1 From WARDA to AfricaRice: an Overview of Rice Research for Development Activities Conducted in Partnership in Africa

Eric Tollens,[1] Matty Demont,[2] Moussa Sié,[3] Aliou Diagne,[3] Kazuki Saito[3] and Marco C.S. Wopereis[3]*

[1]*Centre for Agricultural and Food Economics, Katholieke Universiteit Leuven, Leuven, Belgium;* [2]*Africa Rice Center (AfricaRice), Saint-Louis, Senegal;* [3]*Africa Rice Center (AfricaRice), Cotonou, Benin*

Introduction

The West Africa Rice Development Association (WARDA) was created in 1971 by 11 West African states (Burkina Faso, Côte d'Ivoire, The Gambia, Ghana, Liberia, Mali, Mauritania, Niger, Senegal, Sierra Leone and Togo) – with the assistance of the United Nations Development Programme (UNDP), the Food and Agriculture Organization of the United Nations (FAO) and the Economic Commission for Africa (ECA) – as an autonomous research organization and an intergovernmental association of member states (WARDA, 2001a). The highest governing body of the Center is the Council of Ministers of Agriculture of member states, with statutory meetings being held once every 2 years. In 1975, WARDA joined the growing contingent of international agricultural research centres affiliated through the CGIAR (now the CGIAR Consortium) (CGIAR, 2013). Over the following two decades, six additional countries (Benin, Cameroon, Chad, Guinea, Guinea-Bissau and Nigeria) joined the Association to bring the membership to 17. When it was realized that WARDA's products were gaining ground in countries beyond its traditional mandate region of West and Central Africa, the name Africa Rice Center was adopted in January 2003 (WARDA, 2004). In 2007, a new vision was formulated to encourage such countries to become full members of the Association. This prompted five more countries to join in the midst of the global food crisis of 2007–2008 (Central African Republic, the Democratic Republic of Congo, the Republic of Congo, Egypt and Uganda). These were followed by Gabon (September 2009) and Madagascar (February 2010). Thus, today (June 2013) the Association's 24 member states represent West, Central, East and North African regions. When Africa Rice Center became the official legal name of the Center and the Association in 2009, the abbreviation AfricaRice was adopted in both English and French and was to be applied retroactively.[1]

Like other CGIAR-supported centres, AfricaRice has a Board of Trustees composed of nominees from member states and from

* Corresponding author: m.wopereis@cgiar.org

non-member states. They work together to ensure that AfricaRice management conforms to the resolutions of the Council of Ministers and to the CGIAR guidelines on governance and management in implementing the Center's approved 2011–2020 Strategic Plan (AfricaRice, 2011b).

In this chapter, we look back over rice research for development in Africa, with emphasis on the past two decades. We focus on AfricaRice, but contributions of many other institutions and partners are acknowledged. This is not a comprehensive historical overview of rice research and development in Africa. Rather, we highlight some of the major institutional and technological challenges encountered and achievements obtained since about 1990. Much more information on a wide range of research-for-development activities conducted in partnership in Africa can be found in subsequent chapters of this book.

The chapter starts with a brief overview of the Task Force mechanism, which has been the main vehicle used by AfricaRice to conduct research in partnership with the national agricultural research systems (NARS) of its member states and other African nations and an overview of some other important partnerships. The remainder of the chapter is structured in three thematic areas: (i) genetic diversity and improvement; (ii) crop and natural-resources management; and (iii) policy, impact assessment and rice value-chain development.

Task Forces and Other Partnership Mechanisms

The Task Force mechanism

The Task Force mechanism was introduced as a novel approach to building partnerships between the Center and the NARS in 1991. The mechanism responded to concerns highlighted by two working groups of NARS representatives (WARDA, 1999). Consequently, each Task Force had four primary objectives:

- to coordinate regional research activities, thereby reducing duplication and identifying the most complementary forms of collaboration among rice research programmes;
- to provide national scientists with more complete and rapid access to information and results from regional research;
- to test and transfer technologies in a targeted and systematic manner; and
- to target technical, material and financial assistance to national programmes in such a way as to strengthen the regional rice research system as a whole (Fakorede and Yoboué, 2001).

Between 1991 and 1995, ten Task Forces were established (although, because of re-organization and mergers, a maximum of nine operated at any one time), covering mangrove swamp, upland rice breeding, lowland rice breeding, irrigated rice breeding, Sahel resource management, integrated pest management (IPM), problem soils, cropping systems, rice economics and technology transfer.

Specifically designed to address constraints to rice production identified by the NARS, the Task Forces operated through (annual) meetings, joint research activities, monitoring tours, visiting fellowships, and training (WARDA, 1999). The Task Forces provided for sharing of information and resources so that – on a regional scale – there would be no duplication of effort, isolated national researchers could interact with their peers from other countries, and no one NARS was overstretched in achieving research objectives. The Task Forces attempted to ensure that each national partner and AfricaRice conducted activities according to their institutional comparative advantages, thereby achieving greater overall impact on a regional scale. Finally, the Task Forces also served to help AfricaRice prioritize its work with direct guidance from national partners. A 218-page summary of the first 7 years of AfricaRice–NARS Task Forces activities was published in 2001 (Fakorede and Yoboué, 2001).

In 1998, the decision was taken to merge the AfricaRice–NARS Task Forces with the Rice Network of the West and Central African Council for Agricultural Research and Development (WECARD/CORAF). This was prompted by a review of networks funded by the United States Agency for International Development (USAID) and in light of the fact that the two networks involved the same NARS scientists. Moreover, the composition of the newly created (January 1998) AfricaRice National Experts Committee was almost identical to that of the WECARD/CORAF Executive Committee (WARDA, 1999). Consequently, the Rice Research and Development Network for West and Central Africa (Réseau Ouest et Centre Africain du Riz, ROCARIZ) was created in 1999 (WARDA, 2000). ROCARIZ followed the Task Force mechanism, but replaced the annual meetings of individual Task Forces with a biennial Regional Rice Research Review (4Rs) (e.g. Sanyang *et al.*, 2003; Narteh *et al.*, 2006), which brought together as many of the NARS scientists as possible, with members of the individual Task Forces meeting as 'breakout groups' during the Review. Unfortunately, funding for ROCARIZ dried up and the network ceased to function in 2006 (AfricaRice, 2012).

However, AfricaRice did manage to continue some of the networking activities of some of the Task Forces (e.g. Breeding and Economics) through projects (AfricaRice, 2012; A.A. Touré, Cotonou, Benin, 2013, personal communication).

In 2010, the Second Africa Rice Congress urged African governments to renew commitment to rice research and development, and supported AfricaRice in its proposal to revive the task force mechanism (AfricaRice, 2012). Consequently, by March 2013, there were Africa-wide Rice Task Forces covering breeding, agronomy, processing and value addition, policy and gender, with the final one (mechanization) scheduled for launch later that year (GRiSP, 2013).

Other partnerships

The Consortium for the Sustainable Use of Inland Valley Agro-Ecosystems in Sub-Saharan Africa (**Inland Valley Consortium**, IVC), convened by AfricaRice, is composed of 12 West African NARS and a number of international (IITA, ILRI, IWMI,[2] FAO, WorldFish and WECARD/CORAF) and advanced research institutes (CIRAD,[3] Wageningen University). It was founded in 1993 with the objective to develop, in concerted and coordinated action, technologies and operational support systems for intensified but sustainable use of inland valleys in sub-Saharan Africa. Extensive biophysical and socio-economic characterization work was done during the first phase in 18 key sites in 1994–1999 (e.g. Andriesse *et al.*, 1994; Windmeijer *et al.*, 1998). A second phase (2000–2006) focused on technology development for inland-valley systems. The participatory learning and action-research (PLAR) approach was developed and diffused during this time (see Defoer and Wopereis, Chapter 31, this volume). Lack of funding after 2006 severely restricted IVC operations. Since 2012, IVC has continued as the Inland Valley Community of practice, which better reflects its new modus operandi.

The **Human Health Consortium** (1994–2000) brought together six multidisciplinary West African research institutions to evaluate the health and social impacts of various degrees of wetland water management and irrigation in the humid rain-forest, savannah and Sahel zones of Côte d'Ivoire and Mali. The research concluded that most types of water management in the region have minimal impact on the occurrence of the two main water-associated diseases, malaria and schistosomiasis (WARDA, 2001a).

Various research and development partnerships grew up around and to support the work that led to the development of the NERICA varieties and subsequently promoted them across the continent. First, the **Interspecific Hybridization Project** itself, launched in 1996 – just 3 years after the first successful development of fertile progeny from crosses between African cultivated rice (*Oryza glaberrima*) and Asian cultivated rice (*Oryza sativa*) – brought together three CGIAR centres (AfricaRice, IRRI and CIAT),[4] Cornell University (USA), Institut de recherche pour le développement (IRD, France), Tokyo University (Japan) and Yunnan Academy of Agricultural Sciences (China). The Project sought to develop and utilize the breeding techniques and their products (WARDA, 2001a).

The mechanism devised to disseminate the NERICA varieties and to help resource-poor upland-rice farmers identify varieties best suited to their particular agroecological and socio-economic contexts – participatory varietal selection (PVS) – itself became the focus of a research and development network, the **Participatory Rice Improvement and Gender/User Analysis**, which ran for several years from about 1999 (WARDA, 2001a). Then in 2001, the **African Rice Initiative (ARI)** was established to promote the widespread and rapid diffusion of the NERICA and complementary technologies throughout the rice-growing areas of Africa. Early work targeted upland rice in five pilot countries in West Africa, while enabling PVS and community-based seed systems (CBSS) activities to start in East and Southern Africa (WARDA, 2002a; Bèye *et al.*, 2011).

The African component of the **International Network for Genetic Evaluation of Rice (INGER-Africa)** started life as part of the International Rice Testing Program, a systematic global programme for the collection, distribution and testing of rice genetic materials convened by IRRI. Initially (from its inception in 1985) coordinated by IITA, INGER-Africa was relocated to AfricaRice in 1997.

Since 2008, AfricaRice has been a member of the steering committee of the Coalition of African Rice Development (CARD), led by the Japan International Cooperation Agency (JICA) and the Alliance for a Green Revolution in Africa (AGRA) (see www.riceforafrica.org).

Since 2011, AfricaRice has been participating in CGIAR Research Programmes, in particular the Global Rice Science Partnership (GRiSP), led globally by the International Rice Research Institute (IRRI). AfricaRice is leading the implementation of GRiSP in Africa.

Genetic Diversity and Improvement

Rice breeding

Introducing, testing and disseminating varieties

In the early days (i.e. in the 1970s and 1980s), the AfricaRice philosophy was that rice varieties developed by other organizations could simply be introduced to the region, so the Center's early work comprised coordinated variety trials for the major rice-growing environments (irrigated, mangrove, rainfed lowland and upland). The principal sources of these varieties were IRRI, IITA and Institut de Recherche Agronomique Tropicale (IRAT).[5] This led to the adoption of well-known varieties in West Africa such as BG90-2, Bouaké189, IR1529-680-3, C74 and Jaya for lowland environments and Dourado Precoce, IRAT 144, IRAT 13, ITA 257, ITA 150 and ITA 235 for upland environments.[6]

At AfricaRice, breeding programmes for the main rice-growing environments started in earnest when the Center moved from Liberia to Côte d'Ivoire in 1988, with upland breeding based at M'bé, Côte d'Ivoire, lowland breeding through an AfricaRice breeder based at IITA, Ibadan, Nigeria (taking over from the IITA rice breeder in 1990), breeding for irrigated systems based at Saint-Louis, Senegal, and breeding for the mangrove-swamp environment based at the Rokupr research station, Sierra Leone, alongside the Sierra Leone national programme. Breeding lines were named WAB in Côte d'Ivoire, WAT in Nigeria, WAS in Senegal and WAR in Sierra Leone. In 2010, this naming system was revised to ARS in Senegal, ART in Nigeria, ARB in Côte d'Ivoire and ARC for Cotonou, Benin, reflecting the name change from WARDA to AfricaRice.

The most promising lines (bred or introduced) for the rainfed lowland and irrigated ecosystems south of the Sahel zone were included in the WITA series, the most well-known being WITA 4 (from line TOX 3100-44-1-2-3-3). For the irrigated Sahelian environment, the Sahel series was started, which includes the short-duration Sahel 108 (IR 13240-108-2-2-3, an IRRI line), and the medium-duration varieties Sahel 201 (BW 293-2) and Sahel 202 (ITA 306) now widely grown in Senegal and Mauritania. New aromatic Sahel varieties (Sahel 177, Sahel 328 and Sahel 329) are currently (2012) making rapid headway in Senegal. For the upland environment the most popular varieties were WAB 56-50, WAB 56-104 and WAB 56-125 (before the arrival of the NERICA varieties, see below). Breeding for the mangrove ecosystem was devolved to the Sierra Leone national programme in 1986.

In the 1990s, AfricaRice started developing wide crosses between Asian rice *O. sativa* (improved tropical *japonica*) and African rice (*O. glaberrima*). The idea was to combine specific assets of *O. glaberrima* (e.g. weed competitiveness and tolerance to diseases) with the yield potential of tropical *japonica* parents (Jones *et al.*, 1997; Dingkuhn *et al.*, 1999b). The most promising seven lines were subsequently named 'New Rices for Africa' (NERICA 1 to NERICA 7). The term 'NERICA' is used to indicate interspecific hybrid progeny derived from crosses between

O. glaberrima and *O. sativa*. The NERICA varieties had their first taste of success in Guinea in the late 1990s, primarily through PVS programmes (WARDA, 2000, 2001b). The first NERICA varieties to be officially released were in Côte d'Ivoire in December 2000 (NERICA 1 and NERICA 2). NERICA is now a household name in Africa and earned AfricaRice the King Baudouin award in 2000 (WARDA, 2001c) and, in the person of Dr Monty P. Jones, the World Food Prize in 2004.

WARDA (2002b) lists the varieties released or generally adopted in West and Central Africa up to 2002. Dalton and Guei (2003) estimated that a total of 197 improved varieties were released in seven West African countries between 1960 and 2000, of which 40% (80 out of 197) were developed by national programmes using genetic material that originated within national programmes without any direct or indirect involvement of the CGIAR, but about half of them (38) with support from IRAT/CIRAD. A further 13 varieties were produced by the AfricaRice mangrove rice programme. A total of 27% (54 out of 197) were varieties developed by the CGIAR from genetic material developed by the CGIAR. The third most important source of released varieties, purified landraces, made up 14% of accessions (27 out of 197). The remainder (16%) were developed collaboratively by national and international agricultural research centres, including the CGIAR. These figures do not include the NERICA varieties which were just entering farmers' fields in and around 2000.

Despite the difficult conditions under which AfricaRice worked between 2002 and 2005 (forced relocation from Côte d'Ivoire to Mali and eventually Benin as a result of the civil war in Côte d'Ivoire) AfricaRice's breeding work resulted in an additional 11 varieties for upland conditions (NERICA 8 to NERICA 18). Based on work that started in the late 1990s, AfricaRice and partners also developed a family of NERICA varieties adapted to the lowlands. This new generation of NERICA varieties, derived from crosses between *O. sativa* subsp. *indica* and *O. glaberrima*, currently consists of 60 genotypes (NERICA-L 1 to NERICA-L 60), the most widely grown being NERICA-L 19. The main breeding objectives were yield potential, grain quality, broad adaptation to diverse lowlands in the region, and tolerance to *Rice yellow mottle virus* and African rice gall midge (Sié *et al*., 2008a). This work earned AfricaRice, in the person of Dr Moussa Sié, the Fukui International Koshihikari Rice Prize from Japan in 2006.

AfricaRice breeders and colleagues from NARS are making increasing use of marker-assisted selection and other genomics techniques (see McCouch *et al*., Chapter 9, this volume) to 'upgrade' existing varieties with one or more genes that will give them an edge in farmers' fields or in market segments. For example, in partnership with IRD, AfricaRice has developed varieties that are resistant to *Rice yellow mottle virus* through incorporation of the *rymv1-2* gene (see Ndjiondjop *et al*., Chapter 12, this volume) and these varieties are currently (2012) being tested in farmers' fields in West Africa. Through the newly established Africa-wide Rice Breeding Task Force and as part of the Global Rice Science Partnership (GRiSP), AfricaRice and partners are conducting a systematic, continent-wide and product-oriented breeding approach that is expected to accelerate varietal development. Specific varietal-development pipelines are being defined for different growth environments and market-segments (see Kumashiro *et al*., Chapter 5, this volume).

Box 1.1. Rice breeding in Egypt

Egypt's rice breeding programme started in 1917. The breeding programme has developed an impressive number of medium-duration (120–130 days) high-yielding varieties with good grain quality (Giza and Sakha series) suited to the Egyptian market (short grain, low amylose), mostly resistant to blast. Promising hybrid rice varieties have recently been developed as well. These varieties have contributed to the very high rice yields that can be obtained in the Egyptian climate (10–12 t/ha). The challenge for Egypt is to develop short-duration varieties that can be grown with less water, are resistant to blast and tolerate heat and moderate salinity levels while maintaining yields.

Physiology research

Detailed physiological work on varietal responses of irrigated lowland rice in the Sahel to temperature and photoperiod was done in the early 1990s (Dingkuhn and Miezan, 1995; Dingkuhn *et al*., 1995). A total of 49 varieties were characterized for their photothermal responses through 'rice garden' trials (sown every month over a 1.5 year period). The study identified varieties best suited for different growing seasons in the Sahel. A relationship between minimum air temperature at booting stage and spikelet sterility was established (Dingkuhn *et al.*, 1995). This work led to the development of the RIDEV (RIce DEVelopment) simulation model (see next section, 'Crop and Natural Resources Management').

Work by Asch *et al.* (1997, 1999) and Asch and Wopereis (2001) revealed varietal and seasonal differences in salinity tolerance for the irrigated Sahelian environment, leading to a physiological model of sodium uptake in the rice plant and screening tools for breeding for salinity tolerance.

Studies conducted by Sahrawat (2000, 2004) and Audebert and Sahrawat (2000) identified the role of iron-tolerant rice genotypes and other plant nutrients in reducing iron toxicity in lowland rice and related physiological mechanisms. Screening methodologies for tolerance to iron toxicity are discussed by Asch *et al.* (2005).

A large number of studies on varietal adaptation to different water regimes have been undertaken since the mid-1990s (e.g. Dingkuhn *et al.*, 1999b; Sie *et al.*, 2008b). Saito *et al.* (2010c) evaluated 14 rice varieties in seven experiments to investigate genotype × environment (G×E) interaction for yield, and to identify high-yielding varieties and plant characteristics associated with high yield. Three environment groups were identified from a pattern analysis on yield. Grouping was related to water availability, distinguishing: (i) an aerobic environment, with rice grown under aerobic conditions with supplementary irrigation; (ii) a hydromorphic environment, with rice grown under rainfed conditions with drought spells at the vegetative stage; and (iii) a permanently flooded environment. These results indicate that a systematic effort is needed to screen a wide range of varieties across hydrology gradients to identify varieties that perform well across or within a specific target population of environments. In 2011, a high-throughput phenotyping facility for drought resistance was established at AfricaRice, Cotonou in collaboration with CIRAD.

Weeds are serious constraints to rice production in Africa across all rice environments. An illustrated guide to weeds of rice in West Africa was produced by Johnson (1997). Weed competitiveness of rice plants is considered highly desirable, especially in low-input systems. In the 1990s, AfricaRice developed a plant-type concept for high-yielding, weed-competitive cultivars adapted to low-input management conditions through analysing data from field experiments using a simulation model (Jones *et al.*, 1997; Dingkuhn *et al.*, 1998). The idea was to combine specific assets of *O. glaberrima* such as weed competitiveness and the yield potential of *O. sativa* tropical *japonica* parents. Since the mid-1990s, a number of studies have been conducted to identify varieties with strong weed competitiveness, plant traits related to weed competitiveness, and to develop screening tools (e.g. Dingkuhn *et al.*, 1999a; Rodenburg *et al.*, 2009; Saito *et al.*, 2010b). Saito *et al.* (2010b) indicate that grain yield, plant height at maturity and visual growth vigour at 42–63 days after sowing **under weed-free conditions** are useful selection criteria for developing superior weed-competitive rice genotypes.

The 18 upland NERICA varieties were tested for pre- and post-attachment resistance to *Striga hermonthica*, an obligate hemiparasitic weed that causes severe yield losses in cereals, including rice. Some NERICA varieties showed good pre- and post-attachment resistance to this very damaging weed (Cissoko *et al.*, 2011; Jamil *et al.*, 2011) and research is ongoing to determine the genes behind these different types of resistance. Varieties combining pre- and post-attachment resistances are expected to provide a breakthrough in terms of *Striga* control in rice-based systems in sub-Saharan Africa.

Saito and Futakuchi (2009) and Saito *et al.* (2012) proposed *aerobic* rice and *aus* varieties[7] with high yielding ability, strong weed competitiveness, and superior adaptation to low soil fertility for inclusion in upland breeding programmes in Africa.

Crop and Natural Resources Management

Sahel irrigated systems

In the early 1990s, AfricaRice focused on the development of best-fits between varietal choice and cropping calendars in irrigated lowland systems in the Sahel. From this detailed physiological work (Dingkuhn and Miezan, 1995; Dingkuhn *et al.*, 1995), the RIDEV decision-support tool was derived and physiological knowledge was also captured in the crop simulation model ORYZA_S (Dingkuhn, 1995). ORYZA_S allowed regional analysis of climatic risk to irrigated rice cropping in the Sahel and zonation of regions with potential for double cropping. RIDEV provided advice on best-bet sowing dates and varietal choice, and timing of N fertilizer application, drainage before harvest, and harvest for any site under irrigation in the Sahel.

In the mid- and late 1990s, the research focus shifted to analysis of farmer decision making, their major constraints and opportunities, and determinants of rice productivity (e.g. Adesina, 1996; Adesina and Djato, 1996). Donovan *et al.* (1999) and Wopereis *et al.* (1999) reported on such work in Senegal (Sahel), Mali (Sudan savannah), Mauritania (Sahel) and Burkina Faso (northern Guinea savannah). Results showed that average farmers' yields varied between 3.8 t/ha and 7.2 t/ha, resulting in an overall average of 4.5 t/ha. Yields of individual farmers were highly variable, ranging from 0.3 t/ha to 8.7 t/ha. Maximum yields reached by farmers were only at 40–60% of 10-year-averages of ORYZA_S simulated potential yield (limited by temperature and solar radiation). The yield gap between farmers' average yields and farmers' highest yield was between 0.7 t/ha and 4.1 t/ha, with an average of 2.6 t/ha, indicating considerable scope for improving yields. Surveys on soil degradation in irrigated systems in the Sahel revealed the importance of double cropping and drainage to combat salinity in the Senegal River delta (Ceuppens and Wopereis, 1999). Numerous studies were conducted to quantify and reduce the risk of alkalinization and sodification (e.g. Boivin *et al.*, 2002; Van Asten *et al.*, 2003a,b).

Box 1.2. Irrigated systems outside of the Sahel

AfricaRice has conducted little research on irrigated systems outside of the Sahel. However, Becker and Johnson (1999a) conducted surveys in irrigated systems of the forest zone of Côte d'Ivoire. Yields varied between 0.2 t/ha and 7.3 t/ha, with average yields of 3.2 t/ha under partial irrigation and 4.2 t/ha in fully irrigated systems. Age of seedlings at transplanting, timeliness of operations and application of P fertilizer explained 60% of observed variability.

Haefele *et al.* (2000, 2001) observed the following main agronomic constraints 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) delayed harvesting. Consequently, technology-specific coalitions were established in the Senegal River valley focused on three key issues: soil fertility management, weed management, and timely harvest and postharvest practices. These coalitions developed action plans and worked with farmers and agricultural machinery manufacturers to evaluate and adapt technologies at key sites, often through test plots and regular field visits. To address the harvest and postharvest 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; Wopereis *et al.*, 1998).

Gradually a basket of 'integrated rice management' (IRM) options was developed for the Senegal River valley (Box 1.3). These options provided guidance to extension agents and farmers in terms of good agricultural principles and practices. 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, and certified seed. Over time, AfricaRice 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).

These cropping calendars could be easily adjusted to any choice of sowing date × site × cultivar combination along the Senegal River valley 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 (ADRAO and SAED, 2000), as a support for research and

Box 1.3. Integrated rice management (IRM) options for the Senegal River valley (as formulated in the 1990s by AfricaRice and partners)

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 levelled.
2. Varietal choice: use pre-germinated certified seeds; for the dry season: Sahel 108 (good grain quality, but salinity sensitive) or I Kong Pao (low grain quality, salinity tolerant); and for the wet season: Sahel 108, Jaya, Sahel 201 or Sahel 202.
3. Sowing date: guided by RIDEV to avoid spikelet sterility due to cold or heat.
4. Seeding rates: use certified seed and 100 kg/ha and 40 kg/ha, respectively, for direct seeding and transplanting.
5. Maximum recommended fertilizer rates: 100 kg triple super phosphate (TSP, 20% P) or diammonium phosphate (DAP, 20% P, 18% N) per hectare and 250–300 kg urea (46% N) per hectare, 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 propanil (6 l/ha) and 2,4-D (1.5 l/ha) 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.
8. Harvest and postharvest: 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.

extension staff. Similar work was conducted for irrigation schemes in Burkina Faso (Segda *et al.*, 2004, 2005). Scaling-out of the IRM options was done through training of extension staff and promotional campaigns. A number of these modules have been converted into farmer training videos (entitled 'Rice Advice'), translated into more than 30 local African languages (Van Mele *et al.*, 2010).

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 were positively correlated to the number of IRM options farmers were able to adopt.

The Senegalese version of the thresher–cleaner was officially released by the minister of agriculture of Senegal in 1997 and obtained the 'Grand Prix du Président de la République du Sénégal pour les Sciences' in 2003. There are now hundreds of these machines in Senegal, Mali and Mauritania. 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. Follow-up work led to the development of a reaper to deal with this problem. More recent work on mechanization (2011–2012 cropping seasons) focused on testing mini-combine harvesters imported from the Philippines in Mali and Senegal, and subsequent local adaptation, fabrication and maintenance.

Rainfed lowland systems

Becker and Johnson (2001b) studied the effects of improved water control and crop management on lowland rice productivity in West Africa. Bunding significantly increased rice yield across sites by about 40% and controlled weeds, with approximately 25% less weed biomass in bunded than in open plots. Mineral fertilizer N application significantly increased rice yields (18% on average across sites) in bunded fields only. Levelling together with bunding facilitated water management and decreased weed competition – as many weed species are not well adapted to permanently flooded conditions (e.g. Kent and Johnson, 2001) – and generally increased nutrient use efficiencies, in particular in well-drained fields. Water management and regular drainage will also avoid problems with iron toxicity in inland-valley lowlands. Direct and indirect effects of iron toxicity in inland valleys can lead to 40–45% rice yield reductions in lowlands, depending on the extent of the problem, water, soil and crop management (e.g. cultivar choice) as well as on the availability of other soil nutrients (Becker and Asch, 2005; Audebert and Fofana, 2009). A synthesis of 15 years of multi-disciplinary research on iron toxicity in West Africa by AfricaRice and NARS partners was provided by Audebert *et al.* (2006).

Sakurai (2006) reported on a landmark study conducted in Côte d'Ivoire to explore factors that influence the expansion and intensification of rice production in rainfed lowland sites. Results showed that: (i) expansion of lowland rice cultivation was driven by population pressure and accessibility of the market; and (ii) the adoption of water control technologies is enhanced by the presence of immigrants and accessibility of the market. Investment in water supply canals was strongly influenced by land tenure security. Improved water control greatly enhanced rice productivity.

Erenstein (2006) and Erenstein *et al.* (2006) also studied increased inland-valley use for rice (and vegetable) production around large urban centres in West Africa. They concluded (in line with the conclusions of Sakurai, 2006) that market access was a necessary, but not sufficient factor for technological intensification of lowland use. They also concluded that better targeting of development efforts in terms of enabling lowland intensification is needed. Remote sensing or remote-sensing-derived products have been used to map inland valleys in the past (e.g. Thenkabail and Nolte, 1996). AfricaRice developed an automated mapping procedure based solely on a digital elevation model, which is globally available at a spatial resolution of 30 m (AfricaRice *et al.*, 2012). This standardized methodology is currently being implemented and validated for the entire West African region (S.J. Zwart and C.A. Linsoussi, Cotonou, Benin, 2012, personal communication).

Given the diversity and dynamics of farmer reality and growing conditions in rainfed lowland systems, AfricaRice developed a locally adapted and integrated approach to increase rice productivity in inland-valley production systems in Africa (Wopereis and Defoer, 2007). The approach is based on participatory learning and action-research (PLAR) and IRM. It is essentially a farmer-participatory, step-wise approach to put inland valleys under rice production using good agricultural principles and practices (Defoer *et al.*, 2004; Wopereis *et al.*, 2007).

Discussing these different approaches to technology development based on diagnostic and yield gap surveys, Wopereis and Defoer (2007) note that the need to use a 'PLAR approach' increases as one moves from high- to low-precision systems and from relatively uniform to more diverse production systems. Technology development can be more advanced in Sahelian irrigated lowland systems before evaluation by farmers; farmers in inland valleys need flexible technologies that can be adjusted relatively easily to local settings. Farmers in both low- and high-precision systems can benefit tremendously from decision-support tools and improved knowledge of agroecological and socio-economic principles. More on this approach is given in Defoer and Wopereis (Chapter 31, this volume).

Upland rice-based systems

Becker and Johnson (2001a) analysed cropping intensity effects on upland rice yield and sustainability in four agroecological zones in Côte d'Ivoire. Increased cropping intensity and reduced fallow duration were associated with yield reduction. Intensification-induced yield loss was about 25% (a drop from an average 1.5 t/ha to 1.1 t/ha) and was mainly related to increased weed infestation and declining soil quality.

Following the above study, cropping system alternatives using cover legumes as short-duration fallow crops were tested for reducing weed pressure and sustaining rice yield (Becker and Johnson 1998, 1999b; Akanvou *et al.*, 2000). Furthermore, to increase benefits from the systems, the timing of legume establishment in relation to rice and the effects of removing, burning, mulching or incorporating fallow residues prior to the rice crop on rice and weed growth were determined. Legume fallows appeared to offer good potential to sustain rice yields. Timing of legume establishment into upland rice depended on choice of legume, choice of rice variety, and their crop densities as well as environmental conditions (Saito *et al.*, 2010a). Incorporating or mulching of fallow residues provided no significant yield advantage compared to burning. On-farm participatory legume evaluation was also carried out and selected legumes were grown by farmers. Through this work, AfricaRice researchers learned that, in order to be successful, solutions such as improved fallows must consider the biophysical and socio-economic specifics of prevailing systems.

Box 1.4. Madagascar

Work in Madagascar by the national research institute (Foibem-pirenena Fikarohana ampiharina amin'ny Fampandrosoana ny Ambanivohitra, FOFIFA), Université d'Antananarivo and CIRAD on conservation agriculture in upland rice-based systems has led to expansion of improved fallow systems combined with mulching as residue management in no-tillage system in mid-west Madagascar (about 1800 ha). One of the major reasons for the expansion is the use of *Stylosanthes guianesis* as a fallow crop which seems to reduce *Striga* infestation (Michellon *et al.*, 2011).

Phosphorus deficiency is a major limiting factor in upland rice systems in the humid forest zone (Somado *et al.*, 2011). Responses of upland rice to P were studied by Sahrawat *et al.* (1995, 1997). Numerous other studies have been conducted to test the response of upland rice yield to P fertilizer application, including locally available rock P in West Africa in the 1990s and 2000s (e.g. Sahrawat *et al.*, 2003). Somado *et al.* (2011) reviewed previous studies related to agronomic management options for alleviating P deficiency, and suggested that integrated approaches combining agronomic management options with genetically tolerant or high P-use efficient varieties are essential.

A number of fertilizer management and IPM options were developed for upland NERICA varieties (e.g. Nwilene *et al.*, 2008a; Oikeh *et al.*, 2008, 2009; Sokei *et al.*, 2010; Ogha *et al.*, 2011; Touré *et al.*, 2011). However, these options have not yet been tested sufficiently in farmers' fields to enable out-scaling.

Across systems

Systematic evaluation of rice germplasm for African rice gall midge (AfRGM, *Orseolia oryzivora*) resulted in identification of over 50 primary sources of resistance among *O. glaberrima* and traditional *O. sativa* varieties (Nwilene *et al.*, 2002). AfRGM is attacked by the parasitoids *Platygaster diplosisae* and *Aprostocetus procerae* in rice-production systems (Nwilene *et al.*, 2008b). However, the level of parasitization is low because the parasitoid populations build up too late in the season to prevent heavy AfRGM infestation. Meanwhile, a related gall midge (paspalum gall midge, PGM, *Orseolia bonzii*) that forms galls on *Paspalum* grass is an important alternative host for the two parasitoids of AfRGM. Hence, habitat manipulation to increase the carry-over of parasitoids from PGM (which does not attack rice) to AfRGM, such as dry-season cultivation to encourage *Paspalum scrobiculatum* abundance early in the wet season, could improve the natural biological control of AfRGM.

