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INTRODUCTION

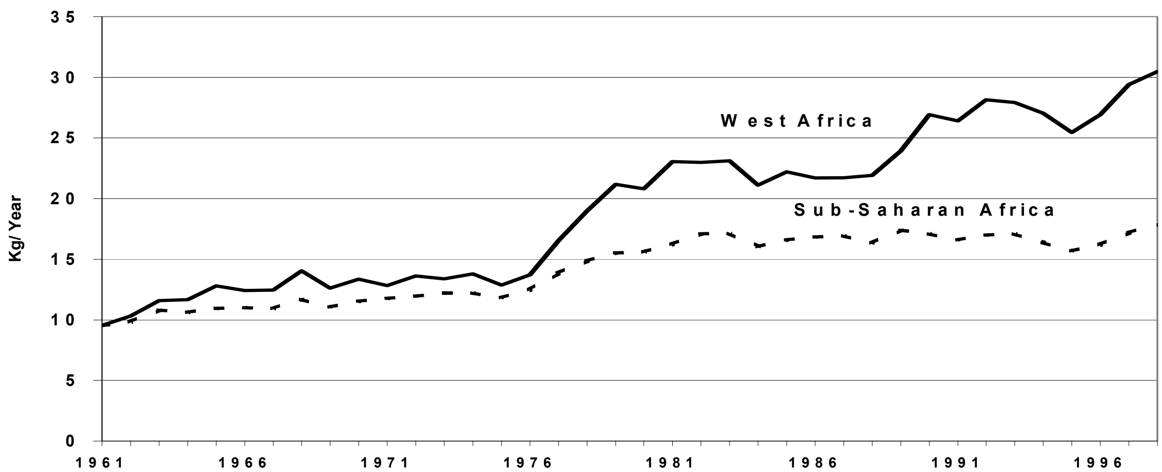
The lack of food security for a large proportion of the African population continues to exacerbate poverty and malnutrition. The high population growth, HIV effects on the productive labor force, degradation of environment, poor agricultural development support services and lack of enabling economic policy environment has aggravated the situation. Rice has great potential and can play a critical role in contributing to food and nutritional security, income generation, poverty alleviation and socio-economic growth of Africa. It is an important food crop in many African countries, and is increasingly preferred over many traditional foods, such as sorghum, millet, and most root and tuber crops. It is the staple food crop in Côte-d=Ivoire, The Gambia, Guinea, Guinea-Bissau, Liberia, Madagascar, Mauritania, Senegal, and Sierra Leone. In most countries, rice supply cannot keep up with demand. Consumption demand is growing rapidly and is now more than 6% per annum over the last two decades and amounts to over 10 million metric tons of milled rice per year (Figures 1 and 2). In West Africa alone FAO projected rice imports to rise to 4 million Mt/year by 2000, drawing approximately $1 billion from foreign exchange earnings. This increase is due to both population growth 2.6% year^{-1}), and the increasing share of rice in the diet of African populations (1.1% year^{-1}); i.e. 30 kg per capita per year in 1998, FAO, 1999), especially due to rapid urbanization (Snrech, 1994). Urban rice consumers facing a relative increase in the rice price, prefer to maintain their consumption level at the expense of other categories of goods rather than shifting to other cereals. This is most probably due to the ease of preparation and the difference in time perception between urban and rural families. The vast majority of rice in Africa is rainfed, and is grown by smallholder farmers, a disproportionate number of whom are women. Growth in demand is creating opportunities for small-scale producers

The production of rice in sub-Saharan Africa has steadily increased since the 1970s, reaching almost 7 million tons of milled rice by the end of the last decade. The increase in rice production is for about 70% due to expansion in area and 30% due to yield increase (Fagade, 2000 and Falusi, 1997). The gap between rice demand and regional supply is increasing and was about 4 million tons of milled rice for sub-Saharan Africa as a whole in 1998 (Figure 2). Nigeria was the major rice importer with almost 1 million tons in 1999/2000 (Mbabaali, 2000).

The social interest in developing regional rice production goes further than only import substitution. As mainly resource-poor farmers grow rice integrating a large range of other agricultural activities, rice research and development can be considered an entry point for the development of the agricultural sector as a whole. Thus rice research and development can be seen as a catalyst, reducing production risks, averting natural resource degradation, enhancing food security and income and contributing to poverty alleviation.

