Exploiting Partnerships in Research and Development to help African Rice Farmers cope with Climate Variability

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Abstract

Climate change is already impacting negatively on Africa through extreme temperatures, frequent flooding and droughts and increased salinity of water supplies used for irrigation. Widespread poverty and high dependence on rainfed agriculture in Africa renders the continent more vulnerable to climate change-induced disasters than other regions of the world. Thus urgent measures need to be undertaken to improve the resilience of African communities, especially those in rural areas, to enable them to better adapt to climate change. Rice is an important crop in the continent, both for food security and commerce, and increased rice production in Africa will be crucial in achieving the necessary adaptation. However, rice production in Africa is affected by abiotic stresses such as heat stress, flooding, drought and salinity, all of which are expected to worsen with climate change. The Africa Rice Center (WARDA) is well positioned to use its partnership-based model through its networks for developing and disseminating climate-resilient rice-based technologies in Africa. Through its partners in regional networks WARDA has developed and disseminated several technologies such as the New Rice for Africa or NERICA®, the adoption of which have led to increased rice production as well as improved livelihoods for farm families in Africa. WARDA could therefore play a critical role in offering African communities further durable options for increased food security and better livelihoods to help them adapt to the effects of climate change. However, more work is needed in environmental characterization, prediction of future climate patterns and wider dissemination of already developed climate-resilient rice-based technologies.

Introduction

Climate change has become a major concern worldwide. In Africa, major symptoms of such change include disruption of normal climate patterns over large areas, increasing incidence of drought and extreme temperatures, heavy flooding and increasing levels of salt stress both in inland and coastal areas. These problems are progressively becoming more and more severe in terms of frequency and severity (Desanker and Magadza, 2001; Hulme et al., 2001). Africa is particularly vulnerable to climate change because of the over-dependence on rainfed agriculture and the high incidence of poverty. A study by ILRI using climate models identified the areas in sub-Saharan Africa (SSA) most vulnerable to adverse effects of climate change to be the West African Sahel; the rangelands, Great Lakes and coastal areas of Eastern Africa; and the drier zones of Southern Africa (CGIAR, 2007a). Millions of Africans in these regions were affected by droughts and floods and consequent disaster-related epidemics of malaria, meningitis or cholera during the last three decades of the past millennium (Figure 1.).

The inter-annual climate variability will compound food production problems in Africa which is already faced with a burgeoning population. Over the last 30 years, food production has kept pace with population growth in developing countries except those in SSA (Desanker and Magadza, 2001; Maclean et al., 2002). Hunger currently affects about half of the continent’s population and is expected to worsen if the current trends are not halted or even reversed. Rice can be used to offset the major impacts of climate change. This is because of the unique properties of rice as a food crop for the urban poor, as well as for rural rice-growing populations. It is one of the major food crops in Africa, especially in Western Africa, and is gaining in popularity in East and Southern Africa. For instance, rice consumption growth rate in Southern Africa and East Africa was largely higher than in West Africa during the 2001-2005 period (CGIAR, 2007b).

However, production of rice, as for other crops, is beset by constraints such as drought, flooding, salt stress and extreme temperatures, all of which are expected to worsen with climate change.

Drastic changes in rainfall patterns coupled with rising temperatures will introduce unfavorable growing conditions (due to drought, flooding etc.) into cropping calendars thereby modifying growing seasons which could subsequently reduce crop productivity. Hence, the underlying processes and the short- and long-term directions of such changes need to be well understood in order to formulate appropriate adaptive strategies and policies. Solutions require multidisciplinary and integrated approaches to develop a combination of improved germplasm with tolerances to prevailing and anticipated stresses and proper crop and environmental management strategies that could transform the agricultural sector to protect farmers, consumers and the environment.

Forging strong and durable linkages between rural communities and national and international research and development partners is a pre-condition to the development of technologies that would reduce the vulnerability of such communities to anticipated adverse effects of climate change. Currently, a range of NGOs, sub-regional organizations, development agencies and farmers' groups are increasingly becoming vehicles for transformation of rural communities. The private sector (e.g. traders, processors and agricultural input agents, and multinationals) is also beginning to play an important role in technology development, testing, marketing and adoption. Partnerships bring these diverse interests together to create synergies and contribute to greater efficiencies in access to knowledge and resource mobilization for research. This paper discusses adverse effects of climate change on rice production in Africa and how the network-based partnership model of the Africa Rice Center (WARDA) could contribute to the development and dissemination of rice-based technologies that would help mitigate negative effects of climate change on African rice production.

Evidence of climate change in Africa

Historical climate records show worrying trends in climate variables for most of Africa: warming of approximately 0.7 C over most of the continent during the 20th century at the rate of about 0.05°C per decade with slightly greater warming in the June–November seasons than in December–May; a decrease in rainfall over large portions of the Sahel (the semi-arid region south of the Sahara); and an increase in rainfall in east central Africa (Desanker and Magadza, 2001; Hulme et al., 2001).

Mean temperatures in Africa over the last 30 years showed a pronounced upward trend and were above the long-term average of the past 100 years (Fig. 2). Furthermore, the five warmest years in Africa in the last century all occurred since 1988, with 1988 and 1995 being the two warmest years (Desanker and Magadza, 2001). These rising temperatures have led to the rapid melting of snow caps on mountains. For example, the glaciers on Kilimanjaro have shrunk by 73% over the last century (Mastny, 2000) and those on Mount Kenya and the Rwenzori Mountains are also gradually receding (UNEP, 2002). Several seasonal rivers and streams fed by water from the annual melting of snow from these mountains have already dried up.

Furthermore, since 1968, the average rainfall in Africa has been decreasing and fluctuating around a notably lower mean (UNEP, 1999). This has led to shortened rainy seasons in many areas thereby further aggravating the insufficient water supply available for agricultural production since many African countries receive less than 500 mm of rainfall and are thus considered dry lands (UNEP, 2006). In addition, inter-annual rainfall variability is great over most of Africa and for some regions, most notably the Sahel, multi-decadal variability in rainfall has also been substantial. The rainfall trends of the continent through the 20th century showed drying of up to 2.5% per decade or more in some western and eastern parts of the Sahel (Hulme et al., 2001). This reduced mean rainfall is expected to persist as a result of climate change. In recent years, the pattern of rainfall has tended towards the extremes, with increasing severity and frequency of droughts and floods. Many countries, including Botswana, Burkina Faso, Chad, Ethiopia, Kenya, Mauritania and Mozambique, experience drought at regular intervals (UNEP, 2006). Floods are also becoming more frequent in Africa despite the generally reduced mean rainfall over most of the continent. The east Africa floods of 1998, the Mozambique floods of 2000 and the more recent floods in West Africa (Ghana, Benin, Togo, Burkina Faso and Nigeria) in 2007 were devastating and led to the loss of much farmland, damage to transport networks, disease outbreaks and loss of human life. The continent already experiences a major deficit in food production in many areas, and potential further declines in soil moisture or inundation of crop lands will be added burdens.

Effects of climate change on rice production in Africa

Many abiotic factors (drought, submergence, extreme temperatures, salinity and low soil fertility) and biotic constraints (weeds and diseases such as blast) limit the continent's rice production. Climate change, by inducing variations in the climate patterns (increasing incidence of drought, extreme temperatures and flooding, and increasing levels of salt stress), is expected to aggravate these constraints, thereby affecting rice yields. However, the extent of loss of production due to climate change will differ between the five rice production systems recognized in SSA – rainfed upland, rainfed lowland, irrigated lowland, mangrove swamp and deepwater. Among these, the greatest threats to rice production due to climate change are anticipated in the rainfed rice production systems due to their often total dependence on rainfall as a source of water. However, mangrove rice production systems also face, increased risks of flooding, coastal erosion, saline intrusion and storm surges (Field, 1995; Ball et al., 1997), and increased salinity in irrigated rice production systems is an expected consequence of climate change.

1. Heat stress: Extreme weather conditions, especially extreme temperatures, are occurring with increasing frequency. In SSA, however, generally rising temperatures mean that heat stress induced by climate change is perceived to be a greater threat to rice production than cold stress. The risk of high-temperature stress is present in all rice production systems from lowlands to uplands. Rice is sensitive to temperature fluctuations but its sensitivity depends on developmental stage. Flowering is the most sensitive stage to extreme temperatures with very cold or very hot weather leading to high spikelet sterility. Also, high air temperatures reduce tillering, cause stunting (Futakuchi, 2005) and accelerate the developmental rate of rice thereby leading to shortened growing cycles. Thus higher temperatures induced by climate change may lead to substantial adverse effects on rice production.

2. Drought: Over 50% of the African continent possesses a dry land climate of which drought is an inherent characteristic. Rainfed uplands and lowlands are more prone to drought stress than other rice production systems and, since these form the bulk of the rice area in Africa, droughts can be particularly damaging to rice production in Africa. Droughts can also affect irrigated rice fields with poor water control. Water stress has been identified as one of the most important production constraint in Africa. Crop failure due to drought generally occurs once every five years (Africa Rice Center, 2004). Compared to other crops, rice is particularly sensitive to drought. Drought can reduce stand establishment, tillering, plant height and spikelet fertility, and also delay flowering. The timing and intensity of drought determine its impact on rice yield. Early season drought affects germination, seedling and early vegetative stages of rice while late season drought affects the later developmental phases such as flowering and grain filling. Intermittent drought stress can occur at any developmental phase. The diversity of affected production systems, variability of drought in terms of timing and severity, and the multiple traits involved in drought tolerance require strategic research to prioritize and develop environment-specific approaches for developing drought-tolerant rice cultivars.