Coyne *et al.* (1999) studied the prevalence of plant-parasitic nematodes associated with rice in Ghana and Côte d'Ivoire in rainfed upland, hydromorphic and lowland rice fields. Thirty days after the introduction of rice, nematode species diversity across ecosystems was reduced by 57% to 17 species. At harvest, species diversity was 55% lower than in adjacent forest and vegetation. With progression of the season, a small number of nematode genera became numerically dominant, while most nematode genera were present at low mean density. Lowland rice communities were characterized by low nematode intensity and low species diversity. An overview of nematode research in rice in West Africa is provided by Coyne and Plowright (2004).

Sy and Séré (1996) discuss the three major pathogens of rice in Africa: blast fungus

(*Magnaporthe oryzae*), *Rice yellow mottle virus* (RYMV) and the bacterium responsible for leaf blight (*Xanthomonas oryzae* pv. *oryzae*). Since the early 1990s, a large number of studies have been conducted on the spatial variability of isolates of these diseases and corresponding resistance genes in rice (e.g. Séré *et al.*, 2007; see also Séré *et al.*, Chapter 17, this volume).

Policy, Impact Assessment and Rice Value-Chain Development

Policy

During the 1980s and 1990s, AfricaRice and its member countries focused their attention on the effects of structural adjustment programmes on local rice production in West Africa. In particular, use was made of the Policy Analysis Matrix (PAM) approach to assess regional comparative advantage of rice across rice environments and markets, and the roles of policy in influencing competitiveness. Economists from national systems were trained in this approach through the Rice Policy Task Force (WARDA, 1997). At the turn of the millennium, AfricaRice began to take a more holistic, value-chain approach to rice policy. A 2-year rice-sector study in Nigeria culminated in 2003 with a strategy for the development of the national rice economy. Recommendations emphasized the need for:

- a consistent agriculture and trade policy, including price protection for local rice;
- upgrading quality management along the value chain;
- increasing value-chain efficiency; and
- enhancing policy dialogue among stakeholders and with government, including the establishment of a national rice stakeholders' forum (Erenstein *et al.*, 2003).

The Nigeria Rice Alliance was established and open debate of policy reform ensued. New policies were implemented in line with the new strategy, including 100% import-tariff increase in 2003 and 150% increase in 2005. Meanwhile, the government maintained subsidies on fertilizers and other agro-inputs. In terms of funding, US$400 million was allocated to boost agricultural production, including rice (AfricaRice, 2011a).

Between 2000 and 2006, AfricaRice conducted a broad review of policy in West Africa, using the Policy Analysis Matrix (AfricaRice, 2011a). The Center maintained the Africa Rice Statistics Databank and produced periodic *Africa Rice Trends* (e.g. WARDA, 2008). AfricaRice also conducted research on rice market efficiency and rice-sector competitiveness (AfricaRice, 2011a).

Policy comes to the fore as the food crisis looms

In June 2007, AfricaRice organized a 2-day workshop of the Africa Policy Research and Advocacy Group, at which it predicted the rice crisis which effectively happened in 2008. That message was delivered by AfricaRice's Director General at the AfricaRice Council of Ministers meeting in Abuja, Nigeria in September 2007, forewarning the ministers of the looming crisis, and encouraging them to turn the impending crisis into an opportunity. Specific recommendations delivered were to:

- establish seed legislation and encourage the involvement of the private sector in seed supply and trade;
- reduce the import tax on small-scale farm and processing machinery that can increase rice farmers' labour efficiency and improve grain quality;
- work together to reduce fertilizer prices (fertilizers in Africa are two to six times more expensive than in Asia and Europe);
- improve capacity at research, extension, processing and marketing levels;
- promote large-scale use of upland and lowland NERICA rice varieties; and
- significantly increase the share of high-yielding irrigated and lowland rice farming (Seck, 2007; AfricaRice, 2011a).

This work resulted in an Emergency Rice Initiative, funded by several donors, that helped over 110,000 farmers gain access to subsidized seed of improved varieties, fertilizer and improved crop-management methods during the 2008 food crisis. AfricaRice also contributed to the development of national rice development strategies for 21 African countries under the Coalition for African Rice Development (AfricaRice, 2011a).

Through its Council of Ministers and National Experts Committee (composed of the directors of the NARS) and engagement with the political authorities (ECOWAS, UEMOA, UNECA West Africa, CILSS,[8] AGRHYMET Regional Centre, etc.) of the region, AfricaRice has guided a gradual change in the policy environment from unfavourable to more favourable (aided by the food crisis) through buy-in from political leaders in the diagnosis of the problems and possible solutions. Frequent spikes in international rice prices – mainly the result of export restrictions in major Asian exporting countries, low stocks and speculation – have been a sobering lesson for most African rice-importing countries. They now realize that they **must** develop their local production. In countries where there are big vested interests in the importing of rice through large-scale, often diversified, powerful companies with political connections, changing the policy framework in favour of smallholder rice production and milling operations will be particularly hard.

Impact studies

Matlon *et al.* (1998) reviewed the adoption and impact of 'modern varieties' in West Africa. Hard data were scarce, but they report 95% adoption of modern varieties Bouaké 189 and IR8 in irrigated systems in the humid zone in Côte d'Ivoire. However, only 40% of the upland-rice area in the same country was planted with improved varieties (original data from AfricaRice–NARS Task Force). Meanwhile, an estimated 68% of the region's rainfed lowland areas was planted with modern varieties, with farmer adoption rates ranging from a low of 5–10% in western Côte d'Ivoire, through 20% in eastern Côte d'Ivoire and 35% in Sierra Leone, to 95% in Niger State, Nigeria. AfricaRice activities had led to high adoption rates in Sahelian irrigated systems in Mali (90%), the Senegal River valley (Mauritania and Senegal) (90%), Niger and Burkina Faso. An *ex-ante* impact study indicated an internal rate of return for the then AfricaRice Sahel irrigated-rice breeding programme in the range 40–55% (Fisher *et al.*, 1995, cited by Matlon *et al.*, 1998). These high internal rates of return were confirmed by Fall (2005). Matlon *et al.* (1998) also report various adoption rates for modern varieties in the mangrove-swamp rice environment of between 10% (for Guinea-Bissau) and 100% (Casamance, Senegal and Sierra Leone). They report additional rate-of-return studies, which are included in our own summary (see Table 1.1).

In 2001–2002, AfricaRice conducted a major study on the impact of improved rice varieties, from both national and international research centres in all West African rice-growing environments. The study estimated that genetic enhancement and transfer had increased the value of rice production by $93/ha (Dalton and Guei, 2003). The study also confirmed that while irrigated and rainfed lowland ecosystems have largely benefited from varietal improvements, the upland

Table 1.1. Meta-analysis of internal rates of return to rice genetic improvement R&D in West and Central Africa.

Country	Period	Internal rate of return (%)	Source
Sierra Leone	1976–1986	18–21	Tré (1995)
Guinea-Bissau	1980–1994	26	Seidi (1997)
Sierra Leone	1993	34	Edwin and Masters (1998)
Burkina Faso	1973–1999	43	Ouedraogo and Ouedraogo (2003)
Niger	1982–2000	66	Ibro *et al.* (2001)
Mauritania	1985–2000	68	Bah (2001); Fall (2005)
Mali	1979–1998	75	Kergna (2003)
Senegal	1985–2000	75–78	Fall (2005)
The Gambia	1988–2000	81	Bittaye *et al.* (2002)
Senegal	1995–2004	121	Fisher *et al.* (2001)
Chad	1983–2000	182	Dastre *et al.* (2003)

rice ecosystem lagged behind due to much lower adoption rates and limited yield gains.

AfricaRice (2011b) estimated that over 700,000 ha of land in Africa was under NERICA varieties in 2010 in 35 countries, with 243,000 ha in Nigeria, 140,000 ha in Guinea, 60,000 ha in The Gambia, 90,000 ha in Mali and 60,000 ha in Uganda. Compared with earlier estimates (Adegbola *et al.*, 2006; Diagne *et al.*, 2006), this shows a considerable increase in the area under NERICA varieties in Africa (see also Wopereis *et al.*, 2008; Diagne *et al.*, 2011). The probability of adoption and amount of area planted were enhanced in Uganda by membership of a farmers' group, formal education of the head of the farming household and the number of farming household members (Kijima *et al.*, 2006, 2008, 2011). There were significant positive effects on rice yields through NERICA adoption in Benin and The Gambia (Dibba *et al.*, 2012). However, no significant effects on rice yields were observed in Côte d'Ivoire and Guinea. Women profited generally more than men in almost all countries (Agboh-Noameshie *et al.*, 2006; Diagne *et al.*, 2011). In Nigeria, uptake of NERICA varieties was reportedly high in Kaduna and Ekiti states, with up to 30% of farmers in Ekiti and 42% of farmers in PVS villages in Kaduna cultivating NERICA varieties in 2005 (Spencer *et al.*, 2006). In Uganda, NERICA varieties have the potential to increase per-capita annual income by $20 (12% of actual per-capita income) and to decrease the poverty incidence by 5 percentage points, measured by the head count ratio (from 54.3% to 49.1%; Kijima *et al.*, 2006).

The global rice sector has been particularly responsive to agricultural R&D investment: the median annual rate of return amounting to 51–60% (Alston *et al.*, 2000; Evenson, 2001). Some 47% of the global R&D payoffs of the CGIAR, for instance, have been attributed to rice breeding (Raitzer and Kelley, 2008) and, in turn, 29% of the returns from rice genetic enhancements in West Africa, in particular, were attributable to the CGIAR (Dalton and Guei, 2003). Alene *et al.* (2007) show that rice R&D yields high returns in different ecosystems, but particularly in the moist savannah. However, only a handful of studies have actually attempted to estimate the rate of return to R&D in the sub-Saharan African rice sector. Our meta-analysis (presented in Table 1.1) suggests a high median rate of return of 68% to rice genetic improvement R&D in West and Central Africa. These findings concur with Renkow and Byerlee (2010), who conclude that the most profound documented positive impacts of the CGIAR are recorded for crop genetic improvement research. It is thus surprising that more is not invested in agricultural R&D, particularly in rice R&D.

Rice value-chain development

The importance of a value-chain approach to rice-sector development and the importance of rice quality came to the forefront with the Nigerian Rice Sector Policy Study of 2002–2003 (see above) and was highlighted by Lançon *et al.* (2004). It was clear that local rice in Nigeria was being discounted by around 30% compared to imports, mainly because of a lack of cleanness and presentation. By contrast, in Guinea and Mali certain varieties of local rice may receive a price premium (USAID, 2009). In order to improve the quality of local rice, institutional innovations are needed that make producers more responsive to end-users' requirements, and attach much more importance to milling and cleaning, and identity preservation (no mixing of different rice varieties).

The growing awareness of grain quality and marketing issues came to a head in the Center's 2006 External Programme and Management Review, which recommended adoption of a value-chain focus.

In 2008, AfricaRice and its national partners started a series of experimental auctions in Benin, Burkina Faso, Cameroon, The Gambia, Mauritania, Senegal and Uganda in order to assess consumers' willingness to pay for rice quality and marketing attributes (Demont *et al.*, 2012, 2013a,b). The main finding was that local rice is or can become competitive with imported rice after the necessary quality improvements (see Demont and Neven, Chapter 24, this volume).