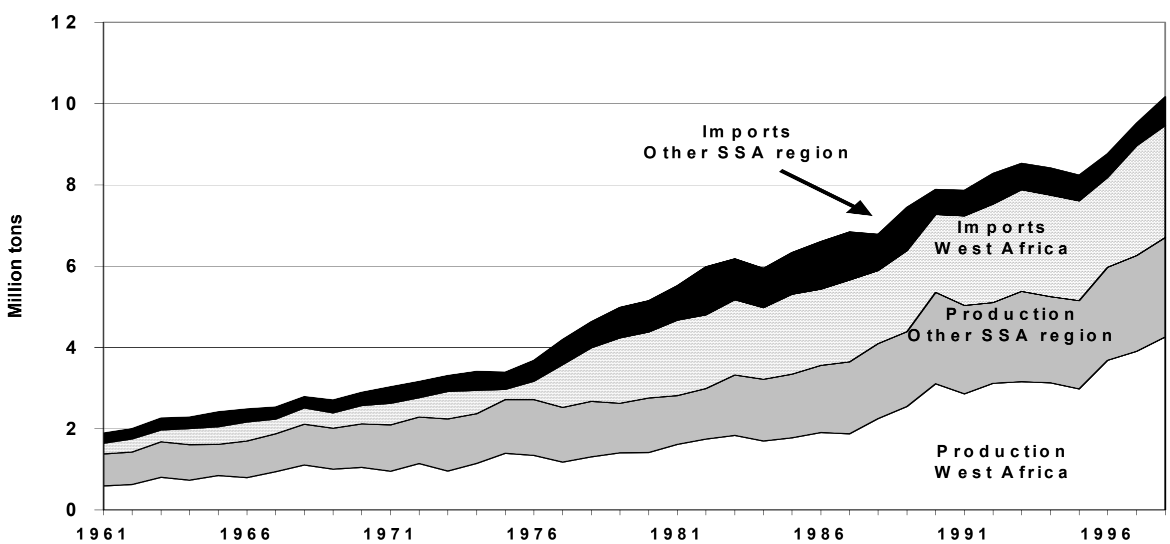
The objective of this paper is to provide an overview of the challenges and technical opportunities in developing rice-based systems for food security and poverty alleviation in sub-Saharan Africa. Data presented mainly relate to West and Central Africa.

Figure 1: Per-capita rice consumption in West and Sub-Saharan Africa



Source: FAO-Agrostat (1999)

Figure 2: Milled rice production and imports in West Africa as compared to the rest of Sub-Saharan Africa (SSA)



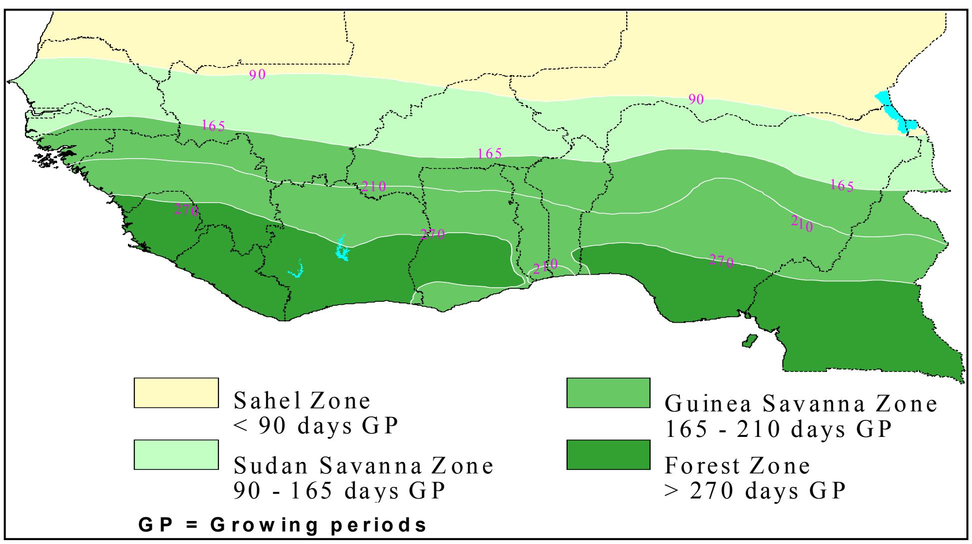
Source : FAO-Agrostat (1999)

RICE ECOLOGIES IN WEST AND CENTRAL AFRICA

The potential for rice development in West and Central Africa is largely determined by the agro-ecological conditions in which rice can be produced. Rice is characterized by its plasticity which allows it to grow in almost any biophysical environment in West and Central Africa. Thus rice is grown in a whole range of agro-ecological zones from the humid forest to the Sahel (Figure 3). The total rice area in West and Central Africa amounts to more than 4 million ha (FAO-agrostat, 1999). Within these regional agro-ecological zones five main rice-based systems can be distinguished with respect to water supply and topography in sub-Saharan Africa (Windmeijer et al, 1994):

- Rainfed upland rice on plateaus and slopes
- Lowland rainfed rice in valley bottoms and flood plains with varying degrees of water control
- Irrigated rice with relatively good water control in deltas and flood plains
- Deepwater, floating rice along river beds / banks
- Mangrove swamp rice in lagunes and deltas in coastal areas

Figure 3: Agro-ecological zones in West and Central Africa



The three main rice ecologies across West and central Africa are the rainfed uplands, the rainfed lowlands, and the irrigated systems (Table 1). These ecologies can be found across agro-ecological zones. A distinction is made between irrigated systems in the desert margins of the Sahel and those in the savanna or humid forest zones. 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. Deep-water and mangrove rice systems are relatively unimportant in terms of surface area.

