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The Green Revolution Arrives in Africa

RICHARD J. BLAUSTEIN

The Green Revolution that brought advances in crop genetics to Asia and Latin America completely bypassed the African continent. Africa's smallholder farmers finally joined the movement in 2006, when the Bill and Melinda Gates Foundation joined the Rockefeller Foundation to create the Alliance for a Green Revolution in Africa.

Its goal is to develop 100 new crop varieties in 5 years, so that within 20 years farmers will double or triple their yields.

The 20th century's Green Revolution, which introduced new varieties of wheat and rice, dramatically increased crop yields in Latin America and Asia. Yet it never became established in sub-Saharan Africa because of daunting political and ecological challenges particular to Africa. Still, sub-Saharan Africa has never been without its own innovations with regard to plant food. For centuries African communities have harvested indigenous plant foodstuffs, such as sorghum, cowpea, and African rice, and adopted such staples as cassava and maize, which together were adequate sustenance for numerous communities.

The population of sub-Saharan Africa is growing, with about 70 percent now living in rural areas, yet African agriculture is not growing fast enough to meet the dietary needs of African communities or provide farmers with sufficient livelihoods. Numerous episodes of pre- or postharvest hunger, extreme environmental stresses such as drought and intense pest and weed infestations, and the insufficiency of global trade for African food needs further weaken the agricultural situation in Africa. In re-



*A student intern makes crosses between African and Asian rice at the Sikasso Research Center in Mali. In Africa, there is one indigenous rice species, *Oryza glaberrima*, which was domesticated in the northern Niger valley by Africa's first farmers. An introduced Asian species, *Oryza sativa*, is currently the dominant rice species in Africa. Photograph: Joe DeVries.*

sponse, foundations and nongovernmental organizations are exploring innovations in crop production and adjustments to national and international assistance policies to better support African agriculture.

Although noteworthy scientific and policy work has gone on for years, the real revolution began in 2006 when the Bill and Melinda Gates and Rockefeller Foundations jointly launched the Alliance for a Green Revolution for Africa (AGRA), a landmark frontline initiative for African agriculture. The Gates Foundation gave a boost to the long-standing work supported by the Rockefeller Foundation, adding its approximately \$100-million investment to Rockefeller's \$50 million, to produce agricultural improvements in Africa. Gary Toenniessen, a managing director of the Rockefeller Foundation in New York, is a trained microbiologist and the interim president of AGRA. He points to AGRA's threefold focus: "One, use agronomic improvements [for example, soil and water management] to increase farm yield potential.... Two, [produce] genetic improvements to reduce losses and en-

hance quality of crops, and three, make sure farmers benefit...from increases in production.”

Plant geneticist Joe DeVries, who works with Toenniessen at the Rockefeller Foundation and is based in Nairobi, leads AGRA's seed systems program. He describes the impact of the Gates Foundation's support for long-sought genetic improvements in African crops: “Prior to the Bill and Melinda Gates Foundation's joining forces with the Rockefeller Foundation, we had discovered that relying on just a few crop varieties wasn't working in Africa. The existing varieties worked well for some farmers, but others were completely left out, because no one had bred improved varieties for their area, and the existing varieties couldn't be grown.

“And so we began funding more localized, farmer-participatory methods of breeding improved crop varieties. That was where we made some breakthroughs, with stress-tolerant maize hybrids in Kenya and beans, rice, and maize varieties bred in Uganda all becoming popular with local farmers. But the cost implications of supporting large numbers of local breeding teams and building a large number of local seed enterprises were too great, really, for the Rockefeller Foundation to handle on its own.... This gives us a chance to do things on a much-expanded scale.”

AGRA also focuses on changing the policy and market conditions for African agriculture. These policy objectives include support for new and more locally oriented seed companies, enhancement of national agricultural research centers, better access to fertilizer and water-maximizing systems, and streamlined farmer participation in the seed improvement process.

Green Revolutions, then and now

The first Green Revolution established the paradigm for a continent-wide agricultural program, but the name “Green Revolution” obfuscates the fundamental challenges presented by the new African effort. “By the early 1960s,” Toenniessen says, “Asia had already made significant agronomic investments—86 million hectares of irrigated land, in

Biological challenges for African crops.

Africa's farmers face many biotic and abiotic challenges to their main crops that scientific and policy efforts must address. Intensified hybridization efforts, in particular, offer great potential for some crops, as hybrid seeds generally produce plants that have greater yield potential and are more resilient than open-pollinated varieties. However, hybrid vigor lasts for one seeding, underscoring the importance of new agroecologically based seed companies and retailers who, as Joe DeVries says, will “get the new seeds into Africa's hinterland...at prices Africa's small-scale farmers can afford.” In addition to cowpea, cassava, finger millet, beans, rice, and pearl millet, AGRA will also focus on maize, sorghum, and bananas.

particular. The yield potential of that irrigated land far exceeded the genetic yield potential of the crop varieties then being grown on it, so crop genetics was the limiting factor. New, semidwarf, early maturing rice and wheat varieties significantly increased the genetic yield potential of these crops and on the irrigated land.” For Africa, Toenniessen continues, “the limiting factor...is not the genetic yield potential of the crops currently being grown. The problem is that so little of their genetic yield potential is realized due to poor soils and crop losses.”

DeVries says the Asian Green Revolution was based primarily on yield increases in two crops—wheat and rice—

which were grown primarily under irrigated conditions. Irrigation is a great equalizing force in agriculture. The African Green Revolution will by necessity involve increasing yields on a much wider range of crops, grown under a much wider range of farming conditions, using rainfall as the main source of water.

“AGRA will support breeding and seed delivery activities on 10 or more different crops, all of which are currently being used by African farmers to provide for their families,” DeVries continues. “All of these crops have their own set of genetic constraints, whether it is susceptibility to diseases, insects, parasitic weeds, or grain molds. The list is long, but it can be



In a field in Kyazanga, in central Uganda, Stanley Nkalubo (in hat) works with farmers participating in a selection trial for new bean lines. Enlisting farmers' participation is key to AGRA's breeding program, and helps breeders assess the taste preferences and growing traits that lead farmers to adopt new lines.

Photograph: Isaac Mugagga.



Plant pathologist Fina Opio, agricultural economist Anton Bua, and cassava breeder Robert Kawuki stand amid a cassava planting at the Namulonge Research Station of Uganda's National Agricultural Research Organization. Interspecific breeding of cassava has already produced greater resistance to two major diseases, African cassava mosaic virus and cassava brown streak virus; improved starch quality; and higher root protein content. Photograph: Joe DeVries.



*Rice breeder Fousseyni Cisse stands in his rice field at the Longorola Research Station, which is part of the Institute of Rural Economics in Mali. Cisse has produced an interspecific hybrid of African rice (*Oryza glaberrima*) and Asian rice (*Oryza sativa*). Photograph: Joe DeVries.*

dealt with, provided we deploy plant breeders into the local landscape to address these issues.

“We are in for a much more complex set of challenges,” he explains, “and therefore the African Green Revolution will probably take longer and come in smaller—but equally meaningful to local farmers—breakthroughs. By taking an agroecology-based approach and by involving farmers in each step of the technology development process, we can achieve a Green Revolution that is more sensitive to environmental factors and more equitable to Africa’s large number of very poor farmers.”

Another substantial difference between the agricultural revolutions is that the public support available for science and infrastructure during the earlier Green Revolution is largely absent today. Wellesley College political scientist Robert Paarlberg, who writes on food security and biotechnology issues, notes, “The share of US official development assistance going to agriculture was 25 percent in 1980; in 2006 it was 1 percent.... The share of World Bank lending that went to the agricultural sector was 30 percent in 1978; in 2006 it was 8 percent.” Paarlberg views this decrease as the result of a polarized policy context in which the left critically questions the fundamental benefits of the Green Revolution, while “the right, Reaganite and Thatcherite market fundamentalists have argued that agricultural development should be left entirely to the private sector.” With respect to African agriculture, Paarlberg says, “private foundations cannot do this job alone,” and he believes governments, both overseas and in Africa, need to invest more in agriculture on the continent.

New appreciation is growing, however, for the public policy considerations concerning African agriculture. With former UN Secretary-General Kofi Annan as chairperson for AGRA, a move toward greater governmental support for agricultural infrastructure in Africa may be under way. And in October 2007, Robert Zoellick, the new World Bank president, publicly embraced criticism of the World Bank’s diminished support for agriculture, promising a renewed commitment for future investments. In the meantime,

while these aspirations blossom or fade, AGRA is plowing ahead with its program for improving African agriculture.

Breeders and crops

AGRA plans to enlist many different policy and scientific efforts, all of which are important. Perhaps AGRA's most noted scientific endeavor is supporting the efforts of the many breeders who work with Africa's diverse agroecologies, which are directly associated with one or more particular crops in Africa.

DeVries describes agroecologies as farming areas "with a more or less common set of constraints and advantages, that is,...rainfall amounts and distribution, temperatures, soils, and other factors important to crop growth." A few examples of agroecologies include the rain-fed lowlands of Nigeria, