessions discussed all aspects of rice cultivation from land preparation to harvest and post-harvest issues. The team of facilitators brought in outside expertise whenever needed.

The two villages involved in the PLAR work eventually became knowledge centers on IRM, with farmers training colleagues from neighboring villages. Scaling-out occurred in this approach through farmer-to-farmer training. Extension and research organizations played a facilitating rather than a directing role. This approach requires quite a shift in approaches currently used in R&D organizations in sub-Saharan Africa. We believe, however, that the need to use PLAR type (peoples oriented) approaches increases moving from high to low precision systems and from relatively uniform to more diverse production systems. Technology development can be more advanced in Sahelian irrigated systems before evaluation by farmers; farmers in inland valleys need flexible technologies that they can be adjust relatively easily to local settings.

Farmers in both low and high-precision systems can benefit tremendously from decision-support tools and improved knowledge of agro-ecological and socio-economic principles.

Our work resulted in a PLAR curriculum for IRM in inland valley lowlands. As inland valleys have large potential for diversification, the PLAR-IRM approach may be gradually extended to other crops and deal with diversification aspects of rice-based inland-valley systems. This direction is likely to be influenced by the precision of farming and 'logic for intensification', i.e. access to factor and output markets. Additional learning modules may be developed to extend the curriculum, including aspects of social organization and conflict management. Others may be irrelevant for certain settings or may need revision. We started with rice management given its importance in inland valleys, but IRM should be seen as an entry point to integrated natural resources management (INRM). Whatever the topic, PLAR with a strong peoples-orientation will be the leading principle. Already some modules in the curriculum pay attention to the interaction between the upland and lowland areas in an inland valley, and implications of changes in water management for downstream users.

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