Table 1: Share of rice ecologies in rice planted areas by country

Country	Total area '000 ha	Share of national rice area under : (%)					Year of reference
		Mangrove Swamp	Deep-water Floating	Irrigated	Rainfed Lowland	Rainfed Upland	
Mauritania	23	0%	0%	100%	0%	0%	95
Senegal	75	8%	0%	45%	47%	0%	91/93
Mali	252	0%	64%	21%	12%	3%	94
Burkina Faso	25	0%	0%	27%	65%	8%	93
Niger	28	0%	50%	50%	0%	0%	92
Chad	31	0%	92%	2%	6%	0%	98
Cameroon	15	0%	0%	98%	2%	0%	93
Gambia	19	14%	0%	7%	64%	16%	88
Guinea-Bissau	65	49%	0%	0%	22%	29%	94
Guinea	650	13%	10%	5%	25%	47%	91
Sierra Leone	356	3%	0%	0%	29%	69%	91/94
Liberia	135	0%	0%	0%	6%	94%	90/91
Cote d'Ivoire	575	0%	3%	6%	12%	79%	91/92/94
Ghana	81	0%	0%	15%	15%	70%	94
Togo	30	0%	0%	2%	18%	80%	94
Benin	9	0%	0%	4%	4%	91%	94
Nigeria	1642	1%	5%	16%	48%	30%	96
Total West Africa	4011	4%	9%	12%	31%	44%	

Source: FAO (1996) and WARDA taskforce estimate (1997)

Using average rice yields of 1 t ha^{-1} in upland, 2 t ha^{-1} in lowland, 3 t ha^{-1} in irrigated areas in the Savanna/humid zone, and 4.5 t ha^{-1} in irrigated areas in the Sahel production figures can be estimated (Table 2). Rainfed rice production systems are still pre-dominant, providing more than half of the total production. Rainfed lowland systems provide 36% of the production, followed by rainfed upland with 25% of the production. The irrigated systems account for 28% of the production, with 22% in the Sahelian zone. Irrigated systems in the Savannah and humid forest zone are rather minimal in terms of rice production.

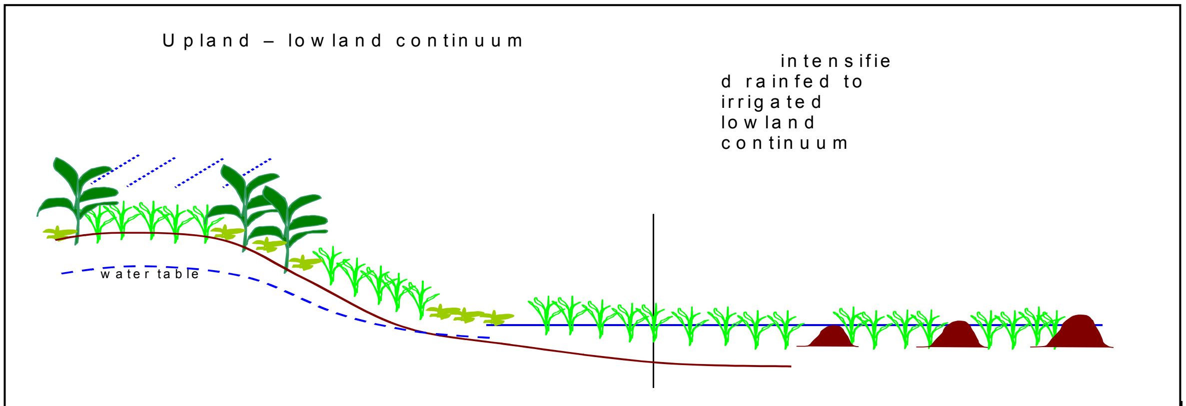
The major rice ecologies present various communalities such as weed and pest pressure and soil fertility decline. In addition, inter-linkages exist between ecologies, e.g. water or nutrient flow from upland to lowland, influencing the ecological sustainability of farmland. In response to this challenge, WARDA has developed the concept of the upland–lowland continuum along a toposequence, based on water-table depth (WARDA, 1989). Furthermore, inter-linkages can blur the borderline between ecologies, like the hydromorphic fringe between the upland and lowland along the continuum. Another fuzzy transition exists between rainfed and irrigated lowland. A water-management continuum, ranging from strict rainfed to fully irrigated lowland can be distinguished, which may evolve depending on investments in water control measures (Figure 4).

Table 2: Estimated share of rice production by ecologies and by country

Country	Mangrove Swamp	Deep-water Floating	Irrigated		Rainfed Lowland	Rainfed Upland
			Sahel zone	Savanna/ humid zone		
Mauritania	0%	0%	100%	0%	0%	0%
Senegal	5%	0%	65%	0%	30%	0%
Mali	0%	35%	50%	0%	13%	2%
Burkina Faso	0%	0%	47%	0%	50%	3%
Niger	0%	18%	82%	0%	0%	0%
Chad	0%	82%	8%	0%	10%	0%
Cameroon	0%	0%	99%	0%	1%	0%
Gambia	14%	0%	0%	11%	66%	8%
Guinea-Bissau	58%	0%	0%	0%	26%	17%
Guinea	17%	7%	0%	10%	34%	32%
Sierra Leone	4%	0%	0%	0%	44%	52%
Liberia	0%	0%	0%	0%	11%	89%
Cote d'Ivoire	0%	2%	0%	14%	19%	64%
Ghana	0%	0%	0%	31%	21%	48%
Togo	0%	0%	0%	4%	30%	66%
Benin	0%	0%	0%	12%	8%	81%
Nigeria	1%	3%	0%	27%	53%	17%
Total	4%	5%	22%	6%	36%	25%

Note : Average rice yields used for % calculation : upland : 1 t ha^{-1}, lowland : 2 t ha^{-1}, irrigated, Savannah/humid zone : 3 t ha^{-1}, irrigated, Sahel zone : 4.5 t ha^{-1}
Source: FAO (1996) and WARDA taskforce estimate (1997)

__Figure 4: The upland-lowland continuum__

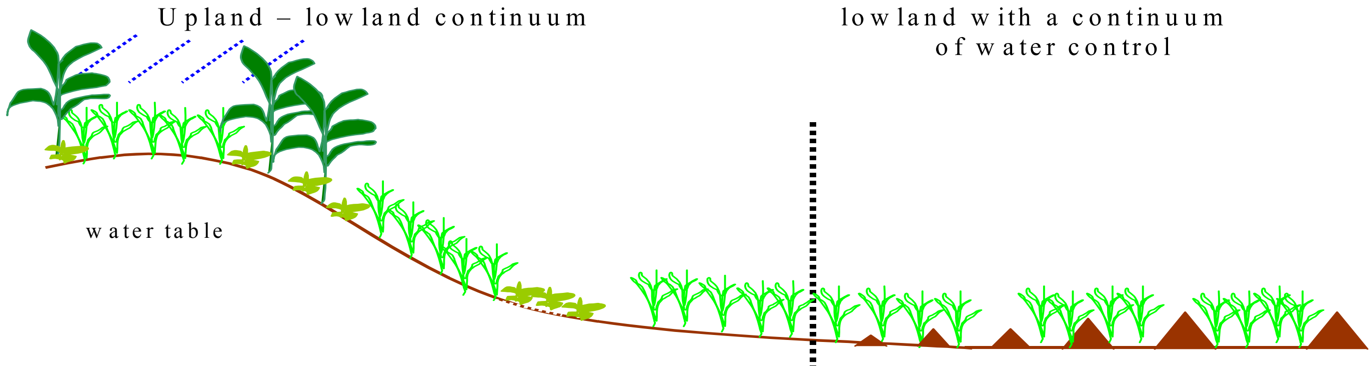


Upland	**Hydromorphic slopes**	**Lowland**	**Intensified lowland**	**Irrigated lowland**
<u>Main water supply:</u> Rainfall	Rainfall + water table	Rainfall + water table + flood water	Regulated flood water	Irrigation
<u>Agro-ecol. Zone:</u> Guinea savanna to humid forest zone	Guinea savanna to humid forest zone	Sudan savanna to humid forest zone	Sudan savanna to humid forest zone	Sahel to humid forest zone

CONSTRAINTS, OPPORTUNITIES AND CHALLENGES

Lançon and Erenstein (2002) calculated that with an annual per capita rice consumption growth of 1% and population growth of 2.5%, the total rice consumption in West Africa would reach 10 million tons in 2010 and 15 million tons in 2020.We distinguish three major options for increasing rice production: (i) area expansion, (ii) increase in cropping intensity (number of crops per year from the same area) and (iii) yield increase (produce per unit area). The opportunities for rice production development depend to a large extent on the biophysical and socio-economic environments. The challenges for area expansion, increase in cropping intensity and yield increase vary widely by ecology. The following sections highlight farmers' major biotic and a-biotic constraints at the plot level, and institutional/organizational constraints at farm, community and regional levels with a specific attention to the divergences between the major rice-ecologies. Combined with specific ecological opportunities, these constraints determinate the major challenges for rice research and development.

Figure 5: Major rice production constraints



Upland	Hydromorphic slopes	Lowland	intensified lowland	irrigated lowland
Main water supply: rainfall	rainfall + water table	rainfall + water table + flood water	regulated flood water	irrigation
AEZ: Guinea savanna to humid forest zone	Guinea savanna to humid forest zone	Sudan savanna to humid forest zone	Sudan savanna to humid forest zone	Sahel to humid forest zone
Main stresses: drought weeds blast low soil fertility soil erosion, soil acidity	drought weeds blast low soil fertility soil erosion, soil acidity, Fe toxicity	drought / flooding weeds gall midge Fe toxicity	drought / flooding weeds gall midge, rice yellow mottle virus Fe toxicity	weeds rice yellow mottle virus salinity, alcalinity, Fe toxicity

Upland ecology

Upland rice is to a large extent produced by subsistence-oriented farm households that represent only a part of the total cropped area and do not use external inputs, mainly due to high production risk and poverty. Rice yields in upland systems average about 1 t ha^{-1}. These figures hide however large differences between farms. Within a given region or village, differences in cropped area and yields between farms may vary ten-fold. These differences may be partly due to differences in the quality of the land, but are also a result of differences in management practices, such as time of sowing, weed control, etc.

Weed competition is indeed one of the most important yield-reducing factors (Johnson, 1997), followed by drought, blast, soil acidity and low soil fertility. Farmers traditionally manage these stresses through long fallow periods. Population growth and resulting pressure on the land has led to increasing reduction of fallow periods and extension of cropped areas, often towards the more fragile upper parts of the slopes. In the rainfed uplands, slash-and-burn agriculture and reduced fallow periods has aggravated weed pressure and general decline in land quality through soil erosion (Oldeman and Hakkeling, 1990) and soil nutrient depletion called soil mining (van der Pol, 1992). The increase in population pressure aggravates the situation, resulting in low and unstable rice yields. Lack of capital limits the use of external resources and intensification of the system. Weed competition further reduces labor productivity and increases the risk of crop failure. Farmers traditionally use long-duration rice cultivars that further undermine the fragility of the system and limit the cropping intensity. Declining productivity and incomes feed the cycle of poverty and environmental destruction (Cleaver, 1993; Cleaver and Schreiber, 1994).

The major challenges for rice research and development in the upland ecology relates to sustainable stabilization and intensification of upland rice production as there is a large opportunity in increasing yields and possibly the cropping intensity. Improved varieties that have high yield capacity under low resource input conditions are an under-exploited potential. However, low-cost complementary soil fertility management practices will have to be introduced, such as crop rotation with legumes to maintain or improve soil quality, avoid soil nutrient mining and enhance sustainability. With short duration varieties it might be possible to introduce rice-legume cropping systems within the same cropping season if rainfall is adequate. Given the complexity and diversity of the upland rice systems, technologies will have to be adapted and fine-tuned *in-situ*. This will require new approaches for farmers to play more important roles in technology development and for effective interaction between researchers and farmers to develop appropriate technologies.

Technical opportunities

Given the fragility of the upland rice system, technologies are urgently needed that reduce degradation of the fragile resource base and ensure sustainable stabilization of the system.

WARDA's breakthrough in developing 'New Rices for Africa' (NERICAs) based on crosses between African rice (*O. glaberrima*) and Asian rice (*O. sativa*) provides an exciting opportunity for farmers to stabilise and intensify low-input upland systems. NERICAs tend to resist better against most African stresses including weeds and drought. They have high yield potential and generally out-yield local varieties, under both low and high input conditions (Jones and Wopereis-Pura, 2001). Moreover, compared to local varieties, NERICAs have generally a much shorter growing cycle (about 90 to 110 days), which provide the opportunity to produce food during the hungry season. Moreover, short duration NERICAs allow rice farmers to adjust their agricultural calendar to climatic variation (Jones, 2001). The early maturing NERICAs have a comparative advantage over local varieties with respect to demand for labor. Labor-saving technologies can motivate farmers to concentrate agricultural activities on a more limited area, allowing the most fragile areas to revert back to natural vegetation. Resource degradation will be reduced, yields and income will be stabilized and labor productivity and income will be increased. NERICAs may also help to stop expansion of cultivated land areas as double cropping of NERICAs is possible under sufficient rainfall.

The idea is, however, not to promote the replacement of local varieties by NERICAs. Rather, WARDA's strategy is to integrate NERICAs into the existing varietal portfolio of farmers. Indeed, in 1997 WARDA set up a Participatory Variety Selection (PVS) approach with farmers selecting varieties from rice gardens with large numbers of local and modern *O. sativa* and NERICA varieties (Figure 5). The PVS-approach is a 3 year program that allow farmers to tests and evaluate their own selected varieties under their site-specific conditions and according to their needs. The most promising varieties are later on proposed to the national release committee (Table 4). This approach is an example of how farmers can be effectively involved early in research-development process of new technologies. A study conducted by Diagne et al. (2001) shows that the PVS-approach leads to increased biodiversity, in terms of numbers of varieties grown per farmer can be enhanced.

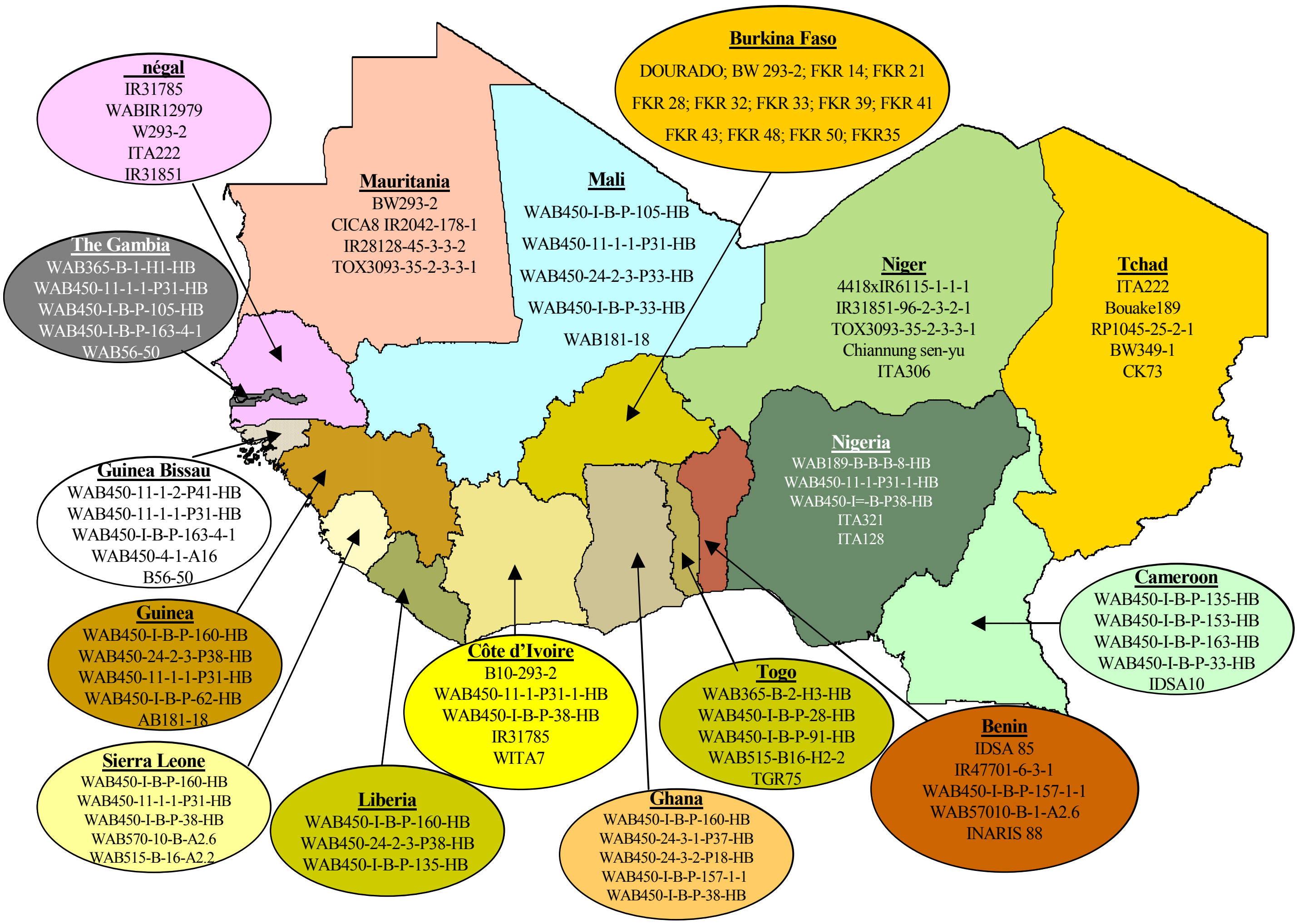


Figure 5 : NERICA Varieties released or in pipeline for release in Africa

Table 4: Non-NERICA WARDA breed upland rice varieties released in West and Central Africa

Cultivar	Countries	Agronomic characteristics
WAB 56-50	Burkina, Côte d'Ivoire, The Gambia, Guinea Bissau, Liberia	Blast resistance, drought tolerance, high yield
WAB56-125	Burkina Faso, Côte d'Ivoire, Nigeria	High yield
WAB56-104	Côte d'Ivoire, Liberia	High yield
WAB56-39	Burkina Faso	High yield
WAB96-1-1	Côte d'Ivoire, Cameroon, Guinea Bissau, Liberia, Sierra Leone	Weed competitiveness, high yield
WAB384-B-B-3-1-2	Cameroon	High yield
WAB36-2LFX	Nigeria	High yield
WAB36-34-FX	Nigeria	High yield

Irrigated ecology

Irrigation systems include dam-based irrigation, water diversion from rivers and pump irrigation from surface water or tubewells. Major differences in constraints, opportunities and challenges exist between irrigated rice-ecologies in the Sahel and in the humid forest and savanna zones.

Average farmers' yields in the Sahel are around 4 to 5 t ha^{-1} $season^{-1}$, with potential yields varying from 6 to 11 t ha^{-1} $season^{-1}$, limited by solar radiation and temperature only. Potential yield gains from improved crop and resource management are, therefore, tremendous. In the Office du Niger in Mali, average yields have increased over the last 15 years from 2 t ha^{-1} to almost 6 t ha^{-1}. Only 10% of the area under irrigation is double-cropped, because of extreme temperatures in both hot and wet seasons. The relatively demanding cropping calendar leaves little room for delays in activities and mechanization is relatively wide spread. However, labor remains a limiting factor and about half of the rice grown in the Sahel is direct-seeded. African Rice Gall Midge, Rice Yellow Mottle Virus, blast are the major pest found in the irrigated rice ecosystems.

Moving south into the Savanna/humid forest zones, schemes become smaller, are mainly transplanted, and are located along major roads and near urban centers. Compared to the Sahel, rice productivity in the savanna/humid forest systems is less constrained by temperature extremes but potential yields are lower, ranging from 5 to 8 t ha^{-1} $season^{-1}$, as a result of lower solar radiation levels. Actual yields are around 3 t ha^{-1} $season^{-1}$, indicating considerable scope for yield gains.

Still, substantial investments have already been made in irrigation infrastructure, especially in the Sahel. Given these sunk costs, the development, maintenance and rehabilitation of existing infrastructure provide concrete opportunities to capitalize on these earlier investments. This is adequately illustrated by the development of rice production in Mali over the last few years and the substantial yield increases achieved in the Sahel (Mali, Senegal), demonstrating that irrigated rice is a feasible option in the sub-region.

In the Sahel, soil alkalinization followed by sodication may affect soil quality, particularly if groundwater tables rise too close to the surface due to lack of drainage combined with irrigation water that is rich in dissolved inorganic ions. Soil alkalinization and sodication problems are found in the *Office du Niger*, Mali, in *Foum Gleita*, Mauritania, and in irrigated systems in Niger.

Until now, rice-rice or other double-cropping schemes are found only in a few zones (e.g. in the Kou valley in Burkina Faso or in Niger). A clear potential exist for the introduction of short-duration cultivars that may allow to grow two rice crops per year on the same land, or an additional non-rice crop following rice, profiting from residual moisture in the soil or supplementary irrigation.

Technical opportunities

Compared to the upland rice ecosystems, the irrigated rice systems are quite robust and homogeneous both in terms of bio-physical and socio-economic characteristics. Innovation and change should concentrate on improving resource use efficiency and factor productivity.

WARDA and partners have developed improved integrated rice management (IRM) options for irrigated rice cropping in the Sahel that are within farmers' means, based on farm surveys, and farmer participatory on- and off-station research (Wopereis et al., 2001; WARDA-SAED, 2000). IRM focuses on land preparation, crop establishment technique, sowing date/rates and cultivar choice, and provides a farming calendar for best-bet management for a given site x sowing date x cultivar choice x crop establishment technique combination, but relevant information can be adapted to a specific site and enables farmers to adapt them according to their means. IRM options further include fertilizer rates for specific target yields and farmers' financial means, weed and water management practices and harvest and post-harvest techniques.

These IRM options have been evaluated with farmers in Senegal and Mauritania (Häfele et al., 2000), and resulted in a mean yield increase of 1.7 t ha^{-1}; from 3.8 to 5.5 t ha^{-1}. Partial budgeting showed that average net benefit increased from 215 to 525 USD ha^{-1}, i.e. a 85% increase in net benefits. IRM production costs were slightly higher than the farmer production costs, mainly due to basal fertilizer application. Even with this assumption, IRM was economically superior to farmer practices across sites. IRM options most attractive to farmers included improved fertilizer and weed management, use of improved varieties and harvesting/post harvest technologies. WARDA and NARES and NGOs from Mauritania and Senegal are now exploring ways to scale up results from these studies to a much larger number of farmers.

Moreover, only a few introduced varieties were grown by farmers in irrigated ecologies of West and Central Africa. WARDA, through inter and intraspecific crosses has increase the genetic diversity and a number of high yielding, good quality, shorter duration, and salinity tolerant varieties have been developed and grown by farmers (Table: 5)

Table 5: New irrigated rice varieties released in West and Central Africa

Cultivar	Countries	Agronomic characteristics
WITA1	Côte d'Ivoire	Blast, iron-toxicity tolerance
WITA3	Côte d'Ivoire	Blast, iron-toxicity tolerance
WITA7	Côte d'Ivoire	RYMV resistance
WITA8	Côte d'Ivoire, Niger	High yield, RYMV resistance
WITA9	Côte d'Ivoire, Niger	High yield, RYMV resistance
Mashuri	Sierra Leone	High yield
IR1561-228-3-3	Mali	High yield
Sahel108	Mauritania, Senegal	High yield
Sahel 201	Mauritania, Senegal	High yield
Sahel 202	Senegal, Mauritania	High yield

Rainfed Lowland ecology

In West and Central Africa alone, an estimated 20 to 40 million hectares of inland-valley swamps are found, of which only 10 to 25% is currently used (Windmeijer et al, 1994). Although WARDA research has shown that no causal linkages exist between water-borne diseases, such as malaria, and the expansion of irrigation in West and Central Africa (*WARDA, 1999*), farmers still perceive human health problems as a major constraint for the development of lowland areas.

Rainfed lowland systems are more robust than the upland systems and have a high potential for intensification, but are largely unexploited. Improved water control is definitely a first step to be taken in order to improve the productivity of the lowlands and control iron toxicity. With improved water control the use of external inputs may become attractive and rice yields may be increased rapidly. As full water control in large schemes is a too costly option, improvement of water control will have to be limited to smaller schemes.

The rice yields in rainfed lowlands are substantially higher than those of the rainfed uplands, but still low; averaging 2 t ha^{-1}. The potential yield is 3 t ha^{-1} at current input levels and 5 to 6 t ha^{-1} at increased input levels and improved water control (i.e. yield levels that are comparable to irrigated systems with full water control in the savanna and humid forest zones). These yield gaps indicate a considerable potential for improvement. Poor water control is a major system constraint, prohibiting more intensive use of these systems. Indeed, with improved water control, use of external inputs may become attractive, potentially resulting into higher yields. Although water management is a key factor for intensification, complementary technologies will be needed to provide sufficient opportunities for increased productivity and profitability. Indeed, major biological constraints for rice production in inland valleys, such as iron toxicity, pests, weeds require major attention to realize those potentials.

