2 RESEARCH PROGRAM

WARDA has two Research Programs, each with several projects (see section on Research program structure under section 1.6). The Panel's assessment of research activities was conducted on a disciplinary basis to focus on science relevance and quality.

2.1 Rice genetic improvement

Brief history of rice genetic improvement at WARDA

WARDA, as all crop-based CGIAR Centers, gives central importance to plant genetic improvement. WARDA has had ongoing breeding activities since its creation in 1971. The work initially covered all ecosystems. In 1987, WARDA became a member of the CGIAR, and moved from Liberia to Côte d'Ivoire. WARDA abandoned its work on mangrove and deep water ecosystems to focus on the upland-rainfed lowland-irrigated continuum that presently represents 87% of the rice area and around 89% of rice production in Africa. The irrigated rice-breeding program, originally set at Richard Toll, is based in N'diaye near St. Louis, Senegal, since 1990. The rainfed lowland program, which was relocated from IITA to Côte d'Ivoire in 1991, together with the upland breeding program were based in Côte d'Ivoire up to the civil unrest of 2002. Both rainfed lowland and upland rice breeding programs are now conducted from Cotonou, after a short passage through Mali between 2002 and 2004. WARDA's target area was initially West and Central Africa (WCA), but is now in the process of being extended to the whole of SSA.

After an initial focus on *Oryza sativa*, WARDA decided in the early 1990s, to exploit the African cultivated gene pool (*O. glaberrima*) seen as complementary to the Asian cultivated gene pool (*O. sativa*). The Center chose to concentrate on interspecific hybridization between *O. sativa* and *O. glaberrima*. Several attempts to produce such interspecific hybrids had been made in the past, but WARDA's breeders deserve credit for having persevered in this domain despite the difficulties, and for solving the sterility problems. These interspecific progenies developed for the uplands were called NERICAs (New Rices for Africa). In 1996, WARDA adopted Participatory Varietal Selection (PVS) to improve NERICA dissemination. The first upland NERICAs were released in 2000. In 2002, the African Rice Initiative (ARI) aiming at large diffusion and seed production of the new varieties was launched. The NERICA program, initially targeting the uplands, was then, extended to include the rainfed lowland ecosystem, then the irrigated ecosystem. The first lowland NERICAs were released in 2005, the first irrigated ones in 2007. There are now 81 varieties named NERICA[25], all target ecologies combined.

Genetic resources

In West Africa, most of the cultivated rice varieties belong to the *O. sativa* species, the Asian cultivated rice species. Farmers also grow some *O. glaberrima*, the African cultivated species, either as pure stand or as mixture of *O. sativa* and *O. glaberrima.*[26] Despite several positive features (see section on "Genetic Resources" on p. 22), *O. glaberrima* has regressed since the introduction of *O. sativa* in Africa between the 15th and 17th centuries[27], because of its poorer yield potential and higher shattering compared to *O. sativa*. This progressive demise justified the

[25] Rodenburg J, Diagne A, Oikeh S, Fukatuchi K, Kormawa PM, Selon M, Akintayo I, Cissé B, Sié M, Narteh L, Nwilene F, Diatta S, Sere Y, Ndjondjop MN, Youm O, Keya SO, Achievements and impact of NERICA on sustainable rice production in sub-Saharan Africa, 2006, International Rice Commission Newsletter, 55:45-58.

[26] Barry MB, Pham J-L, Noyer J-L, Billot C, Courtois B, Ahmadi A, Genetic diversity of the two cultivated rice species (*O. sativa* and *O. glaberrima*) in Maritime Guinea. Evidence of interspecific recombination, 2007, Euphytica 154 (1-2): 127-137.

[27] Pham J., Evaluation des ressources génétiques des riz cultivés en Afrique par hybridation intra- et interspécifique, 1992, PhD thesis, Université de Paris XI, Orsay, Paris.

collections that have been made in the 80s, notably by IRD (ex-ORSTOM) to preserve the African material. *O. glaberrima* varieties represented 15% of the number of cultivated accessions in a survey conducted in upland villages of Guinea in 2005[28], but more precise estimates in terms of area are apparently not available. Wild types are easily encountered in Africa. They belong mostly to *O. barthii* (the direct ancestor of *O. glaberrima*), or to *O. longistaminata*, the species with the widest distribution on the African continent. Hybrids between the various species have long been considered as difficult to produce.[29]

The varietal situation is reflected in the composition of the accessions stored by WARDA's Genetic Resources Unite (GRU) (see also section on "Genetic Resources" on page 61 under section 2.6). Because of the strong focus of WARDA these last years on *O. sativa* x *O. glaberrima* interspecific hybrids, the Panel paid an attentive look at the way the diversity of *O. glaberrima*, that has not yet been explored as much as that of *O. sativa*, was assessed.

Exploration of the diversity of O. glaberrima
Phenotypic variability: Two *O. glaberrima* ecotypes have been distinguished in the past: an "erect" type and a "floating" type corresponding to accessions grown in the upland and the lowland ecosystems respectively.[30] The erect type is also characterized by a gradient of growth duration.[31]

Most *O. glaberrima* accessions possess interesting characteristics: Early vegetative vigor due to fast germination, droopy early leaves with high specific leaf area, and high tillering ability that translates in good weed competitiveness, resistance to African insect pests notably the African rice gall midge, and, more recently demonstrated for a few accessions, resistance to dangerous soil nematodes such as *Meloidogyne graminicola*, a serious pest in upland fields, resistance to the rice yellow mottle virus, and high protein content.

Most *O. glaberrima* accessions, however, have a very limited yield potential due to a limited number of secondary branches on the panicle. *O. sativa* has many more secondary branches than *O. glaberrima. O. glaberrima* accessions are susceptible to lodging and grain shattering, have long seed dormancy, and are generally photoperiod sensitive. Contrasting reports can be found on the drought resistance of *O. glaberrima*. Its main advantage in this respect seems to be its plasticity and capacity to regenerate very fast, because of its vigor and organ thinness (Audebert, personal communication).

Some of these characteristics have been known for a long time. For the sake of simplicity, these trait features are often considered as characteristics of one or the other species, but not all accessions of a species have them, or express them at a high level. Large-scale phenotypic evaluations, multi-local for traits with low heritability, are therefore needed to see the

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[28] Barry MB, Pham J-L, Noyer J-L, Courtois B, Billot C, Ahmadi N., Implications for in situ genetic resource conservation from the ecogeographical distribution of rice genetic diversity in Maritime Guinea. Plant Genetic Resources: Characterization and Utilisation, 2007, 5(1): 45-54.

[29] WARDA, Achievements since the Fourth External Program and Management Review, 2007, Cotonou, internal document, 32p.

[30] Portères R., Taxonomie agrobotanique des riz cultives *O. sativa L.* et *O. glaberrima* Steud, 1956, Journal d'Agriculture Tropicale et de Botanique Appliquées
Second G., Relations évolutives chez le genre *Oryza* et processus de domestication, 1984, PhD thesis, Université de Paris XI, Orsay.

[31] Barry MB, Pham J-L, Noyer J-L, Billot C, Courtois B, Ahmadi A, Genetic diversity of the two cultivated rice species (*O. sativa* and *O. glaberrima*) in Maritime Guinea. Evidence of interspecific recombination, 2007, Euphytica 154 (1-2): 127-137.

pervasiveness of a feature in the genetic resources. In addition, in order to define the best sampling strategy for future work, the organization of the phenotypic variability of a trait in a species has to be looked at through the prism of its genetic structure.

Some overall morpho-agronomic evaluations of the material have been conducted by WARDA[32], but the Panel feels that a sound and systematic characterization of the above-mentioned specific qualities of more than a few *O. glaberrima* accessions is lacking. Little seems to have been published on these aspects. Hybridization relied on very few accessions well known by breeders, but the overall species variability does not seem yet to have been phenotypically explored. For example, little is known about the weed competitiveness mechanisms attributed to *O. glaberrima,* and their prevalence in the species. A recently commissioned GCP project is a step toward remedying this situation with plans to evaluate drought recovery ability, resistance to RYMV and to bacterial leaf blight of an *O. glaberrima* collection on which a molecular characterization is being conducted (see paragraph below).

Because the phenotypic variability of O. glaberrima has not been studied as extensively as that of O. sativa, the Panel recommends exploring more systematically the phenotypic variability of O. glaberrima for desirable traits, using sound, up to date screening methods, and focusing on processes and mechanisms of these traits.

Diversity at the molecular level*:* The first evaluations of the diversity of *O. glaberrima* with isozyme markers conducted in the 80s concluded that the genetic variability of *O. glaberrima* was limited in comparison to that of *O. sativa.*[33] Two recent interesting studies involved present WARDA's scientists as partners. The first study analyzed on a large scale (300 accessions) the diversity of *O. glaberrima* with microsatellites highly polymorphic in this species. It determined that *O. glaberrima* was structured in 5 groups, 2 being strongly admixed with *indica* or *japonica* and the remaining 3 corresponding to a range of ecological adaptations to hydrological environments.[34] The Panel commends the relevance and high quality of this work exploring *O. glaberrima* structure with the best analysis methods, and published in an excellent journal.

Similar work has been done in the framework of GCP sub-program 1, in which 300 accessions of *O. glaberrima* and *O. barthii* were included in the 3000 sample set that was genotyped with 48 microsatellite markers. Because of the difficulties encountered to access genetic resources during this time, the sampling methodology of the *glaberrima* accessions may not have received as much attention as could have been needed. Nevertheless, it should permit to confirm the results from Semon et al. (2005)[35], and compare more thoroughly the diversity of *O. sativa* versus *O. glaberrima* and that of *O. glaberrima* versus that of *O. barthii*. These results are presently being exploited. The Panel feels that excellent work is globally being done on these diversity aspects.

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[32] Jones MP, Dingkuhn M, Aluko GK, Semon M., Interspecific *O. sativa* x *O. glaberrima* progenies in upland rice improvement, 1997, Euphytica 93:237-246 and Semon M, Nielsen R, Jone MP, McCouch S., The population structure of African cultivated rice *Oryza glaberrima*. Evidence of elevated levels of linkage disequilibrium caused by admixture with *O. sativa* and ecological adaptation, 2005, Genetics, 169:1639-1647.

[33] Pham J., Evaluation des ressources génétiques des riz cultivés en Afrique par hybridation intra- et interspécifique, 1992, PhD thesis, Université de Paris XI, Orsay, Paris and Second G., Relations évolutives chez le genre Oryza et processus de domestication, 1984, PhD thesis, Université de Paris XI, Orsay.

[34] Semon M, Nielsen R, Jone MP, McCouch S., The population structure of African cultivated rice *Oryza glaberrima*. Evidence of elevated levels of linkage disequilibrium caused by admixture with *O. sativa* and ecological adaptation, 2005, Genetics, 169:1639-1647.

[35] Idem.

To capitalize on the excellent work done on the understanding of the genetic structure of O. glaberrima, the Panel recommends that the Genetic Resources Unit, breeders and molecular biologists of WARDA collectively focus on defining core collections of O. glaberrima, i.e. collection of accessions representative of the diversity of the whole species. The core collections should include the natural admixed accessions of particular interest because of WARDA's focus on interspecific hybrids. Different imbricated core collections should be constituted, using the best statistical methods, in order to provide breeders, physiologists, weed specialists and pathologists with sets of accessions of different sizes they can use with maximum efficiency and relevance when they want to evaluate O. glaberrima accessions for specific traits as suggested above.

Other African cultivated genetic resources

As mentioned above, the African cultivated genetic resources are not only constituted by *O. glaberrima* accessions but also by thousands of *O. sativa* accessions. Despite the relatively recent introduction in West Africa of *O. sativa*, these accessions have evolved long enough in African harsh conditions to have been used all over the world because of their high level of blast and drought resistance. The Panel recognizes the fact that the *O. sativa* accessions have been the object of much more extensive past evaluation of both phenotypic and genetic variability but the successes obtained with *O. glaberrima* should not lead WARDA's scientists to neglect these extremely valuable African *O. sativa* genetic resources.

Present status of the rice improvement programs

Breeding objectives

WARDA's rice genetic improvement program is organized into the 3 large ecosystems: upland, rainfed lowland and irrigated. The constraints for each ecosystem were presented to us as a long and probably exhaustive list of biotic and abiotic stresses (breeders' oral presentations) but these constraints did not seem to have been hierarchized according to their impact on yield. To our knowledge, no refined stratification leading to a well-defined target population of environments (TPE) has been established. It is unlikely that a single variety can perform well across all rainfed lowland, or all upland conditions of Africa, although the problem is probably less acute for the irrigated ecosystem. Moreover, no socio-economic constraints were associated with the ecological constraints. One was let to assume that the range of socio-economic constraints would follow the risks associated with the ecosystem. A more refined view of production systems in each ecology would certainly be helpful to design sounder objectives for breeding programs, or to assess their appropriateness.

Breeders stated that the diversity within each ecosystem was too large to be easily sub-stratified, and that the importance of constraints varied across countries, and along the ecosystem continuum. Indeed, material developed for the lowlands is being tested in the uplands, and reciprocally, and similarly between lowland and irrigated areas. Although there are possible spillovers from one ecosystem to another, the Panel is of the opinion that much more attention should be given to the concept of target population of environments (TPE) in each ecosystem, the establishment of TPE boundaries, and the weighing of the importance of the various constraints in each TPE, in order to establish clear priorities and ideotypes for each ecosystem, and relevant selection indices for the breeders (for methodology and tools, see section on Priority setting in NRM under 2.2). A training organized by WARDA on these issues may be useful. From the Panel's understanding, in terms of breeding objectives, the upland rice breeding program is focusing on drought resistance, weed competitiveness, resistance to blast and stems borers, tolerance to soil acidity, and N and P deficiency.

The lowland rice-breeding program is focusing on tolerance to iron toxicity and development of low management plant type with good weed competitiveness. African Rice Gall Midge (AfGM) and RYMV resistances are also important priorities. Climatic change conditions induce the need for shorter duration varieties although these are expected to be more sensitive to transplanting delay. Meanwhile photoperiod sensitive varieties are also needed for the deep lowlands. The parallel development of direct seeding gives increasing importance to vigor and weed competitiveness during the first month of crop growth.

The irrigated rice-breeding program is focusing on tolerance to salinity/alkalinity, extreme temperatures and bacterial leaf blight resistance. Two different programs are conducted, one for the rainy season crop, and one for the dry season crop which is shorter and colder. The practice of double cropping is presently very limited because of climatic, technical and economic constraints. Earliness appears an important breeding objective for the dry season crop to permit double cropping (although not on the same plot in the Sahelian environment).

Breeding methods

The three main breeders for the three main rice ecosystems have all joined WARDA recently, and therefore, the organization of the breeding scheme is not completely settled.

The breeding strategy for the upland and lowland ecosystems, aiming at developing pure lines, is a classical one, except for the exceptionally large investment into interspecific hybridization. The two breeders both evaluate their activity ratio at 60% for interspecific hybrids and 40% for *O. sativa* background. While this ratio is reflected in the proportion of interspecific segregating populations that were developed, most of the recently released accessions seem to be NERICAs. The reasons for such imbalance are unclear. From very early generations (F_2 for the rainfed lowland ecology), the material is dispatched to different countries (Benin, Nigeria, Togo, Burkina Faso), and the selection done in collaboration with NARS. Because of the importance of NERICAs in WARDA's research, the results obtained with them are analyzed more in depth in the next section (section 2.1).

The irrigated breeding program, located in the Sahel, is so far mostly using *O. sativa* genetic background. It performs well, with 3 Sahel varieties (108, 201, 202) occupying 70% of the surface, and new *sativa* varieties being released in the Senegal River valley. These varieties are pure lines. In an environment where some farmers reach yields of 10 t/ha, the use of F_1 hybrid varieties can start to be envisioned by these farmers. WARDA could liaise with IRRI and with Chinese institutions, experienced in F_1 hybrid rice breeding programs, and start testing the adaptation of their material to local conditions. The Panel is of the opinion that the F_1 hybrid rice varieties do not deserve yet a large investment by WARDA, since the average yield is closer to 50% of the yield potential in the Senegal valley, since rice is direct-seeded, and since F_1 seed production is technically very complicated. However, preliminary steps are warranted.

Aerobic rice, which was proposed by IRRI as an alternative for irrigated areas with poor water control[36], was tested in Senegal and is mentioned as promising. Broad scale conclusions in terms of yield loss versus water savings should be obtained soon. Nevertheless, a thorough evaluation of the pros and cons has to be conducted before investing in a breeding program for this system in Senegal, since it seems that water savings that could be needed for cost reduction purposes could first come from better management and delivery at the plot level.

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[36] Peng S, Bouman B, Visperas RM, Castaneda A, Nie L, Park HK, Comparison between aerobic and flooded rice in the tropics: agronomic performance in an eight season experiment, 2006, Field Crop Research 96: 252-259.

Genetic approaches to reduce losses due to pests and diseases are given high importance in all three ecosystems. This is also true for abiotic stresses such as salinity (irrigated ecology) or iron toxicity (rainfed lowland ecology), for which screening methodologies are well established. Systematic early screenings of segregating lines (from F_3 to F_5) have been organized in regional nurseries set in countries known to be "hot spots" for the various biotic and abiotic constraints (e.g. St. Louis for salinity, Mali for RYMV, or Mali and Guinea for blast). From what the Panel saw in N'diaye and from discussions with WARDA's pathologist, the work is well conducted, with proper screening methods and experimental designs. This regional screening, that supposes a very good underlying organization, seems to work quite efficiently, and can constitute a good vehicle to share germplasm. One can only regret that it is not implemented every year because of funding issues in some years.