3. Flooding and submergence: Africa is prone to flooding and this problem is becoming progressively more serious with climate change (Futakuchi, 2005). Flooding could occur at any stage of crop development. Flooding of agricultural fields causes crop submergence. This can occur at any stage of crop development and in all rice production systems, even including the irrigated lowlands at the seedling stage because of poor water management. In the floodplains, sudden floods can submerge the rice crop and water-logging can continue during the growth of rice. In savanna and forest zones in West and Central Africa, inland valleys prevail and rice in valley bottoms may experience water-logging for several days after excessive rainfall. Water has slower rates of gas exchange, less capacity to hold gases such as oxygen and CO_2, and a higher extinction coefficient for light than air. In addition, floodwater is usually turbid so that severe shading occurs in the water. Under complete submergence, therefore, photosynthesis and respiration of rice plants are suppressed (Futakuchi, 2005) leading to low concentrations of carbohydrates, reduced growth and finally death of tissues (Palada and Vergara, 1972).

4. Salt stress: Salinity is a major problem limiting rice production in Africa. Approximately 650,000 ha of rice production in West Africa are threatened by salinization, particularly within the Sahel where rainfed rice production is not feasible. In addition, the rising temperatures caused by climate change induce high evapotranspiration rates leading to salt accumulation over time from mineral ions carried in irrigation water, thereby increasing soil salinity. Russell (1978) calculated that 2.5 tonnes of salt may be deposited per hectare during a single season from irrigating with water containing only 0.05% of dissolved salts, a concentration commonly found in most waters used for irrigation in semi-arid areas.

In addition, during years of low rainfall the volume of fresh water that drains from the watershed into rivers reduces and thus salt water from the ocean intrudes much farther inland inundating rice fields and subjecting them to salt stress. Destruction of natural vegetation such as mangroves from coastal regions and river deltas either by severe flooding or human activities has led to intrusion of saline water into productive croplands. These problems are expected to be aggravated by climate change which is predicted to bring about increases in sea level, frequency of storms and rising temperatures (Yeo, 1999). It is thus essential to develop and employ technologies that will reduce the spread of salinization, reduce salinity levels in crop fields or increase salt tolerance of crops.

Role of WARDA networks in adapting rice production to climate change in Africa

The Africa Rice Center (WARDA) is unique among the centers supported by the Consultative Group on International Agricultural Research (CGIAR) in being the only center that was formed by national programs and then later joined the CGIAR system. WARDA has traditionally had strong partnership links with the NARES (National Agricultural Research and Extension Systems) both through direct links and those created and fostered under the aegis of its research and development networks. Through networking, resource-use and research efficiencies will be enhanced, capacity building improved, and rapid and efficient technology dissemination to end-users made easier. This will facilitate rapid response to emergency situations that are often required during climate change-induced natural disasters. WARDA's partnership model which uses participatory approaches for technology development and dissemination enables scientists to get feedback on farmer perceptions of rice technologies and local innovations while also reducing the duration of the research and development cycle. The WARDA networks include ROCARIZ (French acronym for West and Central Africa Rice Research Network), ECARRN (East and Central Africa Rice Research Network), ARI (African Rice Initiative), INGER-Africa (International Network for Germplasm Evaluation of Rice in Africa) and the eco-regional program IVC (Inland Valley Consortium).

INGER-Africa, ROCARIZ and ECARRN are vehicles to distribute rice seeds and associated technologies to NARES for either participatory multi-location trials or production or both. Since its inception in 2002, ARI has been coordinating strategies for disseminating NERICA and other improved rice varieties as well as complementary technologies to meet the increasing demand for rice in SSA. The Consortium for the Sustainable Development of Inland Valley Agro-ecosystems in Sub-Saharan Africa, or the Inland Valley Consortium (IVC), was established in 1993 to respond to social and environmental challenges in West Africa, related to poverty and food security on the one hand and degradation of the natural resource base on the other. The IVC conducts extensive biophysical and socio-economic characterization at key sites in inland valleys of different agro-climatic zones followed by field studies to determine their suitability for intensive agricultural production or vulnerability to degradation. An information and knowledge sharing system – West Africa Inland Valley Information System (WAIVIS) was developed by IVC to classify inland valley systems in West and Central Africa (WARDA, 2006). WAIVIS draws upon data accumulated during 10 years of inland valley research.

WARDA's research is also guided by a national experts committee which comprises research directors from WARDA member countries who meet annually to ensure that WARDA research activities address the priorities of the target beneficiaries of improved rice-based technologies.

Through multi-location trials rice technologies suited to specific locations or for wider application are identified and then adapted through further research to better meet the needs of target farmers. Varieties selected by farmers in these trials are then multiplied and disseminated to ensure farmers have timely access to good quality seeds of selected varieties. Participatory research is a dynamic approach and when implemented through eco-regional networks, it allows WARDA scientists to adapt new rice technologies to changing production needs of farmers as might be necessitated by climate change.

WARDA is also actively participating in other research and development partnerships that are either already working towards developing rice technologies to mitigate the effects of climate change or can be potentially exploited for this purpose. These include the SSA Rice Consortium (SARC), Drought Frontier Project (DFP) of IRRI and direct linkages with advanced research institutes amongst others. SARC was formed by IRRI, WARDA and CIAT to coordinate rice research and development in SSA, train a critical mass of rice scientists in SSA and involve NGOs, private sector and other international partners in technology development and dissemination. The DFP launched by IRRI is an international research consortium aiming to develop improved drought resistance and mitigation strategies in rice producing areas. These partnerships will bring in scientific expertise from outside Africa and thereby enable expanded research to develop rice technologies better suited to a changing climate.

Developing climate-resilient rice technologies through partnerships

Improving the resilience of rice production systems to climate change requires the development and dissemination of appropriate combinations of improved stress-tolerant rice germplasm, natural resource management strategies and creation of appropriate policy environments to help increase and stabilize yields in variable cultivation conditions.

1. Genetic improvement: Through collaborative research WARDA scientists use shuttle breeding to develop rice germplasm with improved tolerance to the abiotic stresses which are sensitive to perturbations in the climate. This is done through on-station research to first identify tolerant germplasm followed by research directed at understanding the physiology of stress tolerance and its genetic control. Promising breeding lines are then screened in participatory multi-location trials for adoption and release by NARES. Farmers' selection criteria determined from participatory trials are then incorporated into the breeding goals of WARDA scientists.

Through such an approach, *O. glaberrima* accessions and varieties were identified with better heat tolerance than *O. sativa* varieties due to their higher leaf transpiration rates and their ability to open flowers in the morning when it is cooler as opposed to the afternoon when it is hotter. Genotypes possessing higher transpiration rates could maintain lower leaf temperatures because of a higher latent heat flux which can dissipate more heat from leaves. In a study to compare the transpiration rates of African rice *O. glaberrima* and Asian rice *O. sativa,* researchers found out that *O. glaberrima* (IRGC accession number 104038) showed higher leaf transpiration rates than *O. sativa* (Taichung 65) especially in the afternoon (Mutou et al., 2004). Under non-moisture limiting conditions such a trait will be important in avoiding heat stress in the rice plant.

The peak period of flower opening for most *O. sativa* varieties is 11.00 a.m. (Purseglove, 1983) at which time temperatures can exceed 35º C on hot days in many rice growing regions of Africa. The critical temperature inducing sterility in rice was found to vary from 32º C (for a sensitive variety) to 37º C (for a tolerant variety) (Satake and Yoshida 1978; Yeo, 1999). *Oryza glaberrima*, on the other hand, has a flowering habit whereby most flowers open early in the morning at around 7 or 8 a.m. and this can be a highly convenient method to escape from the high air temperatures realized later in the day. Nishiyama and Blanco (1980) developed an interspecific line from the cross of *O. sativa* and *O. glaberrima*, flowering time of which was 9–10 a.m. This flowering time was about 1 hour earlier than that of the *O. sativa* parent, IR1561-228-3. This escape strategy of *O. glaberrima*, i.e. flowering before 8:00 a.m. is promising for rice production in African regions where high temperatures are experienced during the flowering period of rice.

In rice some of the mechanisms that have been reported to be associated to drought tolerance include rapid leaf rolling, rapid stomatal closure, high water use efficiency, osmotic adjustment, possession of deep and thick roots and early maturity (Champoux et al., 1995; Courtois et al., 2003; Asch et al., 2005). Researchers at WARDA in partnership with NARES of Mali and Nigeria have identified potential donors of drought tolerance mechanisms for increased rainfed rice production in drought-prone environments of Africa. This has led to the development of several advanced inter- and intraspecific breeding lines with good levels of drought tolerance (Ndjiondjop et al., 2007). Researchers also studied drought tolerance mechanisms in a collection of *Oryza glaberrima, Oryza sativa* and NERICAs *(*12 *O.* sativa, of which 5 are indicas and 7 japonicas, 4 *O. glaberrima* and 8 interspecifics) in a trial where irrigation was withheld for 35 days at the vegetative stage of development (WARDA, 2001). The drought tolerance mechanism of *O. glaberrima* was attributed to its ability to limit transpirational water loss by rapid closure of stomata and possession of a fine and well-distributed root system to explore a larger volume of soil for moisture. Furthermore, in the same trial, *O. glaberrima* (CG14) had higher tiller numbers and slightly larger total biomass than the NERICAs or their *O. sativa* parent, WAB 56-104 (WARDA, 2001).

In flood-prone environments, two plant types are important for varietal adaptation to the production system – those with elongation ability and those with submergence tolerance. There is apparently a trade-off between the two traits which implies difficulties in combining the two traits through breeding (Setter and Laureles, 1996). Elongation-ability types are desirable where water-logging could continue for long periods lasting several weeks such as in the flood plains of large rivers. To tolerate complete submergence caused by sudden flooding until plants re-establish contact with the atmosphere by elongation, it will also be desirable for them to have submergence tolerance to a certain extent. Vigorous initial growth will also be important to reduce the danger from submergence.

Traditional varieties still dominate the deep-flooded rice production systems in Africa. In some locations such as Mopti in Mali and the Sokoto Rima River floodplains in Nigeria, *Oryza glaberrima* or African rice, is still cultivated despite its low yield potential relative to the more widely cultivated *O. sativa* or Asian rice (Jones et al., 1997).

In a study to compare the seedling vigor of Gambiaka, a traditional *O. sativa* variety grown in West Africa, and WITA 4, WARDA’s improved cultivar released in Nigeria for the rainfed lowland ecology, Gambiaka attained a height and dry weight of 42.3 cm and 123 mg at 21 days old, while seedlings of WITA 4, were 28.9 cm and 75 mg, respectively. This demonstrates Gambiaka’s more vigorous seedling growth compared with that of improved cultivars. Gambiaka therefore has a greater possibility of escaping from submergence than WITA 4 (Futakuchi, 2005). In addition to these two traits, resistance to lodging or recovery ability from lodging after water level reduction will be required for varieties acceptable to farmers.

In situations where flooding is short-lived, such as in inland valley bottoms, submergence-tolerant types will be useful. Although such varieties are relatively tolerant to submergence, they do suffer some damage and more or less collapse after several days of submergence. Futakuchi et al.

(2001a, 2001b) studied the elongation ability and submergence tolerance of four *O. glaberrima*s, TOG 5810, TOG 6283, CG 14 and CG 20, together with two *O. sativas* Norin30 and IR36 under submergence at the end of the stem elongation stage., Submergence induced stem elongation in all six varieties relative to the controls but the extent of elongation was much larger in *O. glaberrima* than in *O. sativa* (Fig. 3). Judging from the elongation ability, *O. glaberrima* should have much less tolerance to submergence than the *O. sativa* checks. However, *O. glaberrima* maintained high photosynthetic rates, compared to Norin 30, and the rates were similar to those of IR36. Similar results were obtained for chlorophyll content. *O. glaberrima* had better submergence tolerance than expected based on its good elongation ability under submergence. Thus, *Oryza glaberrima* could be used as a source to develop plant types adaptable to water-logging, providing ability to escape from and moderately tolerate submergence (Futakuchi et al. 2001a, 2001b).

In other research, Sie et al. (2006), through the ROCARIZ network, evaluated the performance of 73 breeding lines of rice across a diversity of ecologies – valley fringe, valley bottom and irrigated lowlands in eight West African countries to determine their specific or general adaptability. The interspecific lines showed a better capacity for general adaptability across environments for they had good yields which often surpassed those of intraspecifics and traditional varieties. Lines with specific adaptation to the low-input cropping system of the valley fringes or for intensive cultivation in the valley bottom and irrigated lowland ecologies were also identified.

Concerning the development of salt tolerant germplasm, research conducted at Ndiaye, Senegal, found seasonal differences for salt tolerance in some rice varieties which were tolerant in the humid wet season but sensitive in the hot dry season, and *vice versa* (Asch et al., 1997). For instance, IR64 and BG-400-1 were more sensitive to salinity during the wet season than in the dry season. In other research at the same location, 200 advanced breeding lines of irrigated rice were screened for salt tolerance at 3.5 dS m^{-1} during the dry seasons of 2003 and 2005. The materials were obtained from previous observational nurseries, preliminary yield trials and earlier salinity trials. From these screenings 20 lines were found to have good levels of salt tolerance with yield losses of less than 40% compared to fresh water treatments (Africa Rice Center, 2005). Knowledge about these abiotic stress-tolerance mechanisms and the associated germplasm will be very useful in developing a pool of germplasm that can be adapted to the already variable cultivation conditions which will worsen with climate change.

A very effective method of climate-proofing crops is to adapt the phenologies of varieties to the favorable cultivation periods of the year. In this regard, WARDA has achieved spectacular success through the development and dissemination of short-cycle interspecific varieties of rice called NERICAs. This specific characteristic of early maturity is one of the main reasons why NERICAs have been adopted by many farmers in Africa. ROCARIZ and ECARRN have directly led and successfully tested intra- and interspecific rice varieties for both rainfed and irrigated production systems leading to the release and adoption of 17 upland and 11 lowland NERICA varieties in SSA (Africa Rice Center, 2006). Since 2002 ARI has produced and distributed more than 4,500 tonnes of foundation, breeder and certified seed of NERICAs and other improved rice varieties at WARDA and in seven project member countries. NERICAs are now planted in more than 200,000 ha of rainfed uplands in Africa and tested in 30 African countries. NERICAs are considered as a technology suited to a changing climate mainly due to their drought-escape characteristic of early maturity (CGIAR, 2007a). With regards to germplasm exchange and testing, INGER-Africa has also played a very effective role in SSA. One decade (1994-2004) of germplasm exchange and testing led to more than 25,000 samples of rice accessions distributed to NARES in West Africa, of which nearly 200 improved varieties were selected, released and grown by farmers in SSA. The development of NERICAs was realized through enduring partnership, giving a clear example of how African partnerships have been exploited to help rice farmers cope with climate change.

2. Integrated crop and natural resource management: Integrated crop and soil fertility management strategies need to be developed and disseminated to enable the realization of the full potential of climate-resilient varieties of rice and also to stabilize yields as well as to reduce environmental degradation arising from climate change in rice ecosystems.

WARDA has developed an innovative and integrated crop management (ICM) decision tool called RIDEV for agro-climatic characterization and crop and natural resources management in irrigated lowlands (Dingkuhn et al., 1997). RIDEV finds optimal combinations between individual technologies and natural resources conditions (soil, water, climate, organisms) using decision support systems and modeling tools. Options identified are implemented taking into consideration the biophysical and socio-economic characteristics of farmers' production systems to facilitate rapid adoption and diffusion. The use of RIDEV in combination with other models such as ORYZA1 and FERRIZ resulted in an array of management options that were evaluated with farmers. Farm modeling results in the Sahel showed significant gains in yields and profits from ICM under farm conditions. WARDA's ICM work is supported by extensive studies on individual technologies for the development of fertilizer recommendations and weed management. Overall, N has been found to be the most important nutrient for Sahelian irrigated rice, while phosphorus has also proven to be required for the attainment of high yields. This characterization work has led to the development and subsequent improvement of fertilizer recommendations in the irrigated rice-based systems through the calibration of FERRIZ. Initial testing in the Niger and Mali stations showed that FERRIZ offers a better framework to improve fertilizer recommendations because the adjusted doses to three soil fertility classes outperformed current uniform recommendations (CGIAR, 2007b). Adaptation of ICM to other production systems will help identify recommendation domains for the different rice production systems for high and stable yields and hence render them more resilient to climate change.

In view of a changing climate and the increased demand for water for non-agricultural uses by an ever-expanding population, water management is now more opportune than ever before in Africa to conserve water in drought-prone areas, but also to preserve valleys from destructive water flows. The effect of water management is linked to soil fertility and weed management and the type of water-management structure required for a given situation depends on a number of factors, like the agro-ecological zone, landform, position in the landscape, soil type etc. To counteract drought, contour stone lines are very effective for the uplands in semi-arid areas for increasing soil water as well as recharging ground water (Kiepe et al., 2001). In the humid zone the construction of a small reservoir may permit a double rice crop while small trunk wells in the sub-humid zone can facilitate off-season vegetable gardening.

To counteract floods, stone lines will act as breaks to overland flow. Water control structures in the lowlands are constructed to conserve water in the dry season, but at the same time withstand torrential water flows. It is important that the community takes part in these land development activities. Firstly to create a sense of ownership, but secondly to ensure that there are members in the community who have the knowledge to maintain and even repair the structures. Without community involvement every land development scheme is bound to fail. Lack of involvement of local communities, lack of training community members in maintenance, and absence of land-user organizations were reported as the main causes of abandoning development schemes in the Zou region of Benin (Djagba, 2006).

A commonly-used practice by rice farmers in SSA to avoid possible submergence and minimize salt injury to the crop is to transplant older seedlings. However, this practice is associated with a yield penalty because of the larger transplanting shock experienced by older seedlings compared to younger seedlings upon transplanting (Futakuchi, 2005). Dibbling seeds on ridges is another method used by farmers to avoid seedling submergence during floods (Singh et al., 1997). Other farming practices aiming to reduce salinity in rice fields include shallow plowing to prevent bringing salts in subsoil to the topsoil and frequent flushing to reduce soil salinity to manageable levels in the field.

3. Promoting favorable policy environments: SSA imports up to 40% of its rice consumption needs despite its large ecological potential for rice production. The challenges facing SSA rice sector are multiple and a deeper understanding of the policy, institutional and market environments in which rice production, marketing and trade are promoted is vital in developing strategies for competitive rice sector development. Creation of favorable policy environments to stimulate domestic rice production is particularly relevant in SSA in view of the region's high dependence on rice imports the availability of which is becoming increasingly threatened as a result of climate change-induced shocks.

WARDA has undertaken various research and development activities to provide policy support to national programs in WARDA member countries and to draw policy-makers attention to the fact that rice is a strategic staple crop for attaining food security and poverty reduction goals. One of the key outcomes of WARDA policy research was the strategy for rice sector revitalization in Nigeria drafted in collaboration with WARDA national partners. The document provides a strategic framework and outlines the main elements in terms of strategic objectives, priorities and implementation (WARDA, 2003). This strategy document led to the launching of the country's Presidential Rice Initiative, which aims at self-sufficiency in rice production. Through this initiative producers have been supported by subsidies on seeds (50%) and fertilizers (25%), the legalization of private fertilizer imports, and strong border protection against rice imports – an import duty of 50% and a levy of 50%. As a result, rice production has increased for five consecutive years in Nigeria (CGIAR, 2007b).

WARDA scientists also endeavor to document the association's research achievements and their impacts on the welfare of SSA rice consumers, producers and member-states. Through collaborative research with national partners in Rwanda, WARDA scientists found out that rice production was highly profitable in Rwanda due to low production costs (WARDA, 2006) and could thus be an entry point to poverty alleviation in rural communities. Impact assessment studies conducted in Benin also indicated that the adoption of NERICA rice varieties increased yields, raised farmers' incomes, all of them leading to increased schooling, demand for more medical care and better diets at the household level (Adegbola et al, 2006). Similarly in Uganda, where until recently, rice was relatively little-grown, it is now a cash crop thanks to NERICA (Kijima et al., 2006; WARDA, 2006). The ensuing financial security accorded to rural communities as a result of rice farming in SSA will provide them with more options and hence reduce their vulnerability to the negative effects of climate change.

Furthermore, to monitor trends shaping the rice sector in SSA, WARDA produced on a yearly basis Africa Rice Trends which provides an overview of salient features of SSA rice sector by synthesizing its development in terms of production, consumption, imports and self-sufficiency (Africa Rice Center (WARDA), 2007). Such decision support tools help policy makers make informed decisions on appropriate lines of action to be undertaken in order to improve the resilience of rice production systems in the face of changing climatic conditions.

Conclusions and perspectives

Climate change is already impacting negatively on livelihoods in Africa as evidenced by the misery caused by floods and droughts which are occurring with increasing frequency and severity. Thus durable strategies should be devised that would assist African communities particularly rural communities to adapt to climate change-induced disasters. In view of the importance of rice both as a food and cash crop in SSA, the ready availability of improved rice-based technologies especially stress-tolerant varieties, would broaden the range of options available to rural communities thereby enabling them to adapt readily to climate change.

The Africa Rice Center (WARDA), due to its strong link with NARES, is uniquely positioned to deploy its partnership model in developing and efficiently disseminating such demand-driven rice-based technologies to help in climate-proofing poor rural communities as well as urban centers in SSA.

The various networks hosted by WARDA (ROCARIZ, ECARRN, ARI, INGER-Africa and IVC) have been instrumental in streamlining these research and development efforts through collaborations with national, regional and international partners.

The discovery that *O. glaberrima* has many characteristics useful for overcoming biotic and abiotic stresses indirectly led to the efforts to cross this African rice species with the higher yielding Asian *O. sativa*. This in turn has led to the birth of a generation of new rice varieties, the interspecific NERICAs. The results in this paper clearly indicate that *O. glaberrima* is an interesting gene source for breeding efforts aimed at mitigating negative impacts of climate change. Tolerance, avoidance or resistance against both abiotic and biotic stresses, expected to increase as a result of changing climate regimes, have been identified in *O. glaberrima* genotypes.

Future research, development and extension efforts to mitigate negative climate change effects will continue to focus on varietal improvement, through further exploration of the gene pool of *O. glaberrima* and wild or weedy rice species (e.g. *O. barthii, O. longistaminata* etc.). In addition, the Integrated Crop Management approach developed by WARDA and partners will be enhanced and improved in order to complement the benefits of the improved (inter- and intraspecific) rice varieties. Farmer participatory development and validation of improved management practices or local farmer innovations to reduce effects of drought, submergence, heat, or salinity stresses on rice, are thought likely to generate the next generation of technologies to mitigate against climate change effects. These technologies should be combined with capacity building of farmer groups and national partners active in the domain of research and development of the rice sector. Greater involvement of climatologists and GIS experts in environmental characterization and more precise prediction of future climate patterns are needed in research aimed at developing climate-resilient, rice-based technologies.

WARDA will continue its efforts to find or improve technologies for resource-poor farmers in SSA that are suitable and effective in reducing the negative effects of climate change on rice production and marketing. The center will continue to use the partnership model that has proven to be successful and try to enhance partnership through increased involvement of the private sector in rice research and development activities in SSA.

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Figure 1. People affected by natural disasters in Africa from 1971-2000

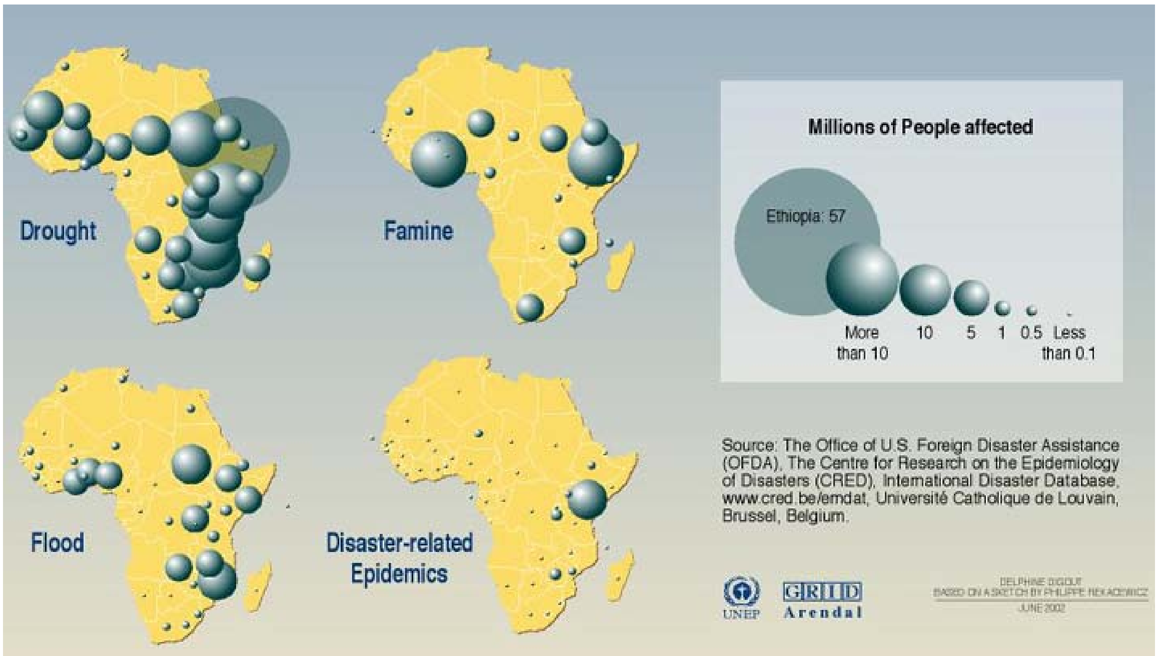

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Figure 2. Mean surface air temperature anomalies for the African continent, 1901–1998, expressed with respect to 1961–1990 average, annual and four seasons (DJF – Dec, Jan, Feb; MAM – Mar, Apr, May; JJA - Jun, Jul, Aug; SON – Sep, Oct, Nov) (Hulme et al., 2001)

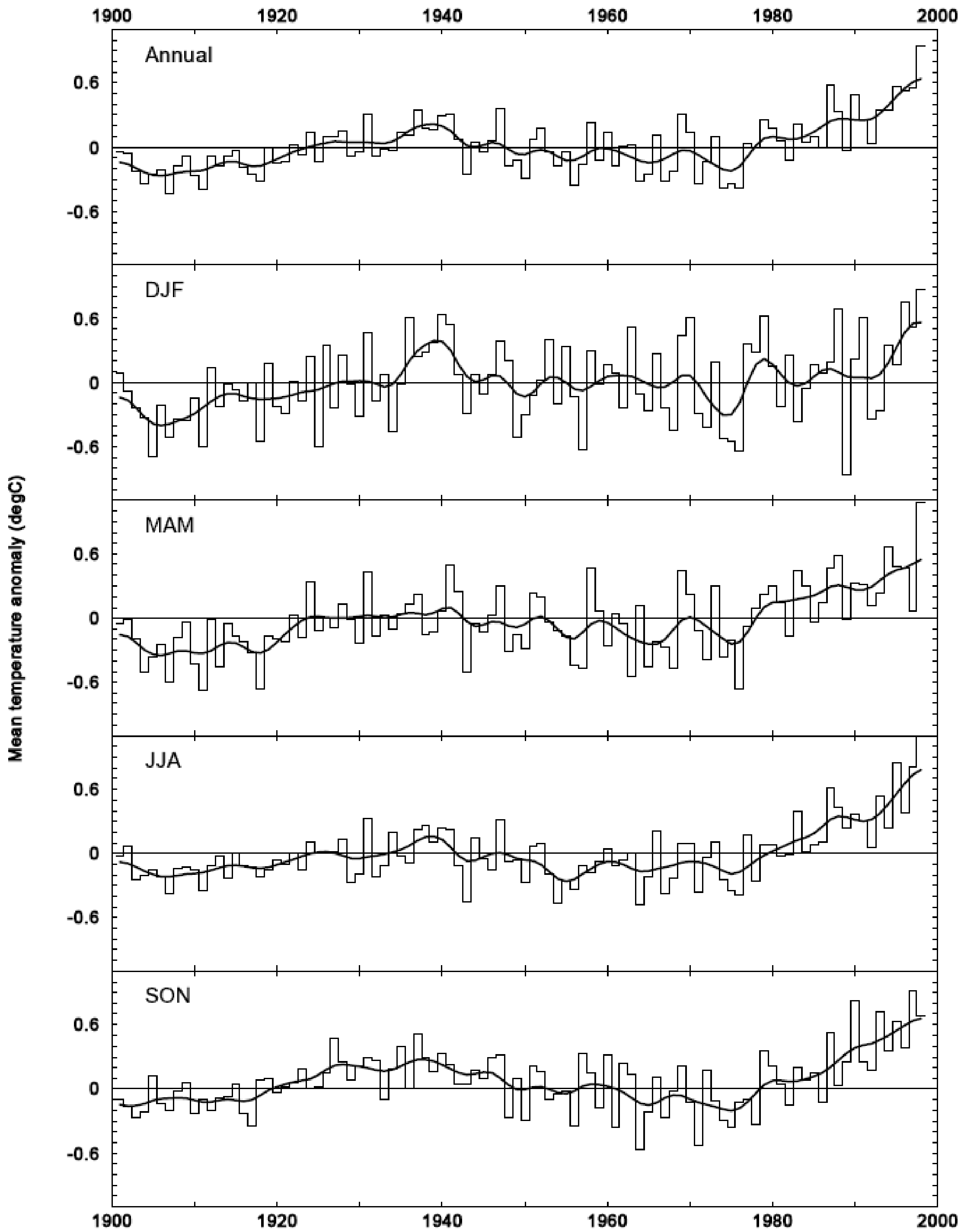

Figure 3. Changes in the rate of increased height to the initial height with the time of the submergence treatment (cited from Futakuchi et al., 2001a). Vertical bars indicate standard deviations. Closed circles = submerged; open circles = non-submerged (control)