Technical opportunities

Important spill-over from technologies developed for irrigated and upland systems are expected. The NERICAs currently available have been developed for upland systems, but are now being screened under lowland conditions. Interspecific progenies of *O. glaberrima* and *O. sativa* subsp. *indica* that were bred for irrigated conditions are also evaluated under lowland rainfed conditions. However, as in the near future water control will not reach the level of the irrigated systems, breeding for lowland conditions will have to take into account multiple stresses such as drought, low N and P conditions and major pests such as RYMV, AfRGM and blast.

Apart from varietal improvement, sustainable development of rainfed lowlands will require complementary technologies, covering all aspects of lowland rice management, from land preparation to harvest and post-harvest technologies. IRM practices developed for the irrigated rice systems will form the basis, but fine-tuning and adaptation according to the site-specific conditions definitely be required. Besides intensification, the potential for diversification will be explored. Particular emphasis will be given to the integration of vegetables in rice production systems, and possibilities to integrate aquaculture and livestock in inland-valley lowlands.

Sustainable intensification and diversification of lowlands require important investments. Therefore, particular attention will be given to the identification of bottlenecks preventing access to capital and other necessary resources and their adequate management. Market forces drive both diversification and intensification; therefore, a particular focus on peri-urban environments and the efficiency of market linkages is warranted. The capacity of locally produced rice to compete with imported rice should be explored, with respect to the efficiency (cost effectiveness and rice quality) of small-scale processing units.

Inland valleys have very complex, dynamic and diverse human, social, natural and physical dimensions and interconnections that need to be understood in order to determine options for improved and integrated crop and natural resources management. There is a need to (*i*) elucidate the different functions of inland valleys and their management; (*ii*) unlock constraints to the more wide-spread use of inland valleys for rice-based systems; (*iii*) identify, develop, adapt a wide variety of options and methods for sustainable inland valley development and management; (iv) scale-up results.

It will be clear that with such a high degree of complexity and diversity, research and extension will never arrive at tailor-made recommendations that would individually suit the numerous rice growers in the inland valleys. Agricultural research and extension has to provide much more specific information and move beyond simple delivery of general messages, recipes or blanket recommendations to be passed to farmers. Sustainable management of inland valleys requires a fundamental change in innovation, development and learning processes. Indeed, what is needed are approaches that strengthen farmers' capacity in making optimal use of the available resources and best choices of alternative ways of resources management. This has important implications in terms of intervention methodology and institutions that support change and development, including farmer organizations. Indeed the inherent complexity, diversity and dynamics of inland valley ecosystems, call for a bottom-up, social learning process will be critical. Only by doing so, a sustainable and lasting impact on food security in the region can be achieved. A participatory learning and action research approach among inland valley development stakeholders (farmers, change agents, extension, research) at grassroots level is required. This will help building bridges between local, indigenous knowledge and scientific expertise. This will ultimately lead to a network of farmer associations in contact with a wide variety of external stakeholders, forming an inland valley platform at regional and national levels. It will also be instrumental to develop an integrated natural resources management (INRM) framework and curriculum for farmer learning for inland valleys in West Africa.

CONCLUSIONS

The development of NERICAs has succeeded in breaking the yield barrier in the upland rice ecology. NERICAs are stress resistant, have short growth duration and respond well to both low and high input conditions. Participatory varietal selection, both researcher-led and extension-led, and community-based seed supply systems are currently being used to get seeds to farmers. This development will ensure that the contribution of the upland ecology to regional rice production will increase in the next years to come. NERICAs are currently being developed for rainfed and irrigated lowland systems as well.

Considerable scope for yield improvement also exists in the irrigated ecologies. The introduction of integrated rice management (IRM) in irrigated systems in the Sahel has resulted in considerable yield increases (2 t ha^{-1}), without major changes in input use, thereby reducing the very large yield gap between actual and potential yields in these systems. IRM is developed with farmers and provides them with options from land preparation to harvest and post-harvest interventions. Existing farmer organizations can often be used as dissemination channels for IRM.

In the long run the rainfed lowlands show great promise as well. Large areas of rainfed lowland are not yet developed. Considerable scope exists to increase cropping intensity and yields in these systems because of sub-optimal crop management and poor water control. This again calls for an IRM approach. However, these systems are characterized by a much larger complexity and diversity than the irrigated systems. The message that needs conveying is, therefore, also much more complex and will take more time and effort. It is proposed to introduce IRM through a participatory learning and action research (PLAR) approach and creation of rural knowledge centers. Pilot farmers in rural knowledge centers should ultimately become agents of innovation and change, stimulating diffusion of knowledge. Research and extension staff should change in the process to assume a much more facilitating role, building bridges between local knowledge and expertise from outside.

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