An important trait that is not included in the "hot spot" system is weed competitiveness. We were told that "each upland or lowland site can be considered as a hot spot for weeds". Good and fast screening methods usable in a breeding program still need to be established and/or validated in collaboration with physiologists and agronomists.

Grain quality is seen as important in all ecosystems. Grain quality traits are being evaluated at an advanced stage in Cotonou where a classical laboratory exists. The efficiency of near-infrared spectroscopy, increasingly used the two last decades in rice and other cereals as a fast way to measure grain quality traits in very small samples, would justify an investment in this type of equipment. This tool works particularly well for protein content, which seems to be WARDA's main grain quality target, and would permit larger scale screenings. Poor quality often explains the price differential between imported and local rices. Cleanliness seems to be the overwhelming factor behind the image of poor quality of local rice, and, on this issue, genetics has no solution to offer. On other more global grain quality issues, strengthening of the research would be useful. This could also be an area of closer collaboration with strong rice quality laboratories (IRRI, CIRAD).

Interspecific O. sativa x O. glaberrima hybrids (NERICAs)
The choice was made in the 90s to invest heavily in interspecific hybridization, originally for the upland ecosystem. The qualities described above make *O. glaberrima* a potentially good complementary type to *O. sativa*. The overall strategy was well described.[37] The Panel commends the decision made by WARDA to exploit the African rice gene pool seldom used before, and is truly impressed by the results obtained from the interspecific hybridization, and the constancy and patience that was needed to obtain the first releasable progenies.

Interspecific hybridization between *O. sativa* and *O. glaberrima* is not any longer a technical problem. We were told that breeders are now able to get interspecific progenies from any combination, and no longer need very advanced backcross generations or the use of anther culture. This generalization of the interspecific hybridization success is a second very important achievement. Nevertheless, two backcrosses and a screening generation on fertility are still needed, which means that interspecific crosses will never be as easy to handle as intraspecific crosses, and fertile progeny production will always take more time.

The difficulties encountered in the first generations of crosses, however, translated in a very narrow genetic basis of the initial progenies: only one *glaberrima* accession (CG14) and three related *sativ*a varieties (WAB56-104, WAB56-50, WAB181-18) are the parents of all the upland

[37] Jones MP, Dingkuhn M, Aluko GK, Semon M., Interspecific *O. sativa* x *O. glaberrima* progenies in upland rice improvement, 1997,

NERICAs presently released. Another *glaberrima* accession (TOG5681) and a *sativa* accession (IR64) are the parents of almost all the released lowland NERICAs.[38] In addition, at least for the first generation of NERICAs, the crossing barriers required the use of a large number of backcrosses on the *O. sativa* parent, in order to restore fertility. The molecular profiling of the NERICAs showed that 8.2% and 7.9% of upland and lowland NERICA genomes respectively originated from *O. glaberrima*. Thus, the introgressions affect a very small part of the genome, notably considering the fact that all interspecific progenies carry the same *glaberrima* allele, probably involved in hybrid fertility, at a specific segment of chromosome 6 that carries the *S1* gene (also noticed in independent progenies developed at CIAT).

The narrow genetic basis and large similarities between lines carries the intrinsic risk associated, as in any other crop, with a largely monovarietal situation. Such a risk may be the trade-off of NERICA's success. The worst may not occur, as seen by the yield sustainability of IR64 grown in millions of hectares in Asia, but there are examples of the opposite as well. All breeders are aware of the classical example of potato, where the growth of a unique variety susceptible to potato late blight led to major crop failures in the 1850s in Ireland. The Panel is aware that steps have been taken to remedy this situation, and encourages more effort in this direction.

Since the interspecific hybridization sterility problem has been solved, the Panel recommends that WARDA greatly broaden the set of O. glaberrima and O. sativa accessions used as parents in interspecific hybridization, using the results of phenotypic and molecular characterizations to ensure larger diversity of parents, monitoring closely the level of introgression and the genetic diversity of the released progenies. The creation of a first generation of interspecific hybrid progenies (NERICAs) should not be seen as the end, but as the beginning of a great "genetic adventure" aimed at making the best possible use of the African gene pools (O. glaberrima, O. sativa and other species).

The Panel commends the way molecular markers have been used at breeders' benefit in the case of the NERICA molecular profiling. The Panel wants to underline the very strong interest for breeders in the availability of such molecular profiles to guide their work, and the importance to optimize the integration of molecular markers in their day-to-day work. Any modern breeding program should have direct access to a molecular marker laboratory. What is presently possible for the upland and lowland breeders with the Cotonou laboratory should also be envisioned for the irrigated breeder in Senegal. Both the establishment of a laboratory in N'diaye, and the possibility of sharing CERAAS unused equipment and facilities at Thies in Senegal should be explored.

NERICA varieties for both the upland and the lowland ecosystems have been produced and released. WARDA wants to produce NERICAs for irrigated ecosystems. In fact, three varieties derived from the rainfed lowland program have already been recommended for the irrigated ecosystem. The Panel wishes that WARDA thoroughly weighs the interest of this approach before launching a larger interspecific program. The yield ceiling in *O. sativa* under irrigated conditions, as favorable as the ones observed in the Sahel, is very high, with an average of 5.5 t/ha during the rainy season. In similar favorable conditions in Egypt, *O. sativa* reaches 8 t/ha on average (FAONET, 2004). *O. glaberrima* is known to have much less secondary branches than *O. sativa*, and does not seem like an obvious parent in this context. Therefore, the Panel does not see a reason for the breeding program to deviate from its focus on *O. sativa,* which has been very

[38] Rodenburg J, Diagne A, Oikeh S, Fukatuchi K, Kormawa PM, Selon M, Akintayo I, Cissé B, Sié M, Narteh L, Nwilene F, Diatta S, Sere Y, Ndjondjop MN, Youm O, Keya SO, Achievements and impact of NERICA on sustainable rice production in sub-Saharan Africa, 2006, Internationla Rice Commission Newsletter, 55:45-58.

successful. Because it will take more time to reach a releasable product with interspecific hybridization than with intra-specific hybridization, there should be very good reasons, based on a clear view of the required *glaberrima* intrinsic qualities, before investing further into interspecific hybridization. Increased diversity *per se,* which was the reason mentioned to us, seems a weak reason for this endeavor, since more diversity can also be obtained through intraspecific hybridization.

To demonstrate the interest of NERICAs for the upland and lowland ecosystems, comparisons were made with classical *O. sativa* material. Several results demonstrated that some NERICAs had a yield advantage over *sativa* accessions under low fertility conditions, but others seemed to show that the results were less clear-cut, notably when the comparison involved a large number of accessions. [39] The Panel is of the opinion that the comparisons were not always as thorough as they should have been, not always including enough *O. sativa* accessions to get an idea of the compared variability of both backgrounds. A good characterization of the trial biophysical and socio-economic environments that could help understand the NERICA or *O. sativa* response heterogeneity is also often lacking.

The Panel expects that data, notably yield data, on performances of all types of varieties, be accompanied by proper descriptive elements (e.g. fertility level, cultural practices, cropping system, stress nature) necessary to help understand the variation of responses according to environmental factors. Moreover, in most reports, yield is the trait being given emphasis, but seldom is attention paid to the specific traits from *O. glaberrima* initially said to be interesting. To focus on these traits could help assess whether these traits were indeed transferred into the NERICAs and could be the source of an improved performance, or whether such improved performance was due to the complementarities of the two parental backgrounds. One has to realize that when a progeny expresses a favorable trait at a high level, the source of the favorable allele can be either of the two parents (for NERICAs, the *O. sativa* as well as the *O. glaberrima*). For a quantitative trait, which is controlled by many genes, a progeny can also be superior to both parents when none of the two parents has all favorable alleles at all genes if, through the hybridization and recombination process, all the favorable alleles are cumulated in the selected progeny.[40] This genetic phenomenon is called transgression. For further breeding work it is important to know what the source(s) of the favorable alleles is/are and what type of situation is encountered.

One study from WARDA showed that the high specific leaf area of the *glaberrimas* was partly retained in the NERICAs during early growth[41], but no clear link was established between this factor and the better yield performance of the NERICAs. The same remark can be made for the high protein content attributed to some of the NERICAs. The source of most of the favorable alleles is the *sativa* parent, the *O. glaberrima* parent CG14 being very poor in this respect, in contrast with most *O. glaberrima* accessions.[42] Transgressions above the *O. sativa* parent can

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[39] Rodenburg J, Diagne A, Oikeh S, Fukatuchi K, Kormawa PM, Selon M, Akintayo I, Cissé B, Sié M, Narteh L, Nwilene F, Diatta S, Sere Y, Ndjondjop MN, Youm O, Keya SO, Achievements and impact of NERICA on sustainable rice production in sub-Saharan Africa, 2006, International Rice Commission Newsletter, 55:45-58.

[40] Parent A may carry alleles (+ + + - + -) at 6 genes; Parent B may carry the complementary alleles (- - - + - +). A progeny derived from this cross could carry alleles (+ + + + + +) and, then, be superior to both parents. Another may carry alleles (- - - - - -) and, then, be inferior to both parents.

[41] Jones MP, Dingkuhn M, Aluko GK, Semon M., Interspecific *O. sativa* x *O. glaberrima* progenies in upland rice improvement, 1997.

[42] Juliano BO and Villareal CP 1993. Grain Quality Evaluation of World Rices. International Rice Research Institute, Manila; Watanabe, H., Futakuchi, K., Jones, M.P. and Sobambo, B.A. 2004. Grain protein

explain the progeny behavior. While the NERICA ideotype was designed to be competitive with weeds, this quality is not observed in the final products. According to survey results, NERICAs do not appear as weed competitive in farmers' eyes (e.g. Uganda, Guinea), an opinion which is confirmed also by NARS's scientists during the Panel's field visits.

NERICAs have other qualities, however. The main reason for NERICA preference in some areas seems to be earliness. Very early duration itself was not an expected quality for the interspecific hybrids even if the *O. glaberrima* parents were photoperiod insensitive. Among the *sativa* parents, only the upland ones can be seen as early. We have seen that transgressions can be obtained with good allelic complementarities, but this confirms that more attention should be paid to the understanding of the genetic control of all-important traits in both *O. glaberrima* and *O. sativa* backgrounds.

Since the need for early varieties seems relatively widespread, even when the rainy season is not short everywhere, one explanation for the preference of early varieties may be the need for rice during the "hunger period", between the moment when previous year food stocks run out, and the new harvest begins. Not surprisingly, that is a period when rice fetches a relatively high price in the market. In other places, the explanation seems to be women's need for cash at a time when kids resume class. The need for early duration varieties is not new. It has been a farmers' request from the 60s onwards, although a shift towards even earlier duration is noticeable. Earliness should have been a feature of the breeding ideotype for similar situations. The major problem associated with early maturity varieties is bird damage, which can be very serious if early varieties do not cover a large contiguous area. The relationship between yield and duration is not linear and at a given point in earliness, the yield "penalty" becomes very important (see also section on Yield potential and maturity p. 39). Attention has to be paid to this trade-off, notably when extreme earliness (60 to 90 days) is mentioned as one of the reasons to undertake *O. barthii* x *O. sativa* crosses.

The earliness attribute constitutes a concrete example of the need for environment stratification in the breeding programs. NERICA's earliness is highly appreciated in some of the upland sites where NERICAs have been tested. For the deep lowland plots, however, photoperiod sensitive varieties are requested by farmers because they allow sowing at any time, but maturity, and therefore harvest, occurs always at the same period, when floods have receded. The existing NERICAs are photoperiod insensitive and will always mature too early in the season so they cannot fill this niche.

Globally, the Panel would have appreciated a more balanced communication on breeding strategy and products. The oral presentations to the Panel focused almost exclusively on NERICAs. It was difficult to get information on what was occurring with *O. sativa* breeding work, which may convey a wrong impression of the Center's overall breeding efforts. NERICAs represent an element, and indeed an important one, in a panoply of solutions to increase yield productivity and stability in some situations, but they are not the unique "silver bullet" for all environments and conditions.

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content of African rice (*Oryza glaberrima* Steud) lines and Asian rice (*O. sativa L.*) varieties in West Africa. *Oryza* 41: 35-38).

Advanced breeding lines testing through PVS
In the 90s, participatory varietal approaches started to be used as a way to speed up the diffusion, and improve the adoption of improved material. Among the various approaches of participatory plant breeding described by Witcombe (1997)[43], WARDA chose participatory varietal selection (PVS) that involves tests in farmers' fields of a large range of fixed lines and selection by farmers. This has shown to be quite an efficient system.

This strategy is a strong positive point of WARDA's breeding approach. The type of PVS system chosen is simple enough to be adopted everywhere. Its principle is to set a varietal garden of around 50 lines in a farmer's field that is visited by farmers 2 to 3 times per season. The next season, farmers are given seeds of the three lines they selected, for on-farm testing. PVS has been used in all ecosystems, and seems to be working well, although the Panel considers that one year of testing is not sufficient to get a clear idea of the line performances in a site. The fact that only the top four varieties selected by farmers are chosen for seed production and distribution seems also to go against PVS principles of giving farmers access to a large basket of varieties.

A major issue in PVS is scaling up from limited well-organized trials. Participatory selection effectiveness can come from two factors: First, the decentralization of the trials into farmers' fields; and/or second, the participation of farmers who use criteria different from those used by breeders to make their varietal choice. Disaggregating the effects of the two factors is useful to determine how to scale up.

Concerning the decentralization effect, the Panel is of the opinion that more added value could be obtained from the work done with little additional effort. The initial varietal garden could easily be designed in a way that the data that were collected (duration, height, and yield) could be scientifically exploited (e.g. by the use of a randomized trial with a simple augmented design in which only a few checks are replicated). Genotype-Environment (GxE) interaction analysis of the results could be invaluable. The mother-baby trial system used in maize[44] and in rice[45] could also be introduced as an improvement of the present PVS system, permitting better exploitation of PVS trial results.

Moreover, no attempt seems to have been made by WARDA to systematically cross farmers' varietal choices with farmers' socio-economic characteristics. The use of such data that are being collected anyhow would add significant value to the global PVS approach, and may help to understand what may appear as contradictory results in farmers' varietal choices. It may not be possible to conduct detailed studies everywhere, but more integration should be attempted, at least in places where data are collected both by breeders and by socio-economists.

Concerning the farmers' participation effect, PVS is also a way for breeders to get feedback on their products, and it should, in return, help breeders to better design the new generation of varieties. A remark was made to the Panel that, in some cases, farmers chose NERICAs because they are taller than their *sativa* equivalents. This type of requirement, as well as the need for earliness, mentioned above, should not be too difficult to factor into WARDA's breeding programs. However, it is unclear to the Panel whether such systematic feedback process exists and how it is exploited by WARDA.

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[43] Witcombe JR, Decentralization versus farmer participation in plant breeding: some methodological issues. In: New frontiers in participatory research and gender analysis, CIAT, 1997, Cali, Colombia, p.135-154.
[44] Snapp, 1999; Bänzinger and Diallo, 1991
[45] Atlin G, Paris T, Courtois B., Sources of variation in rainfed rice PVS trials: implications for the design of "Mother-Baby" trial networks. In: Proc. Workshop on Quantitative analysis of data from participatory methods in plant breeding, 23-25 August 2001, Justus Liebig University, Germany.

Grain quality is known to be a factor not always well taken into account in classical breeding programs, especially when the target population produces for home consumption rather than for sale in the market. It is also well known that "quality" can have completely different meanings in different areas or social groups. The practice of parboiling or not parboiling, both common in Africa, complicates the clear definition of requirements. Sensorial evaluations are conducted, which is commendable. But again, we could not see how the resulting information on requirements by various populations was fed back into the objectives of WARDA's breeding programs.

An issue in plant breeding is the compromises that have to be made between traits. Breeders know that genetic correlations sometimes hamper the development of the best product. Farmers cannot always find their dreamed variety within the proposed set. Assessing the trade-off between farmers' preferences and what breeders are able to offer may bring valuable information. Simple methodologies to evaluate such trade-offs have been developed in Asia[46] that could be easily used in Africa.

A limitation to broad PVS use is the huge transaction costs for the farmers, for the breeders, and for the extension workers involved. Risks of discouragement are on both sides if the varietal basket offered to farmers does not include material of sufficient interest to them. Therefore, the Panel would like to give a warning about the testing of material with too narrow a genetic basis, involving too many sister lines (e.g. NERICAs only), because such strategy may have negative long-term effects on farmers' motivation.

A last but not less important concern with PVS is that it bypasses the official national release system. This has created important problems for PVS projects conducted in India, notably because governmental support (seed production, extension, etc.) was devoted to accessions that followed the rules and standards of the official release system (on-station trials with standard inputs). While official release systems do not exist everywhere in Africa or may be more flexible than in South Asia, the possibility of conflict has to be envisioned. Ways to incorporate results coming from PVS trials and to factor them into official varietal release systems and policies being developed need to be found. The recent example mentioned to us of problems caused by the uncontrolled introduction by Chinese bilateral collaboration of an accession from Taiwan, highly susceptible to bacterial blight, shows that the total absence of rules can be very detrimental to farmers.

INGER-Africa

One of the vehicles for varietal diffusion is the International Network for Germplasm Evaluation in Rice (INGER). Although organized on a continental basis, it allows the exchange of promising material between continents as well, permitting a regular infusion of elite lines into NARS breeding programs. As highlighted in the 4th EPMR, for countries where breeding programs are weak or inexistent, INGER is an essential and appreciated mechanism to access improved varieties. It is through INGER-Africa, housed in GRU, that germplasm developed by CGIAR Centers and NARS from Asia, Latin America and Africa is made accessible to the NARS of Africa.

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[46] Paris TR, Singh A, Luis J, Singh HN, Singh ON, Singh, S, Singh RK, Sarkarung S., Listening to farmers' perception through participatory rice varietal selection: a case study in villages in eastern Uttar Pradesh, India. In Proc. Intern. Symp. on Participatory plant breeding and participatory plant genetic resources enhancement, Pokhara, Nepal, 1-5May 2000, p179-191.

Despite its invaluable role, INGER has had, all over the world, strong difficulties in sustaining its funding since the mid90s. INGER-Africa was no different, when funding from DFID stopped in 2002. This funding instability has translated into a decrease of INGER's activities in Africa. However, the situation seems to be improving. WARDA, which rightly values this network, has recently recruited a coordinator for INGER-Africa. Part of the funding from Canada's CIDA, secured within the framework of an IRRI-WARDA collaboration, will contribute to finance INGER-Africa.

The INGER distribution system has changed in parallel to its financial problems. While in the past the distribution was through structured sets of accessions systematically sent to partners, nowadays it is upon request for specific material. INGER-Africa dispatches requested accessions to African countries and other parts of the world (germplasm consignments, improved varieties, O. *glaberrima* accessions), but at a lower scale than before. The new system may be less costly and does not require logistics as structured as the "old" one, but it results in a considerable loss of information on tested accessions. INGER-Asia and the Maize Network coordinated by CIMMYT have demonstrated the value of these data to get a clear pattern of GxE interactions and a better picture of the mosaic of target environments. Moreover, the systematic diffusion of sets of elite lines allowed breeders to identify interesting material unknown to them (e.g. B6144, an excellent variety from Indonesia that spread all over the world, including Africa, due to INGER's "old" system).

The Panel recommends that WARDA seek to secure, on a sustainable basis, the funding of INGER-Africa, which is a network essential for the diffusion of genetic progress. The Panel further recommends that INGER-Africa clearly focus on understanding Genotype x Environment interaction patterns across testing sites and capitalize on the benefits that derive from it.

Biotechnologies

Molecular markers

Molecular marker laboratories have had to be established in the three places where WARDA's staff were successively located (Bouaké, Bamako and Cotonou). The time and energy lost in the successive relocations had an opportunity cost in terms of scientific production. The Cotonou laboratory is presently operational. The laboratory is globally well equipped, but in the view of the large-scale genotyping activities planned, *the acquisition of a sequencer for genotyping would be useful.* The logistics issues related to the maintenance of a high technology laboratory in a country such as Benin are well under control through good organization and planning. WARDA's staff based in Ibadan also has access to the IITA molecular laboratory through a modest bench fee. The molecular marker laboratories are used for 3 main activities: diversity analyses (discussed above), genetic mapping and marker-aided selection.

Genetic mapping

Most of the work done so far is about the genetic mapping of QTLs for resistance to RYMV and cloning of a recessive gene of resistance.[47] Parallel work has been conducted on the serological and molecular diversity of the virus itself and its evolution.[48] Excellent papers have been

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[47] Albar L, Ndjiondjop M-N, Esshak Z, Berger A, Pinel A, Jones MP, Fargette D, Ghesquière A., Fine genetic mapping of a gene required for Rice yellow mottle virus cell-to-cell movement, 2003, Theoretical and Applied Genetics. 107(2): 371-378

Albar L, Bangratz M, Ndjiondjop M-N, Jones MP, Ghesquière A., Mutations in the eIF(iso)4G translation initiation factor confer high resistance of rice to rice yellow mottle virus, 2006, The Plant Journal, 47(3): 417.

[48] Fargette D, Pinel A, Abubakar Z, Traoré O, Brugidou C, Fatogoma S, Hebrard E, Choisy M, Séré Y, Fauquet C, Konaté G., Inferring the evolutionary history of Rice Yellow Mottle Virus from genomic, phylogenetic, and phylogeographic studies, 2004, Journal of Virology 78: 3252-3261

published and the resistance gene has been cloned. This is a remarkable achievement, and the strategy developed in this project could be used as a model for further work. This work, done with IRD, results from a long lasting collaboration whose quality and adaptation to WARDA's needs through students' training was emphasized to us.

WARDA is associated with several recent projects aiming at producing resources to facilitate *O. glaberrima* diversity exploitation. The main WARDA-led project involving marker-aided genetic analyses is focusing on drought. It is funded by the Rockefeller Foundation with the objective of developing improved lines with high and stable yield. It represents an individual project (MTP project 4), and is coordinated by a molecular biologist. The project involves three components: a characterization of drought profiles using GIS and AGRHYMET, classical selection and marker-aided selection (MAS), and integrated management options (manipulation of sowing dates, variety growing period and sowing density). The integration of the three components is an excellent aspect of this project, since genetic approaches are too often considered as the unique solution to solve all problems.

Drought resistance is a complex integrative character resulting from the interaction of many traits, sometimes with antagonistic effects, and the importance to be given to the respective traits has to be weighed for each drought profile. The "characterization" component will notably help molecular geneticists and breeders to choose, on a more solid basis, the right secondary traits to focus on. The Panel believes that in project 4, it is essential to ensure a close relationship with physiologists in order to understand the fundamental underlying processes. This is expected to be achieved through interactions with a JIRCAS WARDA-seconded physiologist and continued collaboration with previously WARDA-seconded CIRAD physiologists.

The Panel was initially surprised by the strategy apparently developed for genetic analyses in project 4. The genetic control of drought resistance traits in *O. glaberrima* is unknown, while a very large corpus of information is already available in *O. sativa*. Nevertheless, WARDA started developing four new intra-*sativa* crosses involving parents already used in older mapping populations that carry little chance to bring new information. Meanwhile, teams in CIAT have developed two chromosomal segment substitution line populations (CSSLs) involving an *O. glaberrima* parent (Caiapo (japonica) x IRGC103544; IR64 (*indica*) x TOG5681). These already genotyped CSSLs nowadays constitute, without doubt, the best resource to detect QTLs in an interspecific background and validate them. WARDA, that has already excellent collaborations with these CIAT teams, should put more emphasis on phenotyping this material to detect QTLs for a broad range of traits of interest in African conditions, notably because TOG5681 is the *O. glaberrima* parent of the lowland NERICAs. Good recovery after drought seems to be the main specific drought resistance character of *O. glaberrima* and this trait can be evaluated in the CSSL mapping populations. The Panel was told that the new intra-*sativa* mapping populations are also seen as starting points for marker-aided selection projects, which makes their development more understandable.

The choice seems to have been made to focus mostly on secondary traits. The debate is still ongoing to know whether more progress is to be expected from a selection based on yield under

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Traore O, Sorho F, Pinel A, Abubakar Z, Banwo O, Maley J, Hebrard E, Winter S, Séré Y, Konate G, Fargette D., Processes of diversification and dispersion of Rice Yellow Mottle Virus inferred from large-scale and high-resolution phylogeographical studies, 2005, Molecular Ecology 14: 2097–2110.

stress itself[49], or from secondary traits with strong correlations with yield under stress and better heritability. Both are commendable but in both cases, the best solution is to go to the root of the mechanisms. Eco-physiologists are presently trying to link their crop models to genetic models.[50] It seems to the Panel that WARDA, by establishing this multidisciplinary team, has the capacity to invest in this promising field, and ***the Panel strongly encourages the Center to do so in collaboration with advanced institutions.***

Both the molecular biologist in Cotonou and the one based in Ibadan are focusing on drought. One is looking at the drought response at the vegetative stage and the other at reproductive stage in different intra-*sativa* crosses. The Panel feels that the genetics of drought, already the object of strong efforts worldwide, is certainly an important issue that deserves a critical mass to reach fast result. However, more integration between the two teams and other teams dealing with the issue would be useful.

Meanwhile, the understanding of the genetic control of other traits such as iron toxicity in the lowland ecosystem, salinity in the irrigated, or weed competitiveness in the upland and lowland ecologies, which were all mentioned as important, is not presently the object of any effort. The reason given to the Panel for not investing in the genetics of weed competitiveness was the lack of a weed specialist to help define a good phenotyping methodology, which is indeed necessary. For iron toxicity, the first project submitted to a donor was not funded. The Panel hopes that, with the presence of the new IRRI-seconded breeder in Ibadan, who has experience with salinity and other abiotic stresses, the work on biotic and abiotic constraints can be distributed between the collaborating scientists in order to cover most if not all of these constraints.

Since most NERICAs carry only very limited segments of *O. glaberrima*, NERICAs were also used as near-isogenic lines, and compared to their *sativa* parent to check whether the introgression areas carried genes of interest. This work will be published soon.

QTL detection in mapping populations permitted huge progress in understanding the genetic control of quantitative traits. Its weaknesses, however, lie in the lack of precision in the QTL position, and in the limited number of alleles compared. Association mapping in natural populations, derived from human genetics, is now spreading in plant genetics because it does not show the same shortcomings. The important work done on the genetic structure of *O. glaberrima,* combined to the establishment of *O. glaberrima* core collection suggested in this report, open the way to use this approach directly in this species, and to identify alleles different from the *sativa* ones. WARDA has envisioned a whole-genome mapping approach that would represent an excellent valorization of its previous work and of the in depth characterization that the Panel suggests to conduct on *O. glaberrima* for all its valuable traits. Such enterprise has taken the form of a very large project for drought and disease (BLB and RYMV) related issues, which has been submitted for funding to the CGIAR's Generation Challenge Program, and could be submitted to other donors for other traits.

The Panel agrees that WARDA should push its logic of exploiting African genetic resources up to its limit, and pursue at a larger scale the exploitation of the genetic diversity of *O. glaberrima* that no one else is better placed to do, and which the GRU head, molecular biologists and breeders have already started to explore (SC issue 5).

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[49] Atlin G., Improving drought tolerance by selecting for yield. In: Manual: Breeding rice for drought tolerance, 2003,. eds Fisher K, Lafitte R, Fukai S, Atlin G, Hardy B, IRRI, p. 14-22.

50 Hammer G, Chapmann S, van Oosterom E, Podlich D,Trait physiology and crop modeling to link phenotypic complexity to underlying genetic systems. Proc 4th Int Crop Science Congress, 26 Sept-1 Oct 2004, Brisbane, Australia.

The Panel strongly supports the coordinated whole genome association mapping approach undertaken by WARDA for drought resistance traits of interest in O. glaberrima. For higher efficiency, the Panel suggests to build on the experiences accumulated on various species in the Generation Challenge Program, to which WARDA is already contributing. The Panel encourages WARDA to extend the analysis to all traits of interest in O. glaberrima, with the same collection.

Marker-aided selection (MAS)

***WARDA research activities**:* The cloning of the RYMV gene opened large avenues for MAS that are logically explored now.[51] The present work conducted at WARDA headquarters logically concerns the introgression of the resistance allele from Gigante (an *O. sativa* accession from Mozambique) located on chromosome 4, into elite lines such as IR64 and Bouaké 189. The work is presently in BC_3F_2.

One concern is the focus of this research on a single gene that has already broken down in some countries. It may be still useful in other countries such as Mali, but its durability is an issue to tackle. Some genetic mapping work has shown that QTLs coming from other accessions such as Azucena can also contribute to partial resistance to RYMV.[52] These QTLs cannot be neglected. The advantage of marker-aided selection is that it could permit the manipulation of several genes at the same time, and the association of a major gene with QTLs seems commendable. It is also important to keep in mind that most environments will require varieties with multiple resistances and that the need to manipulate several traits and several genes per trait will very soon require going further than just back-cross introgression.

Marker-aided selection is also being used to speed up fertility restoration in interspecifc hybrids (project Ibridge funded by GCP). In addition, while attempts are being made to develop aromatic rice for the irrigated environment through classical approaches, marker-aided selection approaches should also be explored, since the major aroma gene controlling acetyl-pyroline production is now cloned.[53]

The Panel feels that the molecular marker technology is now mature enough to help improve breeding efficiency. The Panel strongly encourages its use in all cases where genes of interest have been cloned (aroma, salinity with *Salto1*, submergence tolerance with *Sub1*) in addition to the already planned work on RYMV resistance.

***WARDA's alertness to developments in molecular breeding**:* The Cotonou laboratory acts as a training and operative center for NARS scientists in molecular marker technology. The training aspects are further described in section 2.5. In addition, WARDA has helped NARS to set their own molecular laboratory in four countries (Mali, Burkina Faso, Guinea and Gambia). The Panel

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[51] USAID funds the MAS for RYMV at WARDA since 2004.

[52] Albar L, Lorieux M, Ahmadi N, Rimbault I, Pinel A, Sy A, Fargette D, Ghesquière A., Genetic basis and mapping of the resistance to Rice Yellow Mottle Virus. I. QTL identification and relationship between resistance and plant morphology, 1998, Theor Appl Genet 97:1145–1154

Pressoir G, Albar L, Ahmadi N, Rimbault I, Lorieux M, Fargette D, Ghesquière A., Genetic basis and mapping of the resistance to Rice Yellow Mottle Virus. II. Evidence of a complementary epistasis between two QTLs, 1998, Theor Appl Genet 97: 1155–1161

Ahmadi N, Albar L, Pressoir G, Pinel A, Fargette D, Ghesquière A., Genetic basis and mapping of the resistance to Rice Yellow Mottle Virus.III. Analysis of QTL efficiency in introgressed progenies confirmed the hypothesis of complementary epistasis between two resistance QTLs, 2001, Theor Appl Genet 103:1084–1092.

[53] Bradbury LMT, Fitzgerald TL, Henry RJ, Jin Q, Wtaers DLE, The gene for fragrance in rice, 2006, Plant Biotechology Journal 3:363-370.

feels that the capacity building effort in this domain is developing very well, that the locations were well chosen, and that the proposed plans are sound. As said before, ***the Panel strongly supports the presence of molecular marker laboratories directly in the breeding sites, since simple and robust techniques are now available. In addition to the 4 existing laboratories, the Panel encourages WARDA to set one in N'diaye in Senegal, where the Center is conducting its irrigated breeding program and where the present breeder is quite competent to make the best use of it.***

WARDA's strategy for the future is to let NARS take care of the development of local products through marker-aided selection and focus on more upstream research on genetic analyses and identification of alleles of interest to African countries (SC issue 6). The Panel commends this strategy but underlines that MAS will soon evolve from very simple backcross introgression schemes to more complex genotype building and marker-aided recurrent selection schemes. NARS will rely on WARDA for MAS methodology and, therefore, theoretical developments in this field have to be carefully followed by WARDA's scientists. WARDA also needs to be part of any overall CGIAR initiative attempting to evaluate the cost/efficiency ratio of MAS. Low-cost, fast techniques for DNA extraction and for field genotyping represent an area of research where the technology is still far from being optimized, and on which CGIAR Centers could make further investments.

Other biotechnology research activities

***Transgenic approaches*:** WARDA does not directly conduct research on transgenics, and does not presently have any comparative advantage to do so. The Center relies on advanced institutions to develop transgenic material of interest to Africa. For example, the John Innes Center (UK) is presently being working on resistance to RYMV, testing a system based on the coat protein that prevents the virus' replication. For the Panel, if needs arose to use genetic transformation at a larger scale, a good option would be to collaborate closely with IRRI, which now has set up a very effective system to introgress any gene of interest into any accession, and is very open to collaboration.[54]

At some point in time, the test of transgenic varieties would have to be done in Africa. This raises the issue of the handling of transgenic plants (need for a transgenic greenhouse) and the status of transgenic crops, first in Benin, and then in the target countries.[55] In Benin, there is a moratorium up to 2007. Since IITA-Ibadan has confinement facilities and an official legislation, work could theoretically be conducted there, although some problems with Nigerian public opinion are to be expected.

WARDA's plant pathologist and molecular biologist therefore, monitor the evolution of the legislation in African countries carefully. The Center is right in getting involved in the development of policies facilitating the correct use of GMOs in Africa, and in ensuring proper information on their biological and social consequences.

WARDA collaborates with the Harvest Plus Challenge Program (HP) but not on genetic engineering activities (SC issue 11). HP seeks to reduce micronutrient malnutrition among the poor by breeding staple food crops that are rich in micronutrients, through a process called bio-fortification. This objective is, of course, of interest for Africa. WARDA indicates to have identified rice varieties with high Fe and Zn content (to be confirmed) through its collaboration

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[54] Hervé P., Allele engineering and drought: a simple solution for a complex trait? In: Drought resistant rice for increased rainfed production and poverty alleviation, 2007, eds. Seraj R and Hardy B, IRRI, Los Baños, Philippines (in press).

[55] Legislation is in place in Burkina Faso, Cameroon and Nigeria, but not voted or not in place in other countries.

with the University of Adelaïde (Australia), and envisions marker-assisted breeding to exploit these alleles. This is, in the Panel's eyes, an option globally less problematic than genetic transformation for genes/alleles originating from the *Oryza* genus. The Panel feels that the Center is taking the best possible advantage from its collaboration with HP in the present context of GMOs in West Africa. If the situation were to change significantly, the best strategy to capitalize on the results obtained by HP on other species would be through collaboration with IRRI for genetic transformation of African varieties, as mentioned above.

Genomics: WARDA has not yet invested in genomics tools, but is considering their use in several areas of structural and functional genomics that could boost progress in molecular genetics and improve marker-aided selection efficiency.

On structural genomics, two *O. sativa* genomes have been fully sequenced and 20 varieties have had the gene part of their genome sequenced (Perlegene project, led by the International Rice Functional Genomic Consortium). Based on this momentum and on the constitution of BAC libraries and BAC-end sequencing of many wild accessions, including African ones, mention has been made to the Panel of the possibility of WARDA sequencing the *O. glaberrima* genome. In the Panel's opinion, although costs have decreased a lot, genome sequencing is still a complex and costly endeavor that can only be taken care of by an international team, led by an advanced institution with large bioinformatics capabilities. Notwithstanding the above, the Panel notes that the sequences of *O. glaberrima* genes would be useful to make marker-aided selection easier to produce and handle. These sequences compared to that of *O. sativa* would allow defining gene markers polymorphic between *O. sativa* and *O. glaberrima* (SNPs or indels), which are among the best markers for MAS. The Panel suggests that, before envisioning any whole genome sequencing project, tests be conducted in collaboration with IRRI to see whether the simpler and cheaper strategy used in the Perlegene project could be used for *O. glaberrima.*

On functional genomics, WARDA is interested in expression studies as a way to identify genes controlling traits of major agronomic importance for Africa, notably drought resistance, by comparing accessions of *O. glaberrima* with different levels of resistance. The Center intends to build on existing CGIAR capacities, notably those developed at IRRI as service laboratory. Indeed, the Panel considers that getting staff trained at IRRI, and initially using their facilities, are the best first steps that WARDA should take before considering investing in Cotonou.

Bioinformatics: Bioinformatics needs generally develop with high throughput activities in genomics that do not yet exist in WARDA. No bioinformatics plan has yet been set (SC issue 5). Collaborations with advanced institutions are seen as a way to fulfill the possible future needs. This strategy appears as an adapted, short-term solution to address specialized needs. Nevertheless, it is the Panel's experience that bio-informaticians are becoming more and more necessary if only to exploit the mass of information available in the world's databases. This is particularly true for rice with all the sequencing efforts that have already been made.

WARDA has to take a longer-term view. The Panel suggests that, capitalizing from the Generation Challenge Program (GCP) momentum, WARDA starts to build a bioinformatics team by recruiting an expert in databases that constitutes the necessary ground for any further work. Connection with the GCP platform can be a starting point and collaboration should be sought with the joint IRRI-CIMMYT Crop Research Informatics Team (CRIL). The International Rice Information System being developed at IRRI should be analyzed for its suitability to respond to WARDA's needs. Adaptations to WARDA's specificities will certainly have to be introduced but it may be a possible way to gain time and money. Tools around the databases would come next. (This is further discussed in section 2.6.5 on biometrics.)

We suggest that WARDA focus strictly on rice issues, and just establish connections with the main other rice and cereals databases. The extension to other cereal crops in West Africa under WARDA's leadership is not a priority in the present situation. The area of comparative genomics in cereals is well occupied by the Gramene project (www.gramene.org), which has world ambition and recognition, and the duplication of their efforts would just divert WARDA’s resources from its core research agenda.

Bioinformatics is defined as informatics applied to genetics and genomic data and does not always include biostatistics. However, in a longer term, the idea of creating a unit comprising biostatisticians, bio-informaticians, and data base management specialists should be considered. The recruitment of an information system specialist could benefit the whole of WARDA’s research community, including the GIS and GRU units. Meanwhile, help can also be expected from the IT unit whose head seems quite competent in data base management. The Panel stresses, however, that such developments would not make any sense without a very serious improvement in internet connectivity at WARDA.

Concluding comments on rice genetic improvement

The 2000-2006 period has been marked by the official release of NERICAs for the three major rice ecosystems. The genetic basis of these varieties, however, is very narrow. Interspecific crosses seem now possible, if not easy, for all types of parental combinations. This opens the way for a more comprehensive exploitation of the African cultivated gene pools (*O. sativa* and *O. glaberrima*), which could mark the beginning of a great genetic adventure. Since *O. glaberrima* has not been as thoroughly evaluated as *O. sativa*, it should be the subject of more in depth phenotypic evaluations for all its recognized valuable traits. The assessment of *O. glaberrima* diversity has started on an excellent basis, and should be pushed to the point of defining core collections that will be useful for all disciplines. The results of phenotypic and molecular evaluations should be combined in a whole genome association mapping study that is, in such situation, probably the best approach to understand the genetic control of the valuable traits, and to identify superior alleles in *O. glaberrima*.

NERICAs have proven to be interesting material in many situations, seemingly because of their short duration. WARDA tends, however, to use them as the only option for a too large variety of situations. It is clear to the Panel that WARDA's breeding program would greatly benefit, in terms of efficiency and impact, from a better analysis of the African agro-ecological and socio-economic environments, and from a definition of homogeneous target zones with their associated ideotypes, and from a better prioritization of the breeding work among these niches. The stratification tools exist at WARDA (see section 2.3), as do the scientists from the needed disciplines. All elements are in place to do the proposed research. The results of this stratification should be factored into the participatory varietal approaches in order for breeders and socio-economists to better understand the reasons behind the variability of variety performances and farmers' choice. Meanwhile, the lack of weed competitiveness in varieties specifically designed to have this quality should be analyzed and lessons drawn for future breeding work.

Very good work has been done during the review period on the understanding of the genetic control of some traits, going up to cloning a RYMV resistance gene, in collaboration with an advanced research institution. Work is only starting for the major abiotic stresses. A clearer division of work between scientists is needed, but the young and dynamic team of WARDA shows promises of producing interesting results. MAS programs have still to prove their efficiency, but laboratory and trained scientists are in place to initiate the first programs at NARS level, and several useful genes are available for introgression.

As a general assessment, the Panel believes that, despite the many difficulties that have marked the review period − with two successive relocations which were very damaging for the continuity of the breeding and genetic programs, and large staff turn over − material was produced, whether intra or interspecific, that has already proven very useful, and the future could be even better. In addition, the Panel stresses that much can be gained in terms of long-term genetic progress by adopting a less empirical approach, with a focus on understanding better the GxE interactions (environment being understood as the combination of the agro-ecological and the socio-economic environments) and the mechanisms explaining superior performances.

2.2 Agro-physiology

Most of crop improvement activities at WARDA have been concentrated on the development of NERICAs. New interspecific hybrids between *O. sativa* and *O. glaberrima* (NERICAs) are expected to have higher yields, earlier maturity, resistance to local stresses, and higher grain protein content. However, questions remain about whether these traits are fully realized in the NERICA varieties, and whether the conclusions reached thus far are supported by agro-physiological evidence.

Yield potential and maturity

Many on-station yield trials have shown that some interspecific progenies or NERICA varieties out-yield their parents. However, yield performance of the varieties differs across ecologies (e.g. between irrigated and rainfed[56]), and the reasons for this are not clear, since the physiological basis of yield performance has been poorly researched. One of the few reports testing the photosynthetic and stomatal conductance of varieties from different origins (including one interspecific hybrid, WAB450-1-B-P-38-HB) showed that the interspecific hybrid had similar stomatal conductance and photosynthetic rate to those of elite *sativa* varieties[57]. However, how these traits can increase yields under both no fertilizer and conventional fertilizer conditions remains unanswered. Fujii et al. (2004)[58] compared growth and physiological characteristics of six upland NERICA varieties (1-6) with several *sativa* varieties (including *indica*, *japonica* lowland and upland varieties) under upland conditions. NERICA 2 and NERICA 3 showed a larger biomass and stomatal conductance than did lowland varieties, but large variation existed amongst six NERICAs, suggesting that the agro-physiological traits of NERICAs cannot be generalized.

Earliness of NERICA varieties is probably the most evident characteristic. *The Panel suggests that the relationship between growth duration and yield potential be examined***.** If the yield potential of NERICAs is reasonably high for their short duration, the physiological basis of the relatively good yield performance would be worthy of research.

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56 Futakuchi K, Jones MP, Osiname O. 2004. Development of lowland rice from the interspecific cross of Orysa sativa and O. glaberrima. Fischer T etal (2004). New directions for a diverse planet: Proceedings for the 4th International Crop Science Congress, Brisbane, Australia, 26 September – 1 October 2004. www.cropscience.org.au

57 Ohsumi A, Hamasaki A, Nakagawa H, Yoshida H, Shiraiwa T, Horie T. 2007. A Model Explaining Genotypic and Ontogenetic Variation of Leaf Photosynthetic Rate in Rice (Oryza sativa) Based on Leaf Nitrogen Content and Stomatal Conductance. Annals of Botany 99:265-273. DOI 10.1093/aob/mcl253.

58 Fujii M, Andoh C, Ishihara S. 2004. Drought resistance of NERICA (New Rice for Africa) compared with Oryza sativa L. and millet evaluated by stomatal conductance and soil water content. Fischer T et al (2004). New directions for a diverse planet: Proceedings for the 4th International Crop Science Congress, Brisbane, Australia, 26 September – 1 October 2004. www.cropscience.org.au.

Drought tolerance

Despite high expectations, experimental evidence for drought tolerance of NERICA varieties is still limited. Presently, CG14's long and thin roots are the trait that may confer drought tolerance of the interspecific progeny, but there has not been concrete evidence that interspecific progenies have inherited this trait. On-station morphological and physiological evaluation of germplasm for drought tolerance, ongoing under project 4, should help provide a fair evaluation of the drought tolerance of NERICAs. However, this project targets the mid-season (reproductive growth stage) drought only. Therefore, a different strategy is needed to address drought that comes at the early and terminal stages of the crop cycle.

Earliness can reduce the water use of the canopy, and in turn can avoid drought, but still very limited information is available on the water use of NERICAs. Fujii et al. (2004)[59] demonstrated that NERICAs 1-6 use less water, particularly from the deeper soil layer, compared to their parents and *sativa* upland varieties. Whether this is due to limited growth duration or root density is not clear. However, interestingly, NERICAs 3 and 5 produce relatively high biomass with limited use of water, which may also be worthy of further research. Contrary to studies on roots, some scientists hypothesize that the interesting focus for research in drought should be *O. glaberrima's* ability to recover after stress. Thus, *the Panel suggests that the drought tolerance ability of the* O. glaberrima *parent and NERICAs be investigated, focusing also on the plant's ability to recover from drought.*

Heat-induced spikelet sterility

Very limited information is available for the heat tolerance of NERICAs. But in their study comparing heat tolerance of 18 varieties of different ecotypes (including one interspecific hybrid, WAB450-1-B-P-38-HB), Matsui et al. (2005)[60] demonstrated that the NERICA is rather susceptible to heat-induced sterility, largely due to the morphological traits of its anthers. Because this trait significantly influences pollination under dry conditions, evaluation of this trait in other interspecific progenies is important.

Submergence tolerance

A few studies have been conducted to identify the submergence tolerance of interspecific varieties. Futakuchi et al. (2001)[61] suggested *glaberrima* varieties have high elongation (avoiding) ability under submergence, compared to *sativa* varieties. More recent results seem to show that the gene responsible for this ability is different from the recently cloned *Sug1*. Whether this trait is inherited to interspecific progenies is not clear. It is also important to note that submergence resistance traits can vary depending on the types of submergence, and that for long-term submergence, stem elongation may not be a desirable trait.

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[59] Fujii M, Andoh C, Ishihara S. 2004. Drought resistance of NERICA (New Rice for Africa) compared with *Oryza sativa* L. and millet evaluated by stomatal conductance and soil water content. Fischer T etal (2004). New directions for a diverse planet: Proceedings for the 4th International Crop Science Congress, Brisbane, Australia, 26 September – 1 October 2004. www.cropscience.org.au

[60] Matsui T, Kobayasi K, Kagata H, Horie T. 2005. Correlation between viability of pollination and length of basal dehiscence of the theca in rice under hot-and-humid condition. Plant Production Science, 8:109-114.

[61] Futakuchi K, Jones MP, Ishii R. 2001. Physiological and morphological mechanisms of submergence resistance in African rice (*Oryza glaberrima* Steud). Japanese Journal of Tropical Agriculture 45(1):8–14.

Grain nutrient quality and nutrient use efficiency
Protein rich interspecific progenies have been developed from the cross between CG14 and WAB56-104.[62] This trait was consistently confirmed over many years and seasons, and is thus under strong genetic control. There was no significant negative correlation between protein content and grain yield, suggesting that the high protein trait can be achieved at limited expense of grain yield. Interestingly, however, the *glaberrima* parent, CG14 is a protein poor variety compared to the *sativa* parent, so the protein rich trait is perhaps attributable to the *sativa* parent. Having a high nutrient concentration often results in a lower nutrient use efficiency. Whether the protein-rich interspecific progenies can also be nutrient efficient needs testing.

In conclusion, and following successful development of NERICAs, considerable research emphasis has been put on NERICAs, but the mechanisms and processes behind NERICA's productive potential are generally unknown. Without a balanced and robust research strategy to substantiate claims and understand the fundamentals behind them, WARDA's scientific credibility may be at risk. *Follow-up studies to better understand the* O. glaberrima *parents and NERICAs, in terms of mechanisms associated with NERICA's superior performance (e.g. higher nutrient-use efficiency, water-use efficiency and productivity, resistance to pest and diseases, protein content and weed competitiveness), are needed and the Panel suggests that these studies be done*. It is important that the target trait is well defined and progeny traits are examined agro-physiologically. More detailed physiological analysis is desirable and this should be done in collaboration with other advanced research institutions.

2.3 Rice agronomy and natural resource management

According to the programmatic structure of WARDA outlined in the Medium Term Plan 2007-2009, most of the agronomic and natural resources management research at WARDA cuts across all ecologies in Program 1 'Integrated Rice Production Systems'. The objectives of the relevant projects are:

- ***Project 1:*** **'Enhancing productivity and stability of the uplands rice-based systems'**: Enhance the productivity and system stability through usage by farmers of high yielding, good quality, multi-stress-resistant germplasm based on accessions that are characterized and safely preserved in WARDA's genebanks.
- ***Project 2:*** **'Sustainable intensification of the lowland rice-based systems for enhanced livelihoods':** Provide improved technologies that can help farms to exploit the lowlands in a sustainable and profitable manner.
- ***Project 3*****: 'Enhancing the performance of irrigated rice-based systems in Africa':** Promote the utilization of options for integrated crop and natural resources management by farmers in a range of irrigated rice-based systems in Africa.

The biophysical aspects of WARDA's agronomy work within these three projects are complemented by studies on socio-economic aspects of technological, institutional and policy changes (Project 6), strategies for better partnerships and for disseminating rice technologies (Project 7), and local agronomic technology development within the framework of the Inland Valley Consortium (IVC). NRM research is designed to find crop management solutions to tackle major constraints to rice production. The constraints to rice production for the three main rice ecologies are shown in Table 2.1 below:

[62] Watanabe H, Futakuchi K, Jones MP, Sobambo BA. 2006. Grain protein content of interspecific progenies derived from the cross of African rice (*Oryza glaberrima* Steud.) and Asian rice (*Oryza sativa* L.). Plant Production Science 9:287-293.

Table 2.1 Ecosystems – biophysical constraints to increased rice productivity and profitability.

Ecology	Constraints	Projects
Upland	Drought, nitrogen (N) & phosphorus (P) deficiency, blast, soil acidity, erosion, stem borers, weeds, birds *, rodents *	P1: Upland P4: Drought
Lowland	Iron toxicity, N deficiency, lack of water control, RYMV, AfRGM, stem borers, nematodes, weeds, birds*, rodents*	P2: Lowland P4: Drought
Irrigated	N deficiency, iron, toxicity, salinity, alkalinity, RYMV, nematodes, AfRGM	P3: Irrigated

* WARDA does not have a comparative advantage for work on birds and rodents.
Source: WARDA Strategic Plan 2003-2012

Rice research has firmly established that rice yield at farm level is determined largely by crop management practices. Considerable progress has been made in the development of intraspecific and interspecific improved varieties. Complementary to this work, WARDA has developed integrated crop management practices for the three major targeted rice ecologies. These developments have led to considerable rice productivity gains in a number of West African countries. However, the huge yield gaps between on-station and farmers' fields in the Senegal River Valley[63,64], for example, demonstrates that factors other than rice varieties can also contribute greatly to rice production.[65] This is mainly because many crop management decisions at local and farm level increase the productivity and profitability of rice systems. These crop management aspects include decisions on: (a) field preparation; (b) cropping calendar; (c) management of weeds, insects, diseases and other enemies; (d) management of nutrients; (e) water management; (f) harvesting; and (g) drying, storage and other post-harvest activities such as milling and straw management, among others.

WARDA's research on crop management issues is done in close collaboration with NARS and other partners, and include: (a) the sustainable use of natural resources as it relates to rice production (e.g., development of crop management options to mitigate or prevent undesirable environmental effects of rice production such as soil salinization, soil fertility mining, resource-use efficiency); (b) timing of weed operations; and (c) options to improve resource use efficiency, such as improving water productivity and nutrient- and water-use efficiency.

Crop, soil and nutrient management

Upland and rainfed lowlands

Weeds and soil fertility are the major constraints for low rice yields in the uplands and rainfed lowlands. Prior research at WARDA has shown that nitrogen (N) and phosphorus (P) are the most deficient soil nutrients for upland rice production in the humid forest agro-ecological zone (AEZ). In the moist savannah AEZ, N is the most limiting factor, while phosphorus is moderately to slightly deficient. In both humid forest and savannah AEZs, potassium is the limiting after three years of continuous rice production without fertilization. In the semi-arid zone, all macronutrients (N, P and K) have been found to be highly deficient. The integrated soil fertility management (ISFM) approach followed by WARDA has included three aspects: (a) improved management of upland fallow, making use of adapted, weed suppressing, multi-purpose cover

[63] van Asten PJA, Wopereis MCS, Haefele S, Isselmou MO and MJ Kropff. 2002. Explaining yield gaps on farmer-identified degraded and non-degraded soils in a Sahelian irrigated rice scheme. NJAS Wageningen Journal of Life Sciences 50(3/4): 277-296.

[64] van Asten PJA, Wopereis, MCS, Haefele SM, ould Isselmou M. and MJ Kropff. 2003. Explaining yield gaps on farmer identified degraded and non-degraded soils in a Sahelian irrigated rice scheme. *Netherlands Journal of Agricultural Science* 50: 277-296.

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

legumes as short-season fallows, combined with low-cost soil amendments such as rock-phosphate[66]; (b) the use of fertilizers and other crop management options; and (c) the use of stress-tolerant varieties to salinity, iron toxicity, water-stress, and low inherent soil fertility.

The Panel notes that WARDA's soil fertility research activities include fertilizer response trials of varieties, and the search for indigenous sources of available soil nutrients or fertilizers in the uplands. The results have led to the development of optimum inorganic fertilizer requirements for the released NERICAs and other *O. sativa* improved varieties for the various agro-ecosystems from the AEZ to northern Guinea savannahs. Good recommendations for low and high input farmers have been developed. These include a survey of mineral occurrences, which are a more affordable alternative to the expensive and often unavailable fertilizers that can be used by small-scale farmers. In addition, crop management practices to improve soil fertility have been developed. Crop management options that have been developed in accordance with the ISFM approach include fallow legumes, legumes as cover crops, residue management, the used of rock phosphate, and combined use of legumes and rock phosphate. Finally, WARDA's research on the nutrient balance of upland rice cropping systems, P-uptake, nutrient use efficiency and recovery, and N fixation from legumes has improved understanding of the nutrient cycle.

In the rainfed lowlands to intensified-lowland continuum, crop response to soil fertility is often influenced by water availability and water control and management. WARDA has developed soil fertility approaches for intensification of lowland rice-based systems, which include the application of watershed management methods for inland valleys for optimizing nutrient resource use, and the development of improved water control and crop management for better productivity and the subsequent adoption of water control technologies by farmers. Other crop management options developed include dry-season cultivation of legumes, vegetables and root crops, and double cropping of rice. Capturing (N-fixation), retaining and recycling upland soil N through deep-rooting crops (e.g., pigeon pea), and capturing loss-prone N in the hydromorphic fringe or during the pre-rice cropping to reduce the release of gases to the atmosphere have also been studied. Soil organic carbon plays a major role. Some of this work was done within the framework of the Inland Valley Consortium (IVC), discussed further below.

Inland valleys constitute an important agricultural and hydrological asset at local and national levels, and can make a major contribution to food security and poverty alleviation in SSA. They cover approximately 190 million hectares in SSA, which is about 8% of the land area. However, only a small fraction of the inland valleys, probably less than 15%, is currently utilized. WARDA is the convening Center for Inland Valley Consortium (IVC), a system-wide initiative, since the latter's inception in 1993. At different points in time, NARES of 7 countries, IITA, CIRAD, and Wageningen UR have participated in the IVC. The IVC competed its phase II (2000-2005), and has started implementing phase III (2006-2010). In addition, IVC has managed to secure funding outside its traditional donors for its networking activities (WB, GTZ), and positive prospects exist to secure additional funding from traditional IVC donors in the near future (SC issue 12). The IVC has conducted soil and water management research in the countries in which it operates. Biophysical and socio-economic characterization work of inland valley dynamics and crop production systems in 18 key sites has continued, and was extended to 3 benchmark sites.

The IVC has established a GIS unit at WARDA, and has developed the West African Inland Valley Information System (WAIVIS) that has facilitated access of NRM information to WARDA scientists and participating countries. This information is also being used by IWMI and FAO.

[66] The incorporation of legumes increases rice yields through N and phosphate accumulation and the weed suppression effect.

Ongoing work includes the development of the national inland valley information system of Africa (NIVISA), a country specific database that will allow cross-country analysis. The Panel considers that this development is of great importance for future research planning and targeting at WARDA and NARS (see also section 2.2). (The IVC is discussed further in section 4.1)

In 2006, WARDA established a soil laboratory in Cotonou with financial support from ARI, ROCARIZ and JICA, as well as technical support from the IITA analytical services unit. The soil and plant laboratory's main equipment includes an Atomic Absorption Spectrophotometer (AAS), an Auto-analyzer, a water distiller, mechanical shakers, a digestion block, a neutron probe, a Time Domain Refractometer (TDR) and pH and electric conductivity gauges. This unit has the capacity to conduct routine soil and water analyses (laboratory and field measurements), and the Panel considers this a very positive development to support WARDA's NRM research. However, *the Panel suggests filling the soil laboratory assistant position, and that necessary steps are taken to improve the capacity of WARDA and NARS scientists to access and use data stored in WAIVIS and NIVISA. Furthermore, the GIS unit team should conduct GIS/GPS*[67] *short-courses to researchers, irrespective of their disciplinary background*. Field information should include geographic coordinates in order to gradually build an interdisciplinary database of field information that can spatially be combined, displayed and integrated to existing database information. Because information from various thematic disciplines can be integrated using GIS/GPS tools, their use by all scientists can also contribute to enhance interdisciplinarity and to make an integrated approach to rice production at WARDA a reality.

Another major contribution of IVC for WARDA's research agenda has been the development of screening tools for iron toxicity. As a result, tolerant varieties have been identified, and location-specific NRM management options have been devised and disseminated to farmers through NARS. Developments in this regard also include contributions to a better scientific understanding of the processes and mechanisms for iron toxicity for inland valleys in West Africa.[68] The Panel commends WARDA (and the IVC) for taking a leading role in research on iron toxicity, and for publishing good scientific work in this area.

The IVC has also developed the Participatory Learning Action Research (PLAR) methodology with WARDA's social science team, an approach that combines agronomic and socio-economic on-farm research, bringing together researchers, extension agents and farmers. In the rainfed lowlands, the IVC has made a concerted effort in the development of soil and water management options (leveling, bunding, etc) that are now available to NARES and farmers. This work is being consolidated and expanded to include diversification into rice-vegetable cropping systems.

More recently, and despite a reduction of funds from traditional donors (EU, DANIDA and France), and building on the results of Phase I and II, the IVC has facilitated the formulation of country level research projects by NARS in region. As a result, the following three country projects have secured funding: (a) Community-based Fish Culture in Irrigation Systems and Seasonal Floodplains project (under the CGIAR Water and Food Challenge Program); (b) Sustainable productivity improvement for rice inland valleys in West Africa (UN-CFC funded); and (c) Promoting ant-based pest control in tree crops in West Africa (funded by the Foundation on conservation, food and health). Projects in the pipeline include: (a) Valorization of underutilized traditional vegetables grown in West African lowland rice systems (GTZ); and (b) Promotion of viable small-scale irrigation for food security and poverty alleviation in West Africa

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[67] Global Positioning System.

[68] Audebert, A., L.T. Narteh, P. Kiepe, D. Millar and B. Beks. 2006 (eds). Iron Toxicity in Rice-based Systems in West Africa, Africa Rice Center (WARDA).Cotonou, Benin. 175 p.

(IWMI and Belgian Government). At this point, the Panel would like to note that all of these country-specific projects are only coordinated by IVC, and are not core WARDA projects (SC issue 9). In the Panel's opinion, these achievements are commendable.

In general, very good papers have been published and a lot of progress has been made in the development and dissemination of best-bet technologies, and in understanding the processes and mechanisms of soil and nutrient management, both in the uplands and rainfed lowlands. The work is relevant and of good scientific quality. This is a commendable achievement. However, based on the analysis of recently (2003-2006) submitted papers on agronomy and soil fertility improvement research, the Panel is concerned with what appears to be a focus mostly on NERICAs. Even taking this bias into consideration, the balance seems to be in favor of applied research (response trials) versus strategic research (understanding crop and soil processes and mechanisms), e.g. research to confirm whether NERICAs have indeed better nutrient- and water-use efficiency, and on identifying soil processes and mechanisms responsible for the perceived better uptake of water and nutrients, including mechanisms responsible for producing protein-rich NERICAs in N-poor soils. *In this respect, the Panel suggests that a better balance between "strategic" and "applied" research be considered in future crop and soil fertility research.* In addition, and in view of the need to support current activities and to attain sustainable intensification and utilization of (fragile) rainfed lowlands, *the Panel suggests that future work could include research on understanding the effects of rice-based cropping systems on soil quality (e.g. biogeochemistry aspects of organic C dynamics, including soil macro- and micro-fauna biodiversity) across soil types and hydrological conditions (continuum between upland to intensified rainfed lowlands).*

Irrigated environment
Average yields in irrigated Sahelian systems are around 4 to 5 t/ha. Studies conducted by WARDA have shown that yield gaps between actual and potential yields often range from 2 to 8 t/ha, indicating considerable scope to increase yields. In general, double cropping of rice practiced in only 20 % of the cropped area under irrigation in the Sahel.[69]

In recognition of the potential and growing importance of the lowland ecology in Africa, WARDA has developed irrigated lowland NERICAs. Some of these interspecific lines have been found to have a yield advantage of 7 to 25% over the dominant varieties *Sahel 108* and *Sahel 202*. However, *Sahel 108, 201* and *202* are still the most dominant varieties in the irrigated Senegal River valley.

Rice yield, productivity and profitability under irrigation can be improved because irrigation allows more control of the timing, mode and dosage of crop and natural resources management interventions, especially water, fertilizers and herbicides. Furthermore, in irrigated systems, labor is often a limiting factor, which explains why mechanization is relatively widespread compared to upland and rainfed lowlands. In this respect, labor-saving equipment developed by WARDA, such as small reapers and thresher-cleaners, are having a major impact in alleviating labor and cropping-calendar constraints in irrigated systems, and in some instances, are allowing double cropping, which has resulted in productivity gains.

The effect of water management is linked to soil fertility and weed management.[70] WARDA has developed an innovative and integrated crop management (ICM) decision tool called RIDEV for crop and natural resources management for the irrigated lowlands. RIDEV finds optimal

[69] WARDA, Annual report, 2001.

[70] Poussin-JC, Wopereis MCS, Debouzie D and Maeght-JL. 2003. Determinants of irrigated rice yield in the Senegal River valley. European Journal of Agronomy. 19(2): 341-356.

combinations between individual technologies and natural resources conditions (soil, water, climate, organisms) using decision support systems and modeling tools. RIDEV continues to be improved, and is used to advise farmers on best timing of crop management interventions, while the crop growth model ORYZA is used to determine potential rice yields. Both RIDEV and ORYZA are complemented by the model for fertilizer recommendations (FERRIZ) which is an adaptation of the QUEFTS model that is now calibrated for rice in the Sahel. The combination results in an array of management options that are undergoing adaptive evaluation with farmers. Farm modeling results in the Sahel show significant gains in yields and profits from ICM under farm conditions. The research on the irrigated lowlands is well planned and uses a good, balanced, integrated approach to increase profitability and productivity of irrigated rice systems.

WARDA's ICM work is supported by extensive studies on individual technologies such as for the development of fertilizer recommendations and weed management. Weed management options in the irrigated rice in the Sahel have focused on the combination of chemical and non-chemical measures while several years work on soil fertility has led to targeted recommendations for fertilizer management for irrigated rice in the Sahel. Overall, N has been found to be the most important nutrient for the Sahelian irrigated rice, while phosphorus has proven to also be required for highest 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 shows that FERRIZ offers a better framework to improve fertilizer recommendations as the adjusted doses to three soil fertility classes have outperformed current uniform recommendations. Since water management should be streamlined into current rice research, the *Panel suggests complementing current soil fertility and sowing date modeling with irrigation/hydrology modeling for better estimation of potential and actual crop yield scenarios caused by NRM interventions and improving irrigation delivery systems at scheme and farm levels. Furthermore, because vegetables ranked first in recent CORAF priority setting in the Sahel of West Africa and rice-vegetables is a common rotation in West Africa*[71]*, the Panel suggests that more research be conducted on rice-vegetable systems.*

Research in the irrigated lowlands has also shown how to mitigate soil degradation, a key aspect for maintenance of high productivity and sustainability in this highly productive environment. For example, ongoing work in the Senegal River valley has clearly demonstrated that good management of soil fertility can maintain yields[72]. However, in view of the slight yield decline being observed, the P*anel suggests that soil fertility long-term trials be continued and possibly be replicated elsewhere. Nutrient balance studies and soil quality aspects could couple experiments. In addition, the Panel suggests that WARDA considers research on development of simple methods for monitoring and analysis of the adverse effects caused by irrigation (including spatial analysis GIS/RS and geo-spatial, quantification of methane emissions and soil quality aspects) and the development of appropriate management options to reduce their impact on rice productivity and on the environment. The Panel* commends the excellent output on soil and nutrient management (SC issue 8) and *suggests that WARDA could benefit greatly from collaboration with CIAT-TSBF on integrated soil fertility management (e.g. biogeochemical aspects of C-dynamics, soil fertility network – Afnet network and exchange of knowledge on their current CP Water and Food).*

[71] Erenstein O, Sumberg J, Oswald A, Levasseur V and H Kore. 2006. What future for integrated rice–vegetable production systems in West African lowlands? *Agricultural Systems* 88: 376–394.

[72] Mando A, Ouattara B, Somado EA, Wopereis MCS, Stroosnijder L and H Breman. 2005. Long-term effects of fallow, tillage and manure application on soil organic matter and N fractions and on sorghum yield under Sudano-Sahelian conditions. *Soil Use and Management* 21(1): 25-31.

Water management

Water has become an increasingly scarce resource worldwide and in Africa. This affects mainly the irrigated lowland ecosystem but also the rainfed lowlands. Rice is a very water-consuming crop, but does not require permanent flooding for better production. Therefore, water management strategies geared toward saving water used by the rice crop are needed to sustain rice crop production (mainly in irrigated lowlands) and for reducing effects of salinization, water logging and methane emissions. In this context and on the SC issue 3 – Is WARDA's research on irrigated rice appropriate to the policy environment in Africa? Water management strategies developed by WARDA in the Sahel have been found to be quite efficient in depleting the salt content of the cropped soil over a period of years. Tools have been developed to make monitoring of soil salinization easier. In addition, recommendations for drainage and crop management are now available so that farmers and extension services can use these to minimize the negative impact of rice cultivation on soil quality.

Water research at WARDA includes characterization of rice production in irrigation systems[73] and studies on effects of water management on lowland rice productivity and profitability, cultivar responses to varying levels of soil and flood water salinity, the hydrology of inland valleys, effects of rice cropping on alkalinity, and improved water control and crop management effects on lowland rice productivity.[74,75] Most water management work is concentrated in the irrigated areas. Although the quality of science of the research conducted is very good, water management research is very limited in quantity even for the irrigated areas. For example, an analysis of peer-reviewed papers over the period under review shows that water management output only represents 5% of the total of peer-reviewed papers published. Nevertheless, irrigation water efficiencies are very low. For example, the Panel was told that 30,000 m^3/annum is used for rice production in Office du Niger, Mali (gravity irrigation system).

Our findings concur with results from the donor review of IVC (2004) and the CCER on IGNRM[76] that have also identified the weakness in water research as it relates to rice production at WARDA, with recommendations for strengthening this area. These include measures to strengthen and widen research on NRM, allocate funds and increase Center's critical mass. New permanent appointments of staff should include a hydrology/irrigation engineer and a land development engineer (CCER on IGNRM). In addition, IVC review recommended training (formal and informal) of NARS scientists in water management and GIS. They also suggested that in order for WARDA to strengthen its current water management capacity, it should collaborate more closely with relevant CGIAR Centers, notably IWMI and IRRI, advanced research institutions such as CIRAD and Wageningen UR and FAO.

In the uplands, rice is grown under rainfed conditions, so the scope for improving yields through better water management is very limited but considerable scope exists for better utilization of rainwater for agricultural production through the establishment of simple water retention structures. The management options are very site specific, adding to the complexity of the upland ecology. Therefore, although NARS have a comparative advantage in taking a leading role in research on this ecosystem, their capacity to undertake water management research, as far as rice is concerned, is weak. Therefore, *the Panel suggests that WARDA facilitates training for NARS and*

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[73] Segda Z, Haefele SM, Wopereis MCS, Sedogo MP and Guinko S. 2004. Agro-economic characterization of rice production in a typical irrigation scheme in Burkina Faso. *Agronomy Journal* 96 (5) 1314-1322.

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

[75] Becker, M. and D.E. Johnson. 2001. Improved water control and crop management effects on lowland rice productivity in West Africa. *Nutrient Cycling in Agroecosystems* 59(2): 119–127.

[76] CCER on Integrated Genetic and Natural Resource Management, WARDA, Cotonou, 2006.

other players at local level in water management so that research on the development of water conservation and water harvesting strategies can be conducted in the uplands and targeted rainfed lowlands outside the scope of the IVC. Residue management or mulching to conserve water and suppress weeds; the use of seepage water, groundwater, small dams, bunds and other barriers to conserve rain water; and other soil and water conservation techniques, etc. are some options that may be considered for future research geared at intensification and diversification of these areas.

Much of the rice production area in Africa is in the uplands and rainfed lowlands (63 %, FAOStat, 2007). With the exception of irrigated areas (17%), the scope for increasing yields is much higher in the lowlands, due to water availability and relative good soil fertility with higher organic matter than in the uplands. Putting inland valleys into productive use remains a key strategy for increasing productivity of rice-based systems in Africa. The Center is responding to this challenge through IVC. However, although many projects are ongoing in this area, national IVC partners are weak in water management expertise. Moreover, the ecological values (changes in hydrology and biodiversity, wetlands functions and carbon sequestration) of inland valleys are still poorly understood and may be damaged when they are put into intensified use (e.g. changes in organic carbon dynamics caused by drainage). Therefore, the *Panel suggests that the capacity of IVC partners, including the national coordination units (NCU), to conduct water and soil research and spatial analysis be strengthened.*

Water management research is concentrated on irrigated areas where rice yields, productivity and profitability are relatively higher, but irrigated lowlands only represent 11% of the rice the area and 26% of production in Africa. However, even St. Louis, the outstation where water research is concentrated, does not presently have a permanent water management/irrigation specialist. WARDA's national collaborating partners also lack capacity in water management (for example critical mass on water management in the NARS of Senegal, Mali, Mauritania and Uganda at the time of Panel visit was very low) but irrigation systems in those countries are faced with low irrigation efficiencies and problems of water delivery at system and farm levels. Research issues may include water crop modeling approaches, water irrigation scheduling, strategies to improve rice yields, efficiency and organization and management aspects of institutions responsible for water delivery and maintenance of the irrigation scheme (e.g. Office du Niger, Mali and SAED, Senegal), crop management strategies to save water, hydrology aspects of rice production and land use planning (to identify the most profitable and sustainable rice-crop rotations in those irrigation schemes or in the rainfed lowlands). Moreover, research on policies and institutional issues such as the organization and management of the institutions responsible for water delivery to rice farmers; how they link with research and other actors of the value chain; how the water price affects the profitability of rice, etc. need also attention. In addition, training of farmers and irrigation farmer organizations, and development of improved water management and distribution beyond the secondary irrigation canals in the major West Africa rice irrigation systems, is needed.

The Panel commends WARDA for the inclusion of water saving strategies and environmental aspects in the Center's research agenda for the irrigated lowlands – which are the most susceptible for environment degradation. Although, work on water saving strategies and collaboration with IRRI are already ongoing at the WARDA St. Louis station (involving a Dutch junior scientist), *the Panel suggests that the collaboration on improving water productivity and the development of water saving strategies be strengthened, possibly with increase involvement of IWMI scientists.*

The scientific achievements in water management are very good if we consider that after the departure of one IWMI seconded scientist based in M'bé in 2000 and another based in St. Louis in

2001, WARDA had no water management specialist due to lack of financial resources. Although the Panel was informed that a water management position was created and the process of filling the vacancy is underway, it is the Panel's view that this situation is very critical, and urgent corrective measures need to be taken. In addition, since there is need to concentrate in both the irrigated areas and rainfed lowlands, WARDA needs to define water management as a Center core research area and one scientist may not be enough. Therefore, the ***Panel recommends that WARDA: (1) recruit without delay two scientists, in irrigation engineering/hydrology and in crop-water modeling/land use-planning, respectively; (2) develop a strategy to mainstream water management research into the Center's core research program; and (3) help strengthen the capacity of national organizations for conducting research on the rice-water-soil interfaces, in collaboration with IWMI and other relevant partners.***

Pest and diseases management

Research on pests and diseases is designed to find both integrated pest management (IPM) and breeding solutions to major problems such as Rice yellow mottle virus (RYMV), African rice gall midge (AfRGM), and blast and stem borers (detailed list constraints per rice ecology is given in Table 2.1). Considerable progress has been made to control both AfRGM and RYMV through IPM. Moreover, through the screening of the genebank materials, genes for resistance to major diseases and insect pests such as RYMV, AfRGM, bacterial leaf blight (BLB) and blast are now available (WARDA Strategic Plan 2003-2012, p. 32). Nevertheless, work on the identification of the mechanisms associated with resistance/tolerance to AfRGM in *sativas*, *glaberrimas* and NERICAs, genetic fingerprinting, and an integrated approach combining host plant resistance and biological control of AfRGM, identification of the genetic bases and mechanisms of resistance/tolerance of major pests and diseases is ongoing. Except for RYMV, progress has been slow, probably due to lack of critical mass.[77]

The work on RYMV and AfRGM is complemented by studies on the search of high yielding rice varieties with stable tolerance or resistance to blast, BLB and stem borers. While much progress has been made on the characterization of blast genetic diversity, characterization of pathogen diversity, screening sites, and potential host resistance[78], varieties with stable resistance are not yet available. This is due to high blast pathogen variability, which is hindering efforts towards development of blast-resistant cultivars adapted to local agro-ecological conditions.

Rice and maize share some common stem borer species. For that reason, in collaboration with IITA and ICIPE, WARDA is exploring the possibility of using maize stem borer natural enemies on rice. In addition, some progress has been made in the identification of upland NERICAs with resistance or tolerance to stem borers in West Africa.

In collaboration with the IITA biotechnology unit, molecular characterization of new gall midge species and AfRGM biotypes from different African countries has been made using molecular tools. Bio-pesticides for termite control of both soil and foliage pests, and options for post-harvest storage management have been developed. Most of this collaboration work is supported by the

[77] Ahmadi, Nourollah and Alastar William Orr, Creating Low Management Plant Types for Resource-Poor Farmers in Rainfed Ecosystems Project, WARDA, Monitoring of CGIAR Projects Co-funded by the European Commission in 2003 in Asia, Latin America and the Mediterranean Regions, ECART-NATURA, Brussels, December 2004, 21 p. + annexes.

[78] Sere, Y., Sy, A.A., Akator, S.K., Onasanya, Z.. and Zai, K.. 2004. Screening strategy for durable resistance to rice blast at WARDA. pp. 38-42. in Sere, Sreenivasaprasad and Nutsugah (eds.). Rice blast in West Africa: Characterisation of pathogen diversity, key screening sites and host resistance. Proceedings of a stakeholder workshop, Project R7552,UK Department for International Development - Crop Protection Programme. Africa Rice Center *WARDA* Bouaké, Côte d'Ivoire, vi + 152 p.

mass rearing facility at Abomey-Calavi University, Cotonou and the IITA biodiversity resources centre where WARDA maintains a reference collection of insects from different countries, and provides services for NARS scientists, students, NGOs and farmers in Africa. Collaboration with IITA has resulted in an integration of varietal resistance and cultural practices utilizing natural enemies (egg and larval parasitoid and pupal parasitoid) to control AfRGM damage. By managing the habitat for natural enemies around the edge of rice fields, the carryover of AfRGM parasitoids onto rice can be increased. *The Panel suggests that the efficacy and impact of this integrated AfRGM management need be evaluated on-farm*. *In relation to the* ***SC issue 8 on integrated pest management****,* the above discussion indicates that the WARDA/IITA collaboration on insect pests of rice is effective, and is expected to produce useful results.

Research on pest and diseases management is well focused, and considerable progress has been made to control pests and diseases through breeding and integrated pest management. The evaluation under natural pest infestation and farmer participation in technology development is essential for improved impact of research. This includes consideration of cropping systems (e.g. rice mixed and strip cropping in uplands) and farmer participation in technology development as they may significantly increase research impact. The Panel was impressed with the level of current collaboration with IITA and ICIPE on integrated pest management, and commends all partners involved in this effort. Many promising and innovative new frontiers of research have been opened, such as in post-harvest management, and on the use of biological control measures for termites and stem borers, and also on the provision of services to a wider community. Given the growing importance of soil-borne pests on yield depression on the diverse and complex upland and rainfed lowland environments, *the Panel suggests that more attention be given to the development of IPM options for mitigating the impact of termites and soil-borne nematodes, especially in the uplands*. Because belowground diversity (BGBD) studies have shown that molecular methods can be used to define dominant microbial populations and monitor shifts within them in response to varying crop management practices, *the Panel suggests that WARDA explore these methods to monitor impact of crop management practices on microbial population structure and functions.*

Weed management

As noted above, weeds are a major constraint to rice production in the uplands and rainfed lowlands. In April 2001, the Weed Research unit merged with Cropping Systems Agronomy (CSA). Previous research in CSA at WARDA focused on two topics: a) yield gap analysis for upland and lowland systems; and b) improved fallows with cover legumes.

Yield gap analysis for upland systems identified weeds and soil fertility as the two major causes for low rice yields. For lowland systems, the reasons for low yields were more diversified, and depended on input use efficiency and management, but again weeds and soil fertility were major factors. Studies have shown that improved fallow systems have a positive effect on weed suppression, but adoption by farmers on WARDA's key sites (Gagnoa, Danané and Boundiali in Côte d'Ivoire) was limited, and one year later, the on-farm trials were terminated. Mainly because of this experience, it was decided to orient research efforts on weeds in upland systems towards the investigation of the response of rice varieties to competition with weeds. For lowland systems, research has focused on improved management options and the response of rice varieties to competition with weeds.

Following the development of inter-specific lines (NERICAs), weed research was almost entirely geared to improving and testing weed-competitive ability of varieties. Rapid vegetative growth and leaf-area development, and droopy lower leaves during early growth stages are the traits that can confer weed-competitiveness of varieties. For this reason, the new inter-specific hybrids between *O. glaberrima* and *O. sativa* varieties have created high expectations for better weed-competitiveness of rice varieties in Africa. Indeed, Futakuchi and Jones (2005)[79] have shown that under lowland conditions, some interspecific hybrid lines show these vegetative growth traits. Haefele et al. (2004)[80] tested 25 cultivars and lines including interspecific hybrids and showed that yield losses due to weeds were up to 84%, suggesting the potential to improve weed competitive ability of the existing varieties by means of interspecific hybridization. In their study, however, the plant traits that appeared under weed-free conditions did not explain the varietal differences in the weed-competitive ability. This suggests that the evaluation of the varieties/lines for weed competitiveness should be done under weed pressure. In this regard, the evaluation of NERICAs for their weed competitiveness needs experimental confirmation**.** *The Panel suggests that the screening method under competitive pressure in the irrigated lowland ecology proposed by Haefele et al. (2004)[81] may be utilized for the evaluation of the existing varieties and can be extended to the rainfed lowlands.*

Other studies in the uplands include those on the effects of host plant genotype on reproduction of the parasitic weed *Striga hermonthica* and *c*haracterization of host tolerance.[82,83] Ongoing work has identified the weed *Rhamphicarpa fistulosa* as the main constraint to rice production in the inland valleys of Benin. Work is ongoing at WARDA HQ to devise control measures for these newly identified weed.

However, the improvement of varieties' weed-competitiveness alone cannot protect rice from yield losses due to weeds, notably in the upland and rainfed conditions. A combination of effective weeding methods that can be afforded by the farmers is essential. In the irrigated lowlands, flooding plays a major role in weed suppression, and farmers can afford chemical measures to control weeds. The Panel has found evidence of studies to determine adequate timing and efficacy of weeding[84] and the interaction of soil fertility and weeds[85] under irrigated lowland conditions. Research has also devised management options. Ongoing work seems to suggest that some lowland NERICAs (e.g. NERICA 31 and 32) are more weed-competitive than their IR 64 (sativa parent), CG 14 (glaberrima parent) but since only one year data is available the experiment continues so that firm conclusions can be reached. While an analysis of peer-reviewed papers between 2000 and 2006 shows that the share of weed management papers published is only 4%, the papers are of very good quality. It is the Panels opinion that the scientific output is good if we consider that the Center has no senior weed scientist since 2001. More recently, it has recruited a weed scientist to be based in St. Louis. The Panel wishes to commend WARDA for that recruitment but is of the opinion that more attention should be given to the uplands and rainfed lowlands, were weed pressure is greater than in the irrigated environment because farmers in irrigated areas already have at their disposal weed management options and water help to suppress weeds. Therefore, on the SC issue 8 - What is the progress on weed management as a major limiting factor for improving labor productivity?, it is the Panel's view that considerable progress has been made in the irrigated lowlands were most research was

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[79] Futakuchi K and Jones, MP. Japan. J. Crop Science, 2005, Vol. 74 extra 2: 260-261.

[80] Haefele et al., Field Crops Research, 2004, Vol. 88:39-56.

[81] Haefele SM, Johnson DE, Mbodj D, Woperies MCS and Miezan, KM. Field Crops Research, 2004, Vol. 88:29-46.

[82] Rodenburg J, Bastiaans L and MJ Kropff. 2006. Characterization of host tolerance to *Striga hermonthica.* Euphytica 147, 353-365. http://dx.doi.org/10.1007/s10681-005-9030-2.

[83] Rodenburg J, Bastiaans L, Kropff MJ and A van Ast. 2006. Effects of host plant genotype and seed bank density on *Striga* reproduction. *Weed Research* 46, 251-263.

[84] Johnson DE, Woperies MCS, Mbodj D, Diallo S, Powers S and hafele SM. Timing of weed management and yield losses due to weeds in irrigated rice in the Sahel. Field Crops Research, 2004, Vol. 85:31-42.

[85] Häfele S, Johnson DE, Diallo S, Wopereis MCS and I Janin. 2000. Improved soil fertility and weed management is profitable for irrigated rice farmers in Sahelian West Africa. *Field Crops Research* 66(2): 101–113.

conducted and farmers can afford chemical measures for weed control. In the uplands and irrigated lowlands, the management of weeds is more important than in irrigated areas, and more could have been done for developing and dissemination of weed management options to farmers (e.g. socioeconomic considerations for previously developed options). Therefore, the Panel recommends that WARDA develop, in collaboration with weed scientists from advanced research institutions, a strategic vision for future research in weed management, and revisit its decision to focus almost entirely on the expected weed competitiveness of NERICAs. This should also include the definition of the elements of the integrated weed management approach (not only relying on weed competitiveness), the identification of research foci in terms of rice ecology and strategy for the testing of crop weed management options at the regional and local levels (SC Q8).

Genotype-environment interactions (G x E) and implications for priority setting

Crop and soil fertility research at WARDA is based on prior identification of nutrient deficiencies in major agro-ecological zones (AEZs) in West Africa. This approach of adjusting research objectives to major AEZs may be appropriate for exploratory work, to look at the regional "big picture" (synoptic view). This has to be followed and/or complemented by "zoom-in" work in targeted areas.

Currently, WARDA's water, pests and diseases management research is based on rice ecologies, which may not capture well the whole complexity and diversity of the hydrological continuum (from the uplands to the irrigated lowlands). Indeed, most crop management results have shown significant genotype by environment (G x E) interactions for yields in multi-location yield trials. For example, five intermediate yield soil fertility trials conducted across sites in Nigeria, Mali, and other countries clearly showed that genotype selection must be location specific (CCER on IGNRM). These differences are mainly because there is still considerable heterogeneity within AEZs and rice ecologies. For example, differences exist in climate (rainfall, temperature and evapotranspiration), hydrology, soil type and soil fertility, and socio-economic conditions, which often may outweigh differences in genotype-based responses. There is therefore a diversity of microenvironment niches. In addition, in order to improve the efficiency and effectiveness of research activities -- the likelihood of finding a solution, e.g. for biotic and abiotic stresses, and improve the adoption of technologies -- there is need for stratification of the biophysical and socio-economic environment into smaller "homogenous" units (microenvironment niches) to be targeted by research. As explained below, homogeneous units can be identified by using GIS-based spatial analysis tools.

Obviously, depending on the objective of research activities, an intervention can be at any level, but the appropriate level is often easier to identify when researchers already have in mind the different levels where solutions are needed (regional, AEZs, ecology, microenvironments, etc.). In addition, prior to conducting the research, a strategy should be designed so that research activities at one level complement those at other levels. In other words, solutions for specific microenvironments can be integrated and generalized for AEZs and regions, but not the other way around. For example, uniform methodologies, experimental design and protocols, soil determination methods, etc. are needed in experiments across locations to reduce confounding factors and improve the integration of multi-locational trial results. This means that appropriate strategies for harmonization, information exchange and dissemination of research results also need to be in place.

Remote Sensing (RS), Geographic Information Systems (GIS), and Geopositioning Systems (GPS) are powerful tools that can enable stratification through spatial analysis. Most of the expertise, information and products are available in the GIS unit at WARDA, and some RS data is available within project 6 – Mitigating human and environmental effects on rice-based livelihoods. Other soil-, water-, climate data can be obtained through AGRHYMET (for the Sahel), FAO and IWMI, while socio-economic data may be available through IFPRI. RS data now available include RS climatic data (Evapotranspiration, etc.), biophysical and socio-economic information stored in WAIVIS. Land degradation, soil maps, etc. for the region are easily available. Ongoing work includes the development of NIVISA. Other decision support tools such as RIDEV and FERRIZ could also be used for predicting cropping calendar and soil fertility aspects. All this wealth of information and tools used appropriately would result in the definition of homogenous units. Constraints to rice production in each of these units would be identified and quantified, allowing for improved research priority setting. Specific activities (breeding, NRM, socio-economics), for example testing and development of crop, soil, water management recommendations, would then be designed for each unit in collaboration with national research partners. Therefore, the *Panel suggests that GIS/RS and spatial analysis tools developed at WARDA and national coordination units of participating IVC countries, and other decision support tools be used for the stratification of regions and rice ecologies into more micro-level homogeneous units.* Interdisciplinarity is essential for improving research efficiency in field activities. The roles and responsibilities for each discipline and researcher from WARDA, NARS and others, and strategies for bringing all parties together should be defined.

Concluding remarks on agronomy and NRM research

In conclusion, NRM research at WARDA addresses the main soil, nutrient, water, weed, pest and diseases constraints to rice production in West Africa. In the Panel's view, this work is relevant and of good scientific quality. Considerable progress has been made in developing and disseminating NRM technologies to farmers through NARS. The Panel's overall assessment and the areas needing further work are outlined below.

Follow-up on NERICAs: The mechanisms and processes behind NERICA's productive potential are generally unknown. The Panel suggests that follow-up studies on better understanding of *O. glaberrima* parents and NERICAs in terms of mechanisms associated with NERICA's superior performance e.g. higher nutrient-use efficiency, water-use efficiency and productivity, resistance to pest and diseases, protein content and weed competitiveness be done. It is important that the target trait be well defined, and progenies traits be examined agro-physiologically.

Crop and nutrient management: WARDA's research addresses the main constraints in the AEZs; and the work is relevant and of good scientific quality. Excellent work has been done in cropping systems and nutrient management that has led to the identification of profitable crop rotations and combinations, the development and dissemination of best-bet technologies in cropping systems and nutrient management, and in understanding the processes and mechanisms of nutrient cycles of NPK, iron toxicity in inland valleys and soil salinity in irrigated areas. Although WARDA has been successful in developing varieties adapted to poor environments, practical evidence from the field has demonstrated that NERICAs yields decline after a couple of years if nutrients are not added. Therefore, future work in this area should be geared at finding strategies to improve the productivity and sustainability of rice cropping systems. Moreover, attention should be given to developing and using advanced methods and concepts for nutrient management such as organic carbon turnover in soil and fluxes within soils and across ecosystems, the use of spectroscopy techniques, GIS, RS and GPS for quick inventories of soil salinity and soil analysis, below-ground interactions in rice ecosystems using molecular techniques, impact of rice production on soil quality aspects (soil stability and particle size fractions), among others. WARDA's agronomy and soil fertility unit should also seek closer collaboration with CIAT-TSBF and other advanced research institutions.

Water management: Although of good quality, very little work has been done on water management. In view of the current water scarcity and competing demands between agriculture and other uses, there is a need to develop water-saving strategies, and to improve efficiencies in the irrigation systems and in crop water use, as well as water productivity in general. In addition, water delivery systems at irrigation system and farm levels, the effects of water prices on rice productivity and farmer organizations and management aspects in the irrigation systems need attention. A combined approach (modeling and experimental) is suggested, because of the various and complex rice-water-soil interactions. Furthermore, capacity in water management at WARDA and NARS needs to be strengthened.

Weed management: Some progress has been made in terms of developing weed management options for irrigated areas. However, weeds are a bigger problem in the uplands and rainfed lowlands, and weed management technologies that can be adopted by farmers are very limited. Furthermore, because varietal improvement for weed-competitiveness alone cannot protect rice from yield losses due to weeds, there is need to develop combined ICM-breeding strategies for future research in this area.

Integrated Pest Management: Excellent work on IPM has been done, especially in options to control blast and stem borers, in collaboration with IITA. However, further evaluation of these strategies under natural pest infestations, as well as farmer participation in technology development is essential for achieving better results. The Panel was impressed with the level of current collaboration with IITA and ICIPE on IPM and suggests that this partnership be strengthened and expanded, for example including research on soil-born nematodes, termites and other explorations of the impact of rice management practices on microbial below ground biomass using molecular techniques, in collaboration with advanced research institutes. Many promising and innovative new frontiers of research have been opened, such as in post-harvest management, and the use of biological control. These need to be pursued further.

Stratification and implications for priority setting: Because most crop management results have shown significant G x E interactions for yields in multi-location yield trials, modeling, decision support systems, and GIS/RS tools already available at WARDA, can be used to improve priority setting through stratification of the AEZs and rice ecologies into "homogenous" (biophysical and socio-economic) areas. This will enable better research targeting and dissemination of research products, will improve research efficiency, and will thereby increase the chances of adoption by rice farming communities.

Communication and visibility of NRM research: Although the Center focuses more on genetic improvement than NRM, considerable progress has also been made on NRM research, and in developing and disseminating NRM technologies to farmers. However, this is not the impression most people get when WARDA communicates its achievements. For example, the summary of WARDA's achievements (2000-2006).[86] The Panel suggests that WARDA improve the visibility, documentation and communication of its NRM achievements, and put greater focus on NRM research, so that rice production can be sustained over time.

2.4 Social sciences at WARDA

This section discusses social sciences research at WARDA, except for adoption and impact studies, which are discussed in Chapter 5.

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[86] Achievements since the Fourth EPMR, WARDA, March 2007.

Social sciences research achievements over the period 2000 - 2006

Over the period 2000-2006, the main research achievements are:

- Nigeria rice sector policy review
- Impact of trade liberalization on the rice sector of Côte d'Ivoire
- Policies and institutional arrangements for irrigated rice in West Africa
- The ASI thresher: adoption and impact
- Software tools for impact assessment
- Enhanced capacity of NARS in impact assessment

These will be reviewed briefly hereafter. Impact assessment research is discussed in chapter 5.

Production Economics Research

The major achievements of production economics research at WARDA are the following: Profiles of production systems along the lowland-irrigated continuum (Senegal, Gambia, Mauritania, Burkina Faso, Togo, Ghana, Nigeria); generation of farm management database (Senegal, Burkina Faso, Gambia); identification of scope for improving resource use efficiency (Senegal, Gambia, Mauritania); ICM and the evolution of productivity gaps (Senegal, Gambia, Mauritania, Burkina Faso); assessment/development of harvest/post-harvest technologies (Senegal, Mali, Burkina Faso, Mauritania, Ghana); and training of students at the University of St. Louis (Senegal).

Technology Transfer Research

Participatory tools utilized by WARDA facilitate not only the understanding of socioeconomic factors for better uptake of proven agronomic technologies, but also help improve and package given technologies in a proactive way. Major participatory tools that WARDA has used in technology transfer and participatory research are the following:

Participatory Learning and Action Research (PLAR): Based on successes in irrigated rice systems in the Sahel, WARDA developed in 2001 its own method called Participatory Learning and Action Research (PLAR). The Panel commends WARDA for developing PLAR. The thrust of PLAR is to facilitate technological and organizational change through improving farmers' capacity to observe, to exchange knowledge, experiences and practices, and to make better-informed decisions. By 2005, four years after its development, PLAR had been introduced in Benin, Burkina Faso, Côte d'Ivoire, Ghana, Guinea, Madagascar, Mali, Nigeria, Gambia and Togo.

Participatory Varietal Selection (PVS): This is discussed in the chapter on genetic improvement.

Community-Based Seed Production Systems (CBSS): This is discussed in 5.6 on Institutional innovations in seed systems.

Post-harvest Activities

Between 2001 and 2005, WARDA's Technology Transfer Unit undertook post-harvest research activities to some extent. However, these have been mainly limited to capacity building of local blacksmiths, and on-farm evaluation of thresher-cleaners and improved parboilers. In 2005, in collaboration with governmental and non-governmental partners, videos were developed with women rice processors to illustrate an improved method of rice parboiling.

Sociology/Anthropology Research

The sociology/anthropology research component at WARDA is incipient. With the recent recruitment of a sociologist from Cornell University, and the projected tripartite institutional arrangement (University of Pennsylvania, State University of Missouri, and WARDA) a new momentum has been created for more systematic sociology research being undertaken at WARDA in the years to come.

Market and Policy Research
The focus of market and policy research rests on two main research questions: (i) What factors affect rice price and market dynamics, and how these factors affect the competitiveness of rice in West Africa; and (ii) what are the impacts of technological, policy and institutional changes in the rice sector on the livelihoods and wellbeing of the poor. To support policy and market research, WARDA set up a West Africa Rice Statistics Data Bank, and published its first edition in 1996 as Rice Trends in West Africa (1972-92). The third edition, which was published in 2005, is titled as "Rice Trends in Sub-Saharan Africa". It summarizes trends in rice production, consumption and trade in 52 countries of SSA. The following three important research outputs in the area of Market and Rice Policy merit special mention:

Rice Competitiveness Study
Country studies were developed using the Policy Analysis Matrix (PAM), a methodology developed by Stanford University and the University of Arizona to assess net effects of policy, competitiveness and comparative advantage of agricultural systems. The seven countries analyzed were: Côte d'Ivoire, Nigeria, Niger, Mali, Senegal, Guinea, and Sierra Leone. Recently (2004), the Guinea rice sector competitiveness study was also completed using the PAM approach.

The Nigerian Rice Sector Policy Study: This work resulted in the production of a range of research reports, and a strategy to revitalize the Nigerian rice sub-sector, all of which were presented at a workshop ('Stakeholders Forum') in September 2003. To a large extent, the proposals focused on issues of rice quality, and on how this affects the comparative consumer acceptability of local and imported rice, (local rice was being discounted by around 30% *vis-à-vis* imports, mainly because of a lack of cleanliness). WARDA's and NISER's research findings focused on quality and branding as a source of competitiveness. This work led to the creation of the country's Presidential Initiative on Rice, which has been raising awareness of the issue throughout the nation, the legalization of private fertilizer imports, the high import duty and levies (over 100%) on imported rice and the subsidies on seeds (50 %) and fertilizers (25 %).

Multi-country Policy Study: A multi-country study on policy and institutional effects on rice production and marketing in West Africa was initiated in 2005. The data collection, which consisted of village level and household surveys, is now complete and has been systematized into a database with data on Burkina Faso, Mali, Niger and Nigeria. In June 2006, a five-day review and planning workshop was organized in Cotonou with NARS partners to finalize data check and ensure quality before embarking on data analysis.

Workshops
Rice Policy and Institutional Arrangements in West Africa: A policy study methodology and planning workshop was held from 2 to 4 May 2005 in Cotonou, Benin. Participants from Burkina Faso (2), Mali (2), Niger (1), and Nigeria (2), including WARDA staff attended the workshop. The workshop provided an opportunity for participants to discuss current policy and institutional situation of their countries. The experts agreed to the formation of a rice policy research and advocacy platform at the regional level, as a channel for transmitting policies to promote the rice sector in the region. The network is to be known as Agricultural Policy Research and Advocacy Group (APRAG).

SSA Regional workshop on Rice Policy and Food security: WARDA held a three-day workshop from 7th to 9th of November 2005, in Cotonou, funded by the Canada Fund for Africa. The workshop was attended by over seventy participants from 16 countries. The final plenary session translated the results of the discussions into resolutions/recommendations, synthesis, and commitments for the way forward.

Core research challenges
WARDA sees its core research challenges in social sciences research (SSR) as:
(i) Integrated Production Systems: How best should existing genetic resources be used to develop rice varieties that best fit or better optimize farmers' existing production systems and are acceptable to both producers and consumers? How can resource use efficiency be further increased for more productive, profitable and socio-economically viable rice production systems? and
(ii) Rice Policy and Development: What factors affect the price of rice and market dynamics, and how do these in turn affect the competitiveness of local rice production? What impacts do technical (adoption of technologies), policy and institutional changes in the rice sector have on the livelihoods and well-being of the poor?

In 2000-2001, as a follow-up to the recommendations of 4th EPMR, the then Program 3: Policy Support and 4: Systems Development and Technology Transfer, were merged into a new Program 2 titled "Rice Policy and Development Program". The social scientists at WARDA form a thematic group, with an elected thematic group leader. The present cadre of the thematic group, and the positions filled, is shown in Table 2.2 below.

This (new) Program 2 on Rice Policy and Development draws from the Center's successful experiences. It highlights the importance of the participatory research approach; appropriate policy and market environment for the rapid uptake of improved technologies; and impact assessment studies on productivity, profitability and poverty in the realm of rice sector. The thrust of Program 2 is on (a) building strategies for competitive rice sector development in SSA through a better understanding of rice policy and market dynamics; and (b) assessment of the impact of technical, policy, and institutional changes within the rice sector. The program functions through a set of well-focused projects with specific outputs and milestones within the MTP. The emphasis is on production-based systems; and socio-economic research issues that cut across productions systems and can be addressed through an integrated approach.

Rice policy and development research needs to be well focused, as this is a very broad area. Only a well-focused approach, as was done in the Nigerian rice sector policy study, can produce tangible results and impact. Moreover, as suggested in the EC report in 2005 regarding institutions, a results-oriented focus is needed to identify what works, what does not and what new approaches should be tried.[87] This involves action-research whereby the research team accompanies ongoing development initiatives and feeds back lessons. The team should compare situations across countries, which will provide a wealth of insights to the research process. It is important that the outcomes of SSR on production systems and adoption of technologies, including non-adoption and disadoption, feedback to technology development at WARDA, e.g. variety development. The Panel concurs that these research foci are appropriate. However, what seems to be missing is ongoing *ex-ante* impact assessment for priority setting of research, although this has been done in preparation for the SP 2003-2012.

[87] Jonathan Coulter and Bohumil Havrland , "Policy Environment and Rice Market Development" project 3.2. (Project 5) for the European Commission, November 2005.

Social Science research team
The cadre of social scientists and the positions actually filled are shown in Table 2.2, below:

Table 2.2 Social science research team at WARDA

Positions	Senior cadre	Position filled	Postdocs cadre	Position filled	Research assistants	Visiting scientists
Economists						
- production economists	2	1	1	-	2	
- policy economist	1	-	1	1	1	21
- impact assessment econ.	1	1	1	1	1	
Sociology/anthropology						
- tech transfer specialist	1	1	1	1	1	2 PhDs
- gender specialist/HIV	1	-2			1	
- sociologist	1	-			1	

1 Only for a limited period in time
2 Temporarily filled by a consultant
Source: WARDA

This cadre, with the positions filled, appears adequate to the Panel. The EPMR benefited from a CCER on social science undertaken in June-July, 2006. This report is, in general, quite helpful; but its main recommendation that the team should be expanded to include two production economists, two policy economists, two sociologists and one each of technology transfer scientist, impact assessment economist, marketing and trade economist, and resource economist, ten IRS positions in total, is not very realistic -- taking into account WARDA's overall budget, the needed balance between disciplines, and the need for operating funds for each scientist.

At the time of the current EPMR, WARDA’s cadre and filled positions are as shown above in Table 2.2. Two economists separated from the Center in February 2007. Two positions are vacant and published: a policy economist, and a production and resource economist. Some of these positions of agricultural economists have been vacant for well over two years. The first recommendation of the social science CCER was to fill the vacant positions immediately and to take the necessary steps to avoid situations of positions remaining vacant for a long time in the future. We agree with that recommendation. In its response, WARDA also recognized that the delay in recruiting core staff in social sciences led to discontinuity in some SSR activities. The question of vacant positions stems from the 2002 Côte d'Ivoire crisis following which the policy economist, the technology transfer scientist and later the upland production economist all left the Center. What is also apparent is the difficulty in recruiting competent agricultural economists at WARDA, from either the region or elsewhere. Thus, the main issue in social sciences at WARDA at the time of the EPMR is that of critical mass in agricultural economics, which is seriously deficient.

The gap is particularly evident in the senior economist's positions. It is clear that the research program in economics has suffered from this. Nevertheless, through the ROCARIZ/ECARRN research network, and particularly the economics task force and the APRAG, economists from the region work together with WARDA on the research agenda. In impact studies, 12 NARS are currently involved with WARDA; on irrigated rice policy studies, 6 NARS are currently involved; on post-harvest, 5 NARS are currently involved. Common methodologies are used, with questionnaires and survey designs, and sharing of analysis tools. This implies methodology learning workshops and training on-the-job by scientists from WARDA. Professors and Ph.D. students from SSA universities, either virtually based at their universities, or as short-term visiting scientists/sabbaticals also contribute to WARDA's research program. However, the lack of critical mass in place at WARDA seriously constrains effective collaboration with agricultural economists in the NARS. A large team of economists in the NARS, even if they are working on WARDA's core research challenges, can only partially compensate for vacant positions at WARDA itself.

Assessment
The Panel concurs with the 2006 CCER on SSR that the social scientists have been doing excellent work to fulfill the objectives of the Center and the CGIAR. The SSR activities and outputs should be feeding directly into the technology generation process, and be helping in dissemination of technologies and be instrumental in shaping a favorable rice development policy environment. This seems to be lacking, as the integration between technology developers, particularly breeders, and social scientists, leaves much to be desired. Integration and feedback, particularly regarding adoption and yield impact findings, appear inadequate. This is further discussed in the adoption and impact chapter. The Panel also feels that had the positions of production economist, policy economist and sociologist not remained vacant for so long, the contribution of the SSR unit could have been much more.

Presently, it is planned for future SSR at WARDA to focus on: functioning of seed systems; post-harvest technologies and systems; trade policy options to counter subsidies in exporting countries; NERICA impact assessment; strategy to improve the influence of policy research on the policy making process. The Panel believes this planned focus of SSR is appropriate; and the ongoing and planned research activities are relevant to, and consistent with the objectives of the Center and CGIAR. The quality of research output is also satisfactory.

The main issues are thus one of critical mass because of unfilled positions, and feedback to the technology generation programs and the policymakers through the COM and NEC. This has seriously affected the strength and effectiveness of the SSR program at WARDA. Feedback to technology development is an issue, because adoption is a complex process, is location-specific and because the environment and the farmers themselves are heterogeneous. Thus, social sciences need to be mainstreamed in WARDA's technology development programs.

Because of research gaps in the social sciences research program (policy analysis, rainfed production economics, adoption studies), the Panel recommends that WARDA recruit a rural sociologist and fill other positions in the social sciences (production economist, policy economist) in a timelier manner.

2.5 Training and capacity building

Training and capacity building needs to be an integral part of the research program, particularly since many NARS are still weak and lack human capital.

Training activities include both formal and informal training for groups and individuals. Strengthening capacity through use of a variety of training modules falls within the strategy of the Center to have tangible impact in Africa. Since its inception in 2002, the Training, Information and Library Services (TILS) has implemented a number of training modules for farmers, students, scientists, extension workers, NGOs, development projects and other organizations. Participants were from various countries in SSA and partners and investors. Summary data illustrating the magnitude of training at WARDA during 2002-2006 is provided in Table 2.3 below.

Table 2.3 Short Courses and Individual-level Training Activities at WARDA (2002-2006)

			2002	**2003**	**2004**	**2005**	**2006**	**Total**
Group training	Number of courses		6	7	4	12	5	34
	Number of participants		108	91	183	244	61	617
Individual training	Degree training	Male	5	14	15	29	13	76
		Female	2	2	2	13	6	25
		Total	7	16	17	42	19	101
	Non-degree training	Male	3	3	3	2	0	11
		Female	1	1	1	0	0	3
		Total	4	4	4	2	0	14
Total number of people trained			119	111	204	288	104	746

Source: Achievements since the Fourth EPMR, WARDA, Cotonou, March 2007.

The recently completed Science Council-commissioned study that evaluated training in the CGIAR and its impact provides additional information on Training at WARDA, as shown in Table 2.4 below.

Table 2.4 Number of persons trained by WARDA 2001-2006

Nature of training	2001	2002	2003	2004	2005	2006	Total
Visiting Scientists	7	6	1	1	1	2	18
Ph.D.	5	8	8	17	10	7	55
Masters	9	16	12	9	38	25	109
BS and lower	10	22	12	9	9	10	72
Total							247
Non-degree/short term							125
Farmers							335

Source: Elliot Stern, Lucia de Vaccaro and John Lynam, Evaluation and Impact of Training in the CGIAR, Science Council Secretariat, Rome, July 2006.

As expected, WARDA trains predominantly nationals from its Member countries. A major effort has been put on training of NARS scientists in molecular techniques. During the field visits, the Panel received requests for training in post-harvest technologies, rice grain quality and other areas. NRM training, particularly on soil and water management, needs attention in the future. In addition, more and better linkages with higher education institutions in SSA should be sought, including linkages contemplating outsourcing of training activities for NARS.

Training of NARS scientists in molecular techniques

The Cotonou laboratory acts as a training and operative center for NARS scientists in molecular marker technology. It is necessary that every country possesses the research capacity in molecular techniques to identify and adapt technology to its own needs and constraints. Therefore, eight scientists from Burkina Faso, The Gambia, Guinea and Mali attended two weeks of intensive hands-on course training in molecular techniques to prepare them in generating, analyzing and presenting data from different molecular markers. The training included all steps from DNA extraction up to data analyses for genetic diversity studies, linkage mapping, QTL analysis, and MAS. Equipment necessary for DNA extraction, PCR reaction, migration of amplified products and gel documentation were purchased and sent to the four countries. This is very commendable. The Panel agrees that it is essential for proper development and use of these techniques that simple operations be conducted locally, mainly because the technology has evolved towards more simplicity and does not require complex equipment. Nevertheless, attention should be paid to possible logistical problems in the Member countries.

The Panel feels that the capacity building effort in this domain is developing well; and that the proposed plans are sound. The present focus is mostly on NARS scientists; but an important issue is who should be selected for training. Laboratory work is time consuming enough to have persons just dedicated to this activity; but the involvement of breeders is essential if one wants to see MAS fully utilized as a tool by NARS breeders. The Biotech Unit of WARDA also hosts students from sub-regional universities to conduct thesis research within the unit. The laboratory does not seem to be much involved with African universities, except through hosting students doing their research at WARDA, but the Panel does not see how it could go further in these collaborations without stretching too thinly its limited resources and losing its primary focus.

The Post-Masters Internship Program

WARDA plans to launch a new post-masters internship program for M.Sc. graduates of Africa from the Member States. Many M.Sc. graduates lack professional experience and have difficulty finding a first job; at WARDA, they will serve as research assistants, which are in short supply. The appointment would be for two years, non-renewable, at a salary comparable to that of entry-level positions in the public civil service. The plan is to recruit fifty of these per year, depending on the needs of each program and project, available budget, and requirements of the different locations where WARDA is operating. A condition for engagement will be the presence of senior scientists-supervisors. Through this original scheme[88], WARDA hopes to attain better critical mass, while at the same time contributing to capacity building of the NARS. The recruitment will be through a public call, and the selection of candidates through a selection committee at WARDA. WARDA insists that the post-masters will not be a substitute for the recruitment of post-docs. The Panel endorses this innovative approach.

2.6 Research support

Farm development and operations

WARDA manages research stations in Benin and Senegal, and is hosted by the research units of IITA in Nigeria (Ibadan) where the farm is managed by IITA, and Tanzania (Dar-es-Salaam) where WARDA just occupies an office from where it coordinates ECARRN but has no farm operations. Only farm development and operations are commented on below.

Benin

Since 2005, WARDA established its temporary headquarters in Cotonou IITA station and is conducting its experiments there. The WARDA farm unit (2 permanent staff; 200 casual workers) is in charge of managing the greenhouses, the trial areas, as well as the demonstration plots and the varietal seed multiplication.

The land available for WARDA research on the Cotonou station is far from satisfactory. The farm unit was able to solve the water resource problem by a well/pump system. The available space, however, is too limited. WARDA has access to 15 ha land (compared with the 80 to 90 ha used in M'bé). This is already insufficient to set the planned trials (20 ha needed) and, *a fortiori*, to organize a serious crop rotation −which is absolutely needed since nematode problems have started to appear − for which at least double the amount of land is needed. Some research

[88] The director-general had already implemented such a scheme with success at ISRA, Senegal, where he was previously director-general.

units/projects are using other more distant sites kindly shared by partners (INRAB in Benin, or IITA in Nigeria) and a large part of the activities are conducted in a decentralized manner in NARS partners' stations, or on-farm. Although partnership certainly helps to solve some of the space issues, it is essential for WARDA to be able to conduct experiments under well controlled conditions in a well managed station, without too much time lost in travel.

However, a reasonably satisfactory solution was mentioned to us that would consist in utilizing an old seed production farm of 62 ha, with its buildings, offered by the Benin government in Devé, 2 hours drive from Cotonou. The soil is good. WARDA's very competent farm manager seems confident in his ability to adapt the area to WARDA's needs. Squatters presently occupy the area but there is a possibility of overcoming this constraint.

The Panel is also concerned about the lack of trained personnel in the farm unit (only 2 permanent staff). Some very important farm operations, such as land preparation, are delegated to daily workers. The Panel understands the reluctance of WARDA's management to recruit permanent staff in Cotonou, because of the possible return to M'bé and the strict Benin labor laws, but hopes that compromise solutions can be found to ensure the availability of well trained staff for important operations. The WARDA-IITA alignment will induce large changes in the present situation in Cotonou and may put at WARDA's disposal trained staff and a large array of buildings, and may even provide some additional field space. However, plans regarding this are not yet finalized; the Panel is unable to comment further on this.

Outreach farm-operating stations

WARDA does research in countries other than Benin. An external consultant has prepared an Evaluation Report on Out Stations in 2007[89]. Quantitative data presented below are extracted from this report.

WARDA has been present in Senegal since 1989. WARDA's team in Senegal is large. The installations include a main station in N'diaye (4 scientists, 5 research assistants and 16 other staff) and a secondary station at Fanaye, in the Middle Valley, with 4 people. The Panel visited the main station (see report in Annex 10a). The CCER report concluded that N'diyae station buildings and science equipment were in an advanced state of deterioration and should urgently be restored. A research assistant has taken over the task of farm management as an additional responsibility after the 2005 retrenchment, which is not very satisfactory.

M'bé station is very well maintained with 4 Farm Unit permanent staff (36 staff are still based there). The Panel Chair visited the station, which is used for large-scale seed production (several hundred tons) but not anymore for experiments. In IITA station in Ibadan, where 4 scientists and their 15 staff are located, the situation regarding farm operations is good.

Genetic Resource Unit (GRU)

The Genetic Resource Unit (GRU) handles around 17,000 accessions of *O. sativa*, mostly from West and Central Africa, 2,500 accessions of *O. glaberrima*, and 2,600 accessions of African wild species collected mostly in West Africa. The whole collection is located in M'bé genebank and represented in Cotonou, with a copy in IITA (Nigeria). It is being triplicated in Fort Collins, USA. An additional installation in Cotonou is being brought into service, funded by the World Bank and the Canada Fund for Africa, but is not yet fully functional (a germination room is still missing and a better generator needs to be installed).

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[89] Mohamadou El Habib Ly, Out Stations Evaluation Report, From Ibadan in Nigeria, to M'bé in Côte d'Ivoire, through Dar es Salaam in Tanzania and Saint Louis in Senegal, WARDA, 2007.

GRU distributes small amounts of seeds of the genetic resources they have in stock. They shipped 2,967 samples in 2005, and 1,390 in 2006. GRU is in charge of genetic resource seed rejuvenation (done on an INRAB station; 2/3 of the collection has been rejuvenated in the 2003-2006 period). It is envisioned to rejuvenate the wild accessions that have not been tested for viability for a long time at IRRI, which has proposed to give access to their facilities. GRU takes care of phenotypic characterization during the accession rejuvenation and uses advanced experimental designs that enable the bridging of information across years. In collaboration with the molecular marker laboratory, it also does some molecular characterization of the accessions with microsatellite markers. New collections of landraces and wild species of *Oryza* will be undertaken in collaboration with IRRI and Cornell University since the project submitted to the Gatsby Foundation has just been accepted. The intellectual property issues linked to the signature of the International Treaty on Plant Genetic Resource for Food and Agriculture by the countries to be prospected (Kenya, Mozambique, Tanzania and Uganda), however, have not yet been completely solved.

GRU takes care of information management with four well-trained technical staff devoted full time to these operations. The GRU database including passport, pedigree and characterization data is accessible through internet since April 2007. The interfaces could not be tested at the time of our first visit. GRU benefits from support of CGNET, which primarily is hosting the database on its servers in the USA. The database specifications have been developed to be compliant with SINGER (Systemwide Information Network for Genetic Resources). GRU is also in charge of INGER Africa (see 3.1. and 5.1).

The Panel commends the effort of GRU to set a working system for accession rejuvenation and characterization of the material in a scientific way. The Panel is very satisfied by the efforts to make detailed information available to the scientific community while respecting international standards. The Panel reminds WARDA's management that the role of a GRU is the conservation of genetic resources, which involves small-scale multiplication of a wide range of accessions, not the large scale multiplication of released lines for which the responsibility has to be taken by ARI.

Quarantine

All seeds shipped by WARDA-Cotonou (10 t/year), including INGER material, go through the Quarantine Unit before receiving the approval of relevant Benin officials. The seeds are fumigated and chemically treated against grain nematodes. The quarantine is the responsibility of WARDA's senior pathologist who manages the operation with his own research team; and there is no backlog, which shows good efficiency considering the large volume treated. As for other activities, the temporary location of WARDA at Cotonou has led to a decrease in staff number and in the kind of work that can be done at Cotonou station, primarily for testing the quality and purity of seeds.

Information and communication technology

The IT unit (4 permanent persons and ½ time temporary staff) ensures support for hardware, software, procedures, and staff training. The unit has already an integrated system with homogeneous professional hardware, common e-mail system, anti-virus and anti-spam systems, and data centralization. The unit is integrated in the overall CGIAR system that allows scale economy in software purchases (contract with Microsoft), and gets good support from CGNET (e.g. anti-spam, homing of GRU database, etc.).

Following the "Ivorian crisis" and successive relocations by the Center, emphasis has been put on system security, data storage, and archive reconstitution. An automatic back-up system has been put in place that requires some discipline from scientists in terms of file management. Two back-ups are routinely done, besides the local one: one in Benin, in the DG's house, another in Senegal. The Panel commends this effort to ensure proper data storage and possibilities of data recovery in case of major problems.

Concerning telephone and internet communications, the constraints for a landline are very strong in Benin where the national government-owned operator is not very efficient. The present system is not sufficiently fast and reliable for WARDA's research needs. Therefore, the option has been chosen to rely on an autonomous satellite connection. It costs US$ 2,500/month for a 512 kb bandwidth. Nevertheless, the system is far from perfect since everything stops in case of a power cut which happens frequently. WARDA is not self-sufficient in terms of power supply (it depends on IITA). To get spare parts in case of problems takes a lot of time. It is the Panel's own experience that it is difficult to receive or send e-mails with attachments and that browsing the internet is a slow process. We do not think it can continue this way without hampering day-to-day work in WARDA, for both the administration and scientific teams, in a global world used to fast connections. To get equipment back-up would cost US$ 25,000, and the needed extension of the bandwidth to 2.0 Mb an additional US$ 8,000 per month.

Internet connectivity of the WARDA's station in St. Louis was said to have improved due to important investments recently made but is still not very good.

The Panel recommends that WARDA makes the necessary investments and provide funds on a regular basis to ensure communications (e-mail and internet) that meet the performance standards expected at an international research institute, both in its headquarters and outstations.

Biometrics

One junior biometrician working half time for WARDA and half time for INRAB presently provides the research support in biometrics. His contract with WARDA is for 3 months renewable. As we were told, "it is better than nothing", but we do not feel the solution is adequate nor sustainable.

The biometrician has a crucial role during the process of approval of trial designs. The requests for support seem to be coming more from biologists than from social scientists. The biometrician uses a SAS for Windows version to run analyses but, with such limited support, it would be better if scientists themselves had access to a good general biometrics package, preferably open source or cheap. IRRI Stat is an option that should be explored for simple analyses. "R" software package, with its numerous libraries covering a wide array of topics, would be an excellent choice for scientists willing to invest some time into it though there would be a long learning curve.

Faster computers are needed for the biometrics unit. Appropriate books and subscriptions to biometrics journals are missing. Training of WARDA's staff in specialized topics of biometrics would be useful to partly compensate for the presently limited support in biometrics through an upgrade of WARDA’s general level in biometrics. The competences of the present biometrician are not in question, but the Panel feels that WARDA does not possess sufficient scientific capability in biometrics with only one part-time junior scientist with a very short-term contract. ***Because good statistical design and analysis is an essential component of research quality, the Panel recommends hiring as soon as possible one full time biometrician preferably with good experience in Genotype x Environment interaction analysis, designs of on-farm trials, and analysis of survey data coming from Participatory Varietal Selection.***

GIS unit
The IVC has been hosted by WARDA since its inception and is now in its third phase. The GIS unit was established within IVC in 1995, as the need for GIS analysis had increased. The Unit is within the Regional Coordination Unit (RCU) that manages the secretariat of IVC, based in WARDA. The mission of the Unit is to support WARDA projects, partners, and consortia with GIS and remote sensing analysis, modeling, and development of tools for collecting, analyzing and visualizing spatial information. The unit was active until the crisis of 2002 in Bouaké, but subsequently lacked GIS hardware and dedicated office space, with the remaining local GIS/IT assistant operating from the IER-ICRISAT-CIRAD GIS lab based at Sotuba in Bamako, Mali. The unit was revived in September 2004 and reinforced by a junior Dutch professional officer.

IVC has a website and a database on CD of WAIVIS. This system draws upon the data accumulated during 10 years of inland valley research. In 1998, with the completion of agro-ecological characterization, data of 10 member countries, 15 valley systems (semi-detailed level) and 10 watersheds (detailed level) were stored. The characterization covered agronomy aspects, socio-economics, climatology, geology, geomorphology, soils, hydrology, flora and fauna.

National databases have been developed in Benin, Burkina Faso, Togo, and Guinea, and have been recently started in Mali. National scientists are trained by WARDA GIS staff in the structure and creation of a national database using a new format called NIVISA to facilitate information exchange between participating countries. The unit also offers short-term thematic training on GIS to some members of NCU – a body that brings together national institutions involved in sustainable development of the inland valleys.

The unit is well equipped in terms of hardware and software to perform RS and GIS analysis. Currently, there is limited usage of this service by WARDA's scientists, most probably due to lack of knowledge in RS/GIS. These tools are extremely useful for the stratification of the biophysical and socio-economic environment for research targeting. Therefore, the Panel suggests that WARDA's scientists, irrespective of discipline, be trained in the use of these tools.

Library services
The role of the library (previous staff of 6 now down to 5) is to ensure scientific information collection, processing, preservation and dissemination. After the Côte d'Ivoire crisis, the library strategy was to develop electronic support and web connections to documentation suppliers. The library directly subscribes to 86 journal titles, which are available in both print and electronic forms for headquarter as well as out-posted staff. Through collaboration with CGIAR Libraries and Information Services Consortium and Documentation Centers, the library has access to many additional journals, to inter-libraries loans (fast procedure), and to the FAO WAICENT portal for grey literature.

Most of the physical collection of journals and volumes is still in M'bé, where one library staff is still posted. Through the installation of The Essential Electronic Agricultural Library update (Cornell University), users now have access to retrospective journal issues from 1999-2003. Around 70% of the requests received by the library come from WARDA and 30% from the rest of the world. Conversely, anyone can have access to WARDA-produced documents through the CGIAR virtual library site (http://vlibrary.cgiar.org), but this does not give access to the content of WARDA's library. The library manages the scientists' list of publications. Therefore, it would make sense for WARDA's management to ask them to also compute the indicators of the Center's productivity in terms of publications. The library budget is said to be reasonable. Overall, the library seems well managed and efficient, but would greatly benefit from improvement of the internet connectivity for literature search.

Publications unit

WARDA's Publications Unit works actively with WARDA and NARS scientists to assist them in journal article preparation, as well as in publishing documents in various forms from leaflets and posters to conference or workshop proceedings, often in English and French (1 full time English editor and 2 French editors). WARDA is a bilingual institution (French and English), and the most important documents are published in the two languages. The "Ivorian crisis" had delayed a number of printed publications, and created a temporary fall in scientific submissions to journals that has now been corrected (see 3.2.). The presence of high-level in-house editors is an advantage in CGIAR Centers, and is extremely helpful for scientists (and envied by other research institutions). Attention has, however, to be paid to keep a reasonable balance between time devoted to institutional versus scientific publications. The Publication Unit is also in charge of the website. It has been revamped several times. Good work was done in terms of both design and content of the present version.

Overall assessment of the quality of research infrastructure, facilities and services

Adequate infrastructures, facilities and services are an important element for ensuring high quality research. As for most CGIAR Centers, the general quality of the research support available at WARDA ranges from good to very good. In the Panel's view, the major issues deserving urgent attention are those pertaining to N'diaye farm situation (building, equipment and staff), the phone and internet connectivity with the external world, and the reinforcement of WARDA's biostatistics capabilities. With regard to the Cotonou farm situation (space and staff), clarification on the options available at Cotonou will be possible with the advancement of the WARDA-IITA alignment of corporate services.