Since 2011, AfricaRice and partners have adopted the concept of 'Rice Sector Development Hubs', referred to by Seck (2012) as 'fronts de développement agricole et rural'. These Hubs represent key rice-growing environments and different market opportunities across African countries and are linked to major national or regional rice-development efforts to facilitate broader uptake of rice knowledge and technologies. The geographic positioning of each Hub is determined in national workshops, convened by the NARS. Activities in the Hubs focus on producing sufficient quantities of the right quality of rice and rice-based products of interest to the national or regional markets in a sustainable manner. Hubs are regions strategic for rice development, where local innovations and research products and services are tested, adapted and integrated in 'baskets of good agricultural practices' (GAP, i.e. IRM options) with feedback provided to researchers on technology performance. Hubs also work to improve value chains by investing in institutional innovations and market development. Care is taken that women and youth are not marginalized, but rather strengthened in the process of rice value-chain development. By January 2013, some 59 Hubs had been identified in 20 countries in sub-Saharan Africa.

Surveys are currently (2012–2013) being conducted in the Hubs to understand farmers' practices and to identify constraints to rice production, processing and marketing. Gaps between actual yields obtained by farmers and what would be possible through improved management are being quantified (rice yield and productivity gaps). The surveys will also help to assess farmers' needs, gender dimensions, institutional and political arrangements, and linkages among value-chain actors. The results from these surveys will be used to set research priorities and for developing 'GAP baskets' for each Hub, analogous to what was done in the 1990s for irrigated systems in the Sahel (see Box 1.3), but with greater precision, across rice-growing environments and moving beyond production to postharvest issues and rice processing.

Hubs are built around large groups of farmers and involve other value-chain actors, such as rice millers, input dealers and rice marketers. Change agents from research, NGOs and extension agencies work with these actors to evaluate technological and institutional innovations, facilitate diffusion of knowledge and establish linkages along the rice value chain. These types of interactions are stimulated through the establishment of multi-stakeholder platforms (MSPs).

MSPs refer to a process which aims to bring stakeholders together in a new form of communication, 'decision finding' and, possibly, decision making on a particular issue (Hemmati, 2002). MSPs are also platforms for interaction among different stakeholders who share a common resource and interact to improve mutual understanding, create trust, define roles and engage in joint action (Thiele *et al.*, 2011). MSP participants can include those directly involved in agricultural production, processing and marketing, and also public- and private-sector partners with technical knowledge about extension and agriculture.

In Benin, MSP participants noted that the most significant outcomes of multi-stakeholder involvement were capacity development and increased rice yields in an inland-valley setting (Dossouhoui and Kinha, 2012). In relation to capacity development, participants noted how the MSP process helped actors who had otherwise worked individually to come together to complete certain activities – notably cultivation, processing and wholesaling. Actors felt that they had gained more confidence and technical experience through the MSP process, which helped the collective but also the actors/producers themselves. One of the MSPs in Benin noted that their yields had almost doubled, which was explained by access to improved rice varieties (i.e. IR841, NERICA-L 14, NERICA-L 19 and NERICA-L 20; Dossouhoui and Kinha, 2012).

In Mali, MSP participants noted similar benefits related to collective management of natural resources; however, their benefits focused more on improving governance (Bengaly *et al.*, 2012). Members felt that by participating in the MSP process, they better understood others' needs and resource-management objectives. They felt more cohesion among various resource-user groups such as fishers and potato farmers, who may not have been working in a collaborative capacity prior to MSP establishment. In addition, MSP actors noted that involvement in multi-actor processes provided access to rice technology (introduction of improved rice varieties). Women parboilers who were MSP members had become better organized with respect to rice parboiling and processing to sell their product. In terms of governance, the MSP facilitated negotiations among various sub-groups (e.g. fishers, potato farmers) for the use and management of irrigation systems within the inland valley. In addition, institutionally the MSP became the conduit to develop and implement the 5-year community plan for land and water development within the inland valley.

Conclusions

Agricultural R&D can be classified into two main categories: supply-shifting and demand-lifting. Supply-shifting R&D can be further sub-divided into: (i) **yield-increasing R&D** (e.g. genetic enhancement, breeding, biotechnology, IRM, crop husbandry); and (ii) **cost-reducing R&D** (e.g. technical change, collective management, efficiency increase, enhanced crop protection, labour-saving technologies). Demand-lifting R&D can be further sub-divided into: (iii) **quality-enhancing R&D** (e.g. grain quality, homogeneity and purity, visual, cooking, sensory and nutritional characteristics); and (iv) **marketing R&D** (e.g. processing, storage, transport, aggregation, distribution, value-chain development, access to markets, branding, advertising and generic promotion). Marketing R&D can also be supply-shifting (e.g. by reducing marketing and transaction costs and increasing efficiency of marketing systems). A final category which may have both supply-shifting and demand-lifting effects is: (v) **policy R&D** (creating a more conducive general policy climate for agribusiness, production, marketing and consumption).

Looking back at over 20 years of rice research for development in Africa, it is clear that most rice R&D has been related to supply-shifting and policy R&D. The outbreak of the civil war in Côte d'Ivoire in 2002 and the forced relocation of AfricaRice to Mali and then Benin in 2005 severely disrupted the research programmes, forcing the Center to essentially focus on rice-breeding efforts and networking activities. Since 2007, the Center has regained stable ground and research activities have increased rapidly, including both supply-shifting and demand-lifting R&D as documented in this book. The annual budget of the Center tripled from about $10 million in 2007 to $32 million in 2013. This book itself is an excellent illustration of the renewed vigour of the Center.

The new 2011–2020 strategic plan of the Center (AfricaRice, 2011b) emphasizes the need to conduct demand-lifting R&D through one of its seven priority areas, 'Creating market opportunities for smallholder farmers and processors by improving the quality and the competitiveness of locally produced rice and rice products'. The creation of Rice Sector Development Hubs, which is central in the 2011–2020 AfricaRice strategy (AfricaRice, 2011b), also points to the importance of combining different types of R&D and testing and developing technologies with partners along the rice value chain. The objective in these Hubs is to produce rice or rice-based products that respond to consumer preferences in urban and rural markets in quantities that are of interest to rice traders, who would usually import such products. Hubs will be strategically selected to allow linkage with major national or regional rice-development efforts to facilitate broader uptake of rice knowledge and technologies.

Supply-shifting R&D and demand-lifting R&D complement each other. Supply-shifting R&D creates value, but part of the value is transmitted to consumers through lower prices. Synchronous demand-lifting R&D redistributes part of this consumer welfare back to producers and strengthens vertical links between production and consumption throughout the value chain. Hence, the ultimate challenge for African policy makers, researchers and donors will be to find the optimal mix of investment between supply-shifting and demand-lifting R&D (Demont and Rizzotto, 2012) and ensure optimal links with public- and private-sector partners involved in Africa's multiple national and regional rice-sector development efforts (Seck *et al.*, 2012). As an association of currently 24 member states (February 2013), recognized by the African Union as the Center of Excellence for Rice Research in Africa, AfricaRice is well placed to coordinate these rice research-for-development efforts across the continent over the decades to come, in close collaboration with partners.

Notes

[1] AfricaRice is used throughout the rest of this chapter and book to refer to the Association and Center from its inception to the present day. One notable exception to this rule is the use of the correct name as it appears on publications in both citations and lists of references.
[2] IITA, International Institute of Tropical Agriculture; ILRI, International Livestock Research Institute; IWMI, International Water Management Institute.
[3] CIRAD, Centre de coopération internationale en recherche agronomique pour le développement.
[4] IRRI, International Rice Research Institute; CIAT, International Center for Tropical Agriculture.
[5] IRAT was responsible for crop genetic improvement in the French colonies and continued its rice breeding activities in most of francophone West Africa after independence. Many varieties were created through this research during the 1960s and 1970s – in particular, upland varieties developed by crossing African *japonica* (63-104, 63-83) and Brazilian *japonica* (Iguape Cateto, Dourado Précoce) with Asian temperate *japonica* (e.g. Lung Sheng 1). These crosses formed the basis of the IRAT series (e.g. IRAT 110, IRAT 112, IRAT 144, IRAT 146, IRAT 147). IRAT 13 was a product of gamma mutation on 63-83 from Senegal. West African countries such as Burkina Faso, Côte d'Ivoire, Mali and Senegal continued to receive bilateral support from IRAT and later CIRAD to strengthen upland rice breeding, in some cases up to the 1990s (Dalton and Guei, 2003). CIRAD continues to support the rice varietal improvement programme for high-altitude upland systems in Madagascar in collaboration with the NARS.
[6] During this period (1970s and 1980s), IITA conducted rice varietal improvement research at its headquarters in Ibadan, Nigeria. Its early programme (1974–1975) was primarily for upland rice environments, because it was believed that for irrigated systems with good water control there were many Asian-bred dwarf cultivars which could yield very well under West African conditions (Miézan and Sié, 1997). This resulted in the ITA series, the most well-known varieties being ITA 212 and ITA 306 released for irrigated systems in 1986, and ITA 150 released for upland cultivation in 1992 in Nigeria.
[7] Aus cultivars are very early maturing, drought-tolerant rice varieties grown under upland conditions in Bangladesh and West Bengal state of India during the so-called *Aus* season (March–June).
[8] ECOWAS, Economic Community of West African States; UEMOA, West African Economic and Monetary Union (Union économique et monétaire ouest-africaine); UNECA, United Nations Economic Commission for Africa; CILSS, Interstate committee for drought control in the Sahel region (Comité permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel).

References

Adégbola, P.Y., Arouna, A., Diagne, A. and Souléïmane, A.A. (2006) Evaluation de l'impact économique des nouvelles variétés de riz NERICA au Bénin: évidence avec les modèles basés sur l'approche contre factuel. Paper presented at the first Africa Rice Congress, Dar es Salaam, Tanzania, 31 July–4 August.
Adesina, A.A. (1996) Factors affecting the adoption of fertilizers by rice farmers in Côte d'Ivoire. *Nutrient Cycling in Agroecosystems* 46, 29–39.
Adesina, A.A. and Djato, K.K. (1996) Farm size, relative efficiency and agrarian policy in Côte d'Ivoire: Profit function analysis of rice farms. *Agricultural Economics* 14, 93–102.
ADRAO and SAED (2000) *Manuel Pratique pour la Riziculture Irriguée dans la Vallée du Fleuve Sénégal*. Association pour le développement de la riziculture en Afrique de l'Ouest, Saint-Louis, Senegal.
AfricaRice (2011a) *Lessons from the Rice Crisis: Policies for food security in Africa*. Africa Rice Center, Cotonou, Benin.
AfricaRice (2011b) *Boosting Africa's Rice Sector: A research for development strategy 2011–2020*. Africa Rice Center, Cotonou, Benin.
AfricaRice (2011c) Multi-national NERICA rice dissemination. Project report. Africa Rice Center, Cotonou, Benin.
AfricaRice (2012) The new Africa-wide Rice Breeding Task Force. In: *Africa Rice Center (AfricaRice) Annual Report 2011: A new rice research for development strategy for Africa.* Africa Rice Center, Cotonou, Benin, pp. 7–11.

AfricaRice, CBF (Cellule Bas-Fonds), ITRA (Institut Togolais de Recherche Agronomique) and IWMI (International Water Management Institute) (2012) Sawah, Market Access and Rice Technologies for Inland Valleys (SMART-IV) project Annual technical project report 2011–2012. Africa Rice Center, Cotonou, Benin.

Agboh-Noameshie R.A., Kinkingninhoun-Medagbe, F.M., Diagne, A. Simtowe, F.P. and Biaou, G. (2009) Who benefit more from NERICA varieties? Gender impact on production and income in Benin. Paper presented at the Conference on Perspectives on Impact Evaluation, an International Initiative for Impact Evaluation, Cairo, Egypt, 29 March–2 April.

Akanvou, R., Becker, M., Chano, M., Johnson, D.E., Gbaka-Tcheche, H. and Toure, A. (2000) Fallow residue management effects on upland rice in three agroecological zones of West Africa. *Biology and Fertility of Soils* 31, 501–507.

Alene, A.D., Manyong, V.M., Tollens, E.F. and Abele, S. (2007) Targeting agricultural research based on potential impacts on poverty reduction: Strategic program priorities by agro-ecological zone in Nigeria. *Food Policy* 32, 394–412.

Alston, J.M., Chan-Kang, C., Marra, M.C., Pardey, P.G. and Wyatt, T. (2000) A meta-analysis of rates of return to agricultural R&D: *Ex pede herculem*? *Research Report* 113. International Food Policy Research Institute, Washington, DC.

Andriesse, W., van Duivenbooden, N., Fresco, L.O., Windmeijer, P.N. (1994) A multi-scale approach to characterize inland valley agro-ecosystems in West Africa. *Netherlands Journal of Agricultural Science* 42: 159–179.

Asch, F. and Wopereis, M.C.S. (2001) Responses of field-grown irrigated rice cultivars to varying levels of floodwater salinity in a semi-arid environment. *Field Crops Research* 70, 127–137.

Asch, F., Dingkuhn, M., Wopereis, M.S.C., Dörffling, K. and Miezan, K.M. (1997) A conceptual model for sodium uptake and distribution in irrigated rice. In: Kropff, M.J., Teng, P.S., Aggarwal, P.K., Bouma, J., Bouman, B.A.M., Jones, J.W. and van Laar, H.H. (eds) *Applications of Systems Approaches at the Field Level*, vol. 2. Kluwer Academic Publishers, Dordrecht, Netherlands, pp. 201–217.

Asch, F., Dingkuhn, M., Wittstock, C. and Dörffling, K. (1999) Sodium and potassium uptake of rice panicles as affected by salinity and season in relation to yield and yield components. *Plant and Soil* 207, 133–145.

Asch, F., Becker, M. and Kpongor, D.S. (2005) A quick and efficient screen for resistance to iron toxicity in lowland rice. *Journal of Plant Nutrition and Soil Science* 168, 764–773.

Audebert, A. and Fofana, M. (2009) Rice yield gap due to iron toxicity in West Africa. *Journal of Agronomy and Crop Science* 195, 66–76.

Audebert, A. and Sahrawat, K.L. (2000) Mechanisms for iron toxicity tolerance in lowland rice. *Journal of Plant Nutrition* 23, 1877–1885.

Audebert, A., Narteh, L.T., Kiepe, P., Millar, D. and Beks, B. (2006) *Iron Toxicity in Rice-based Systems in West Africa*. Africa Rice Center, Cotonou, Benin.

Bah, M.S. (2001) *Impact économique de la recherche et de la vulgarisation sur le riz irrigué en Mauritanie*. Centre National de Recherche Agronomique et de Développement Agricole (CNRADA), Kaedi, Mauritania.

Becker, M. and Asch, F. (2005) Iron toxicity in rice – conditions and management concepts. *Journal of Plant Nutrition and Soil Science* 168, 558–573.

Becker, M. and Johnson, D.E. (1998) Legumes as dry season fallow in upland rice-based systems of West Africa. *Biology and Fertility of Soils* 27, 358–367.

Becker, M. and Johnson, D.E. (1999a) Rice yield and productivity gaps in irrigated systems of the forest zone of Côte d'Ivoire. *Field Crops Research* 60, 201–208.

Becker, M. and Johnson, D.E. (1999b) The role of legume fallows in intensified upland rice-based systems of West Africa. *Nutrient Cycling in Agroecosystems* 53, 71–81.

Becker, M. and Johnson, D.E. (2001a) Cropping intensity effects on upland rice yield and sustainability in West Africa. *Nutrient Cycling in Agroecosystems* 59, 107–117.

Becker, M. and Johnson, D.E. (2001b) Improved water control and crop management effects on lowland rice productivity in West Africa. *Nutrient Cycling in Agroecosystems* 59, 119–127.

Bengaly, M., Konaté, P., Dembélé, U., Yattara, K. and Senou, O. (2012) *Rapport Annuel: Les plates-formes multi-acteurs (PMA) pour le renforcement des capacités de changement institutionnel et de développement des acteurs au niveau des bas-fonds*. Institut d'Economie Rurale (IER), Bamako, Mali and Africa Rice Center, Cotonou, Benin.

Bèye, A.M., Jones, M. and Simpson, B. (2011) *The Community-based Seed System: The case of traditional rice farming system. The Technician's Manual.* AfricaRice Training Course Collection. Africa Rice Center, Cotonou, Benin.

Bittaye, A., Jones, K. and Drammeh, E. (2002) Economic impact assessment of the rice research program in The Gambia. National Agricultural Research Institute (NARI), Serekunda, The Gambia.

Boivin, P., Favre, F., Hammecker, C., Maeght, J.L., Delarivière, J., Poussin, J.C. and Wopereis, M.C.S. (2002) Processes driving soil solution chemistry in a flooded rice-cropped vertisol: analysis of long-time monitoring data. *Geoderma* 110, 87–107.

Ceuppens, J. and Wopereis, M.C.S. (1999) Impact of non-drained irrigated rice cropping on soil salinization in the Senegal River delta. *Geoderma* 92, 125–140.

CGIAR (2013) Centers chronology. www.cgiar.org/who-we-are/history-of-cgiar/centers-chronology/ (accessed 18 March 2013).

Cissoko, M., Boisnard, A., Rodenburg, J., Press, M.C. and Scholes, J.D. (2011) New Rice for Africa (NERICA) cultivars exhibit different levels of post-attachment resistance against the parasitic weeds *Striga hermonthica* and *Striga asiatica. New Phytologist* 192, 952–963.

Coyne, D. and Plowright, R.A. (2004) *Nematode Parasites of Rice*. The Africa Rice Center (WARDA), Bouaké, Côte d'Ivoire, and International Rice Research Institute, Los Baños, Philippines.

Coyne, D.L., Thio, B., Plowright, R.A. and Hunt, D.J. (1999) Observations on the community dynamics of plant parasitic nematodes of rice in Côte d'Ivoire. *Nematology* 1(4), 433–441.

Dalton, T.J. and Guei, R.G. (2003) Productivity gains from rice genetic enhancements in West Africa: countries and ecologies. *World Development* 31, 359–374.

Dastre, A.M., Betetmbaye, D., Ngawara, K.N. and Bagda, V. (2003) *Evaluation économique de l'impact de la recherche et de la vulgarisation sur le riz au Tchad*. Institut Tchadien de Recherche Agronomique pour le Développement, N'Djaména, Chad.

Defoer, T., Wopereis, M.C.S., Idinoba, P.A., Kadisha, T.K.L., Diack, S. and Gaye, M. (2004) *Curriculum for Participatory Learning and Action Research (PLAR) for Integrated Rice Management (IRM) in Inland Valleys of Sub-Saharan Africa: Facilitators' manual*. Africa Rice Center (WARDA), Cotonou, Benin, and IFDC, Muscle Shoals, Alabama.

Demont, M. and Rizzotto, A.C. (2012) Policy sequencing and the development of rice value chains in Senegal. *Development Policy Review* 30, 451–472.

Demont, M., Zossou, E., Rutsaert, P., Ndour, M., Van Mele, P. and Verbeke, W. (2012) Consumer valuation of improved rice parboiling technologies in Benin. *Food Quality and Preference* 23, 63–70.

Demont, M., Rutsaert, P., Ndour, M., Verbeke, W., Seck, P.A. and Tollens, E. (2013a) Experimental auctions, collective induction and choice shift: Willingness-to-pay for rice quality in Senegal. *European Review of Agricultural Economics* 40(2), 261–286.

Demont, M., Rutsaert, P., Ndour, M. and Verbeke, W. (2013b) Reversing urban bias in African rice markets: evidence from Senegal. *World Development* 45, 63–74.

Diagne, A., Sogbossi, M.J., Diawara, S. and Camara, A. (2006) L'étendue du succès de la dissémination des variétés NERICA en Guinée: estimation des superficies emblavées. [Mimeo]. Centre du riz pour l'Afrique (ADRAO), Cotonou, Benin.

Diagne, A., Midingoyi, S.-K. G., Wopereis, M. and Akintayo, I. (2011) Increasing rice productivity and strengthening food security through New Rice for Africa (NERICA). In: Punam, C.-P. and A. Manka (eds) *Yes Africa Can: Success stories from a dynamic continent*. The International Bank for Reconstruction and Development/The World Bank, Washington, DC, p. 492.

Dibba, L., Fialor, S.C., Diagne, A. and Nimoh, F. (2012) The impact of NERICA adoption on productivity and poverty of the small-scale rice farmers in The Gambia. Rice. *Food Security: The Science, Sociology and Economics of Food Production and Access to Food* 4(2), 253–265.

Dingkuhn, M. (1995) Climatic determinants of irrigated rice performance in the Sahel. III. Characterizing environments by simulating the crop's photothermal responses. *Agricultural Systems* 48, 435–456.

Dingkuhn, M. and Asch, F. (1999) Phenological responses of *Oryza sativa*, *O. glaberrima* and inter-specific rice cultivars on a toposquence in West Africa. *Euphytica* 110, 109–126.

Dingkuhn, M. and Miezan, K.M. (1995) Climatic determinants of irrigated rice performance in the Sahel. II. Validation of photothermal constants and characterization of genotypes. *Agricultural Systems* 48, 411–434.

Dingkuhn, M., Sow, A., Samb, A., Diack, S. and Asch, F. (1995) Climatic determinants of irrigated rice performance in the Sahel. I. Photothermal and micro-climatic responses of flowering. *Agricultural Systems* 48, 385–410.

Dingkuhn, M., Jones, M.P., Johnson, D.E. and Sow, A. (1998) Growth and yield potential of *Oryza sativa* and *O. glaberrima* upland rice cultivars and their interspecific progenies. *Field Crops Research* 57, 57–69.

Dingkuhn, M., Johnson, D.E., Sow, A. and Audebert, A.Y. (1999a) Relationships between upland rice canopy characteristics and weed competitiveness. *Field Crops Research* 61, 79–95.

Dingkuhn, M., Audebert, A.Y., Jones, M.P., Etienne, K. and Sow, A. (1999b) Control of stomatal conductance and leaf rolling in *O. sativa* and *O. glaberrima* upland rice. *Field Crops Research* 61, 223–236.

Donovan, C., Miézan, K.M., Wopereis, M.C.S., Diack, B.S. and Douthwaite, B. (1998) Technology transfer from Asia to Africa sets the stage for public and private sector collaboration in new technology in Senegal. *International Rice Research Notes* 23(2), 41–42.

Donovan, C., Wopereis, M.C.S., Guindo, D. and Nébié, B. (1999) Soil fertility management in irrigated rice systems in the Sahel and savanna regions of West Africa. Part II. Profitability and risk analysis. *Field Crops Research* 61, 147–162.

Dossouhoui, F. and Kinha, C. (2012) Rapport finale d'atelier de capitalisation des acquis et de relance de la dynamique des PMA de Dogbo et Houeyogbe. Africa Rice Center, Cotonou, Benin.

Edwin, J. and Masters, W.A. (1998) Returns to rice technology development in Sierra Leone. *Etudes et Recherches Sahéliennes/Sahelian Studies and Research* 1, 67–74.

Erenstein, O. (2006) Intensification or extensification? Factors affecting technology use in peri-urban lowlands along an agro-ecological gradient in West Africa. *Agricultural Systems* 90, 132–158.

Erenstein, O., Lançon, F., Akande, S.O., Titilola, S.O., Akpokodje, G. and Ogundele, O.O. (2003) Rice production systems in Nigeria: a survey. West Africa Rice Development Association, Abidjan, Côte d'Ivoire.

Erenstein, O., Oswald, A. and Mahaman, M. (2006) Determinants of lowland use close to urban markets along an agro-ecological gradient in West Africa. *Agriculture, Ecosystems and Environment* 117, 205–217.

Evenson, R.E. (2001) Economic impacts of agricultural research and extension. In: Gardner, B.L. and Rausser, G.C. (eds) *Handbook of Agricultural Economics*, Vol. 1. Elsevier, Amsterdam, Netherlands, pp. 573–628.

Fakorede, M.A.B. and Yoboué, N. (2001) *Summary of WARDA/NARS Task Forces Activities 1991–1997*. West Africa Rice Development Association, Bouaké, Côte d'Ivoire.

Fall, A.A. (2005) Impact économique de la recherche rizicole au Sénégal et en Mauritanie. *Agronomie Africaine* 5, 53–62.

Fisher, M.G., Masters, W.A. and Sidibé, M. (2001) Technical change in Senegal's irrigated rice sector: impact assessment under uncertainty. *Agricultural Economics* 24, 179–197.

GRiSP (2013) Beyond the 'good old times'. In: *GRiSP (Global Rice Science Partnership) Annual Report 2012.* International Rice Research Institute, Los Baños, Philippines, pp. 22–23.

Haefele, S., Johnson, D.E., Diallo, S., Wopereis, M.C.S. and Janin, I. (2000) Improved soil fertility and weed management is profitable for irrigated rice farmers in Sahelian West Africa. *Field Crops Research* 66, 101–113.

Haefele, S., Wopereis, M.C.S., Donovan, C. and Maubuisson, J. (2001) Improving productivity and profitability of irrigated rice production in Mauritania. *European Journal of Agronomy* 14(3), 181–196.

Hemmati, M. (2002) *Multi-stakeholder Processes for Governance and Sustainability: Beyond deadlock and conflict*. Earthscan, London.

Ibro, G., Oumar, A.A., Amir, S.Y., Hamidou, O., Yaovi, S. and Hassane, A.M. (2001) *Analyse économique de l'impact de la recherche sur le riz au Niger*. Institut National de la Recherche Agronomique du Niger, Niamey, Niger.

Jamil, M., Rodenburg, J., Charnikhova, T. and Bouwmeester, H.J. (2011) Pre-attachment *Striga hermonthica* resistance of NERICA cultivars based on low strigolactone production. *New Phytologist* 192, 964–975.

Johnson, D.E. (1997) *Weeds of Rice in West Africa*. West Africa Rice Development Association, Bouaké, Côte d'Ivoire.

Jones, M.P., Dingkuhn, M., Aluko, G.K. and Semon, M. (1997) Interspecific *Oryza sativa* L. × *O. glaberrima* Steud. progenies in upland rice improvement. *Euphytica* 92, 237–246.

Kebbeh, M. and Miézan, K.M. (2003) *Ex-ante* evaluation of integrated crop management options for irrigated rice production in the Senegal River valley. *Field Crops Research* 81, 87–94.

Kent, R.J. and Johnson, D.E. (2001) Influence of flood depth and duration on growth of lowland rice weeds, Côte d'Ivoire. *Crop Protection* 20(8), 691–694.

Kergna, A. (2003) *Evaluation économique de l'impact de la recherche et de la vulgarisation sur le riz au Mali*. Institut d'Economie Rurale, Bamako, Mali.

Kijima, Y., Sserunkuuma, D. and Otsuka, K. (2006) How revolutionary is the 'NERICA Revolution'? Evidence from Uganda. *The Developing Economies* 44(2), 252–267.

Kijima, Y., Otsuka, K. and Sserunkuuma, D. (2008) Assessing the impact of NERICA on income and poverty in central and western Uganda. *Agricultural Economics* 38, 327–337.

Kijima, Y., Otsuka, K. and Sserunkuuma, D. (2011) An inquiry into constraints on a green revolution in sub-Saharan Africa: the case of NERICA rice in Uganda. *World Development* 39(1), 77–86.

Lançon, F., Erenstein O., Touré, A.A. and Akpokodje G. (2004) Qualité et compétitivité des riz locaux et importe sur les marches urbains ouest-africains. *Cahiers d'études et de recherches francophone / Agricultures* 13(1), 110–115.

Matlon, P.J., Randolph, T. and Guei, R. (1998) Impact of rice research in West Africa. In: Pingali, P.L. and Hossain, M. (eds) *Impact of Rice Research*. International Rice Research Institute, Los Baños, Philippines, pp. 383–401.

Michellon, R., Husson, O., Moussa, N., Randrianjafizanaka, M.T., Naudin, K., Letourmy, P., Andrianaivo, A.P., Rakotondramanana, Raveloarijoana, N., Enjalric, F., Penot, E and Séguy, L. (2011) *Striga asiatica*: a driving-force for dissemination of conservation agriculture systems based on *Stylosanthes guianensis* in Madagascar. Paper presented at the 5th World Congress of Conservation Agriculture incorporating 3rd Farming Systems Design Conference, Brisbane, Australia, September 2011.

Miézan, K.M. and Sié, M. (1997) Varietal improvement for irrigated rice in the Sahel. In: Miézan, K.M., Wopereis, M.C.S., Dingkuhn, M., Deckers, J. and Randolph, T.F. (eds) *Irrigated Rice in the Sahel: Prospects for sustainable development*. West Africa Rice Development Association, [Bouaké, Côte d'Ivoire], pp. 443–455.

Narteh, L.T., Millar, D. and Beks, B. (Eds) (2006) *Proceedings of the 3rd Regional Rice Research Review (4Rs 2004)*. Accra, Ghana, 27 September to 1 October 2004. Africa Rice Center (WARDA), Cotonou, Benin.

Nwilene, F.E., Williams, C.T., Ukwungwu, M.N., Dakouo, D., Nacro, S., Hamadoun, A., Kamara, S.I., Okhidievbie, O., Abamu, F.J. and Adam, A. (2002) Reactions of differential rice genotypes to African rice gall midge in West Africa. *International Journal of Pest Management* 48(3), 195–201.

Nwilene, F.E., Agunbiade, T.A., Togola, A., Youm O., Ajayi, O., Oikeh, S.O., Ofodile. S. and Falola, O.O. (2008a) Efficacy of traditional practices and botanicals for the control of termites on rice at Ikenne, southwest Nigeria. *International Journal of Tropical Insect Science* 28, 37–44.

Nwilene, F.E., Togola, A., Agunbiade, T.A., Ogah, E.O., Ukwungwu, M.N., Hamadoun, A., Kamara, S.I. and Dakouo, D. (2008b) Parasitoid biodiversity conservation for sustainable management of the African rice gall midge, *Orseolia oryzivora* (Diptera: Cecidomyiidae) in lowland rice. *Biocontrol Science and Technology* 18(10), 1075–1081.

Ogha, O.O., Omoloye, A.A., Nwilene, F.E. and Nwogbaga, A.C. (2011) Effect of neem seed kernel extracts in the management of rice stem borers in the field in Nigeria. *Nigerian Journal of Biotechnology* 23, 13–21.

Oikeh, S., Touré, A., Sidibé, B., Niang, A., Semon, M., Sokei, Y. and Mariko, M. (2009) Responses of upland NERICA rice varieties to nitrogen and plant density. *Archives of Agronomy and Soil Science* 55, 301–314.

Oikeh, S.O., Houngnandan, P., Abaidoo, R.C., Rahimou, I., Toure, A., Niang, A. and Akintayo, I. (2008) Integrated soil fertility management involving promiscuous dual-purpose soybean and upland NERICA enhanced rice productivity in the savannas. *Nutrient Cycling in Agroecosystems* 88, 29–38.

Ouedraogo, S. and Ouedraogo, M. (2003) *Evaluation économique de l'impact de la recherche et de la vulgarisation sur le riz au Burkina Faso*. Institut de l'Environnement et des Recherches Agricoles, Ouagadougou, Burkina Faso.

Raitzer, D.A. and Kelley, T.G. (2008) Benefit–cost meta-analysis of investment in the international agricultural research centers of the CGIAR. *Agricultural Systems* 96, 108–123.

Renkow, M. and Byerlee, D. (2010) The impacts of CGIAR research: a review of recent evidence. *Food Policy* 35, 391–402.

Rodenburg, J., Saito, K., Kakai, R.G., Toure, A., Mariko, M. and Kiepe, P. (2009) Weed competitiveness of the lowland rice varieties of NERICA in the southern Guinea savanna. *Field Crops Research* 114, 411–418.

Sahrawat, K.L. (2000) Elemental composition of the rice plant as affected by iron toxicity under field conditions. *Communications in Soil Science and Plant Analysis* 31, 2819–2827.

Sahrawat, K.L. (2004) Iron toxicity in wetland rice and the role of other nutrients. *Journal of Plant Nutrition* 27, 1471–1504.

Sahrawat, K.L., Jones, M.P. and Diatta, S. (1995) Responses of upland rice to phosphorus in an Ultisol in the humid forest zone of West Africa. *Fertilizer Research* 41, 11–17.

Sahrawat, K.L., Jones, M.P. and Diatta, S. (1997) Direct and residual phosphorus effects on yield and phosphorus efficiency of upland rice in an Ultisol. *Nutrient Cycling in Agroecosystems* 48, 209–215.

Sahrawat, K.L., Jones, M.P., Diatta, S. and Sika, M. (2003) Long-term phosphorus fertilizer effects on phosphorus uptake, efficiency, and recovery by upland rice on an Ultisol. *Communications in Soil Science and Plant Analysis* 14, 999–1011.

Saito, K. and Futakuchi, K. (2009) Performance of diverse upland rice cultivars in low and high soil fertility conditions in West Africa. *Field Crops Research* 111, 243–250.

Saito, K., Azoma, K. and Oikeh, S. (2010a) Combined effects of *Stylosanthes guianensis* fallow and tillage management on upland rice yield, weeds and soils. *Soil and Tillage Research* 107(2), 57–63.

Saito, K., Azoma, K. and Rodenburg, J. (2010b) Plant characteristics associated with weed competitiveness of rice under upland and lowland conditions in West Africa. *Field Crops Research* 116, 308–317.

Saito, K., Azoma, K. and Sokei, Y. (2010c) Genotypic adaptation of rice to lowland hydrology in West Africa. *Field Crops Research* 119(2–3), 290–298.

Saito, K., Sokei, Y. and Wopereis, M.C.S. (2012) Enhancing rice productivity in West Africa through genetic improvement. *Crop Science* 52, 484–494.

Sakurai, T. (2006) Intensification of rainfed lowland rice production in West Africa: present status and potential green revolution. *The Developing Economies* 44, 232–251.

Sanyang, S., Ajayi, A. and Sy, A.A. (Eds) (2003) *Proceedings of the Second Biennial Regional Rice Research Review (4Rs 2002)*. M'bé, Bouaké, Côte d'Ivoire, 9–12 April 2002. Africa Rice Center (WARDA), Bouaké, Côte d'Ivoire.

Seck, P.A. (2007) Rice crisis in Africa, myth or reality? Presentation at the 26th AfricaRice Council of Ministers Session, Abuja, Nigeria, 26 September.

Seck, P.A. (2012) *Eloge de la Recherche: Passion et tension d'un chercheur africain*. Editions Panafrika, Silex – Nouvelles du Sud, Dakar, Senegal.

Seck, P.A., Diagne, A., Mohanty, S. and Wopereis, M.C.S. (2012) Crops that feed the world 7: rice. *Food Security* 4, 7–24.

Segda, Z., Häfele, S.M., Wopereis, M.C.S., Sedogo, M.P. and Guinko, S. (2004) Agro-economic characterization of rice production in a typical irrigation scheme in Burkina Faso. *Agronomy Journal* 96, 1314–1322.

Segda, Z., Häfele, S.M., Wopereis, M.C.S., Sedogo, M.P. and Guinko, S. (2005) Combining field and simulation studies to improve fertilizer recommendations for irrigated rice in Burkina Faso. *Agronomy Journal* 97, 1429–1437.

Seidi, S. (1997) An economic analysis of mangrove rice research, extension and seed production in Guinea-Bissau: preliminary evidence from the Tombali region. Mimeo. Department of Agricultural Economics, Purdue University, West Lafayette, Indiana.

Séré, Y., Onasanya, A., Akator, K., Afolabi, A. and Abo, M.E. (2007) Serological differentiation indices and phylogenetic analysis of *Rice yellow mottle virus* isolates in Côte d'Ivoire. *Journal of Biological Sciences* 7(7), 1147–1154.

Sié, M., Sere, Y., Sanyang, S., Narteh, L.T., Dogbe, S., Coulibaly, M.M., Sido, A., Cisse, F., Drammeh, E., Ogunbayo, S.A., Zadij, L., Ndri, B. and Toulou, B. (2008a) Regional yield evaluation of interspecific hybrids (*O. glaberrima* × *O. sativa*) and intraspecfic (*O. sativa* × *O. sativa*) lowland rice. *Asian Journal of Plant Sciences* 7, 130–139.

Sié, M., Futakuchi, K., Gridley, H., Mande, S., Manneh, B., Ndijondijop, M.N., Efisue, A., Ogunbayo, S.A., Moussa, M., Tsunematsu, H. and Samejima, H. (2008b) Drought research at WARDA: current situation and prospects. In: Serraj, R., Bennett, J. and Hardy, B. (eds) *Drought Frontiers in Rice: Crop improvement for increased rainfed production.* World Scientific Publishing, Singapore, and International Rice Research Institute, Los Baños, Philippines, pp. 61–73.

Sokei, Y., Akintayo, I., Doumbia, Y., Gibba, A., Keita, S. and Assigbe, P. (2010) Growth and yield performance of upland NERICA varieties in West Africa. *Japanese Journal of Crop Science* 79(Extra issue 2), 2–3.

Somado, E.A., Kiepe, P. and Niang, A. (2011) Alleviating phosphorus deficiency in rice-based systems in humid Africa. In: Yanagihara, S. (ed.) Next Challenges in Rice Development for Africa: Workshop for New Collaboration between JIRCAS and AfricaRice. *JIRCAS Working Report* 70. Japan International Research Center for Agricultural Sciences, Tsukuba, Japan, and Africa Rice Center, Cotonou, Benin, pp. 29–35.

Spencer, D.S.C., Dorward, A., Abalu, G., Philip, D. and Ogunbile, D. (2006) Evaluation of adoption of NERICA and other improved upland rice varieties following varietal promotion activities in Nigeria. A study for the Gatsby and Rockefeller Foundations, Final Report.

Sy, A.A. and Séré, Y. (1996) *Manuel de formation en pathologie du riz*. Association pour le Développement de la Riziculture en Afrique de l'Ouest, Bouaké, Côte d'Ivoire.
Thenkabail, P.S. and Nolte, C. (1996) Capabilities of Landsat-5 Thematic Mapper (TM) data in regional mapping and characterization of inland valley agroecosystems in West Africa. *International Journal of Remote Sensing* 17, 1505–1538.
Thiele, G., Devaux, A., Reinoso, I., Pico, H., Montesdeoca, F., Pumisacho, M., Andrade-Piedra, J., Velasco, C., Flores, P., Esprella, R., Thomann, A., Manrique, K. and Horton, D. (2011) Multi-stakeholder platforms for linking small farmers to value chains: evidence from the Andes. *International Journal of Agricultural Sustainability* 9(3), 423–433.
Touré, A., Rodenburg, J., Saito, K., Oikeh, S., Futakuchi, K., Gumedzoe, D. and Huat, J. (2011) Cultivar and weeding effects on weeds and rice yield in a degraded upland environment of the coastal savanna. *Weed Technology* 25, 322–329.
Tré, J.-P. (1995) The rates of return to mangrove rice research in West Africa. MSc thesis, Purdue University, West Lafayette, Indiana.
USAID (2009) *Global Food Security Response: West Africa rice value chain analysis*. United States Agency for International Development, Washington, DC.
Van Asten, P.J.A., Wopereis, M.C.S., Haefele, S., Ould Isselmou, M. and Kropff, M.J. (2003a) Explaining yield gaps in farmer-identified degraded and non-degraded soils in a Sahelian irrigated rice scheme. *Netherlands Journal of Agricultural Science* 50, 277–296.
Van Asten, P.J.A., Barbiero, L., Wopereis, M.C.S. and Maeght, J.L. (2003b) Actual and potential salt-related soil degradation in an irrigated rice scheme in the Sahelian zone of Mauritania. *Agricultural Water Management* 60, 13–32.
Van Mele, P., Wanvoeke, J. and Zossou, E. (2010) Enhancing rural learning, linkages and institutions: the rice videos in Africa. *Development in Practice* 20(3), 414–421.
WARDA (1997) Rice or semiconductors? In: *WARDA Annual Report 1997*. West Africa Rice Development Association, Bouaké, Côte d'Ivoire, pp. 50–55.
WARDA (1999) Task Forces: a successful mode of operation with national partners. In: *WARDA Annual Report 1998*. West Africa Rice Development Association, Bouaké, Côte d'Ivoire, pp. 9–15.
WARDA (2000) *WARDA Annual Report 1999.* West Africa Rice Development Association, Bouaké, Côte d'Ivoire.
WARDA (2001a) *WARDA: 1970–2001.* West Africa Rice Development Association, Bouaké, Côte d'Ivoire.
WARDA (2001b) *NERICAs in Guinea: Towards food security. The history and keys of success.* West Africa Rice Development Association, Bouaké, Côte d'Ivoire.
WARDA (2001c) *Bintu and Her New Rice for Africa: Breaking the shackles of slash-and-burn farming in the world's poorest region.* West Africa Rice Development Association, Bouaké, Côte d'Ivoire.
WARDA (2002a) The African Rice Initiative: taking the NERICAs to sub-Saharan Africa. In: *WARDA Annual Report 2001–2002.* West Africa Rice Development Association, Bouaké, Côte d'Ivoire, pp. 9–14.
WARDA (2002b) *Promising Technologies for Rice Production in West and Central Africa.* West Africa Rice Development Association, Bouaké, Côte d'Ivoire, and Food and Agriculture Organization of the United Nations, Rome.
WARDA (2004) The Africa Rice Center – recognizing WARDA's role in sub-Saharan Africa. In: *WARDA Annual Report 2002–2003.* WARDA – The Africa Rice Center, Bouaké, Côte d'Ivoire, pp. 7–12.
WARDA (2008) *Africa Rice Trends 2007.* Africa Rice Center (WARDA), Cotonou, Benin.
Windmeijer, P.N., Stomph, T.J., Adam, A., Coppur, R., De Ridder, N., Kandeh, M., Mahaman, M. and Van Loon, M. (1998) Transect sampling strategies for semi-detailed characterization of inland valley systems. *Netherlands Journal of Agricultural Science* 46(1), 15–25.
Wopereis, M.C.S. and Defoer, T. (2007) Moving methodologies to enhance agricultural productivity of rice-based lowland systems in sub-Saharan Africa. In: Bationo, A., Waswa, B., Kihara, J. and Kimetu, J. (eds) *Advances in Integrated Soil Fertility Management in Sub-Saharan Africa: Challenges and opportunities.* Springer, Dordrecht, Netherlands, pp. 1077–1091.
Wopereis, M.C.S., Miézan, K.M., Donovan, C., Ndiaye, A.M. and Douthwaite, B. (1998) A new Senegalese thresher / cleaner responds to small-farmer postharvest needs. *International Rice Research Notes* 23(2), 39–41.
Wopereis, M.C.S., Donovan, C., Nebié, B., Guindo, D. and N'Diaye, M.K. (1999) Soil fertility management in irrigated rice systems in the Sahel and savanna regions of West Africa. Part I. Agronomic analysis. *Field Crops Research* 61, 125–145.
Wopereis, M.C.S., Haefele, S.M., Dingkuhn, M. and Sow, A. (2003) Decision support tools for irrigated rice based systems in the Sahel. In: Struif-Bontkes, T.E. and Wopereis, M.C.S. (eds) *Decision Support*

Tools for Smallholder Agriculture in Sub-Saharan Africa: A practical guide. IFDC, Muscle Shoals, Alabama, and ACP–EU Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen, Netherlands, pp. 114–126.

Wopereis, M.C.S., Defoer, T., Idinoba, M.E., Diack, S. and Dugué, M.J. (2007) *Participatory Learning and Action Research (PLAR) for Integrated Rice Management (IRM) in Inland Valleys of Sub-Saharan Africa: Technical manual*. Africa Rice Center (WARDA), Cotonou, Benin, and IFDC, Muscle Shoals, Alabama.

Wopereis, M.C.S., Diagne, A., Rodenburg, J., Sié, M. and Somado, E.A. (2008) Why NERICA is a successful innovation for African farmers: a response to Orr *et al.* from the Africa Rice Center. *Outlook on Agriculture* 37(3), 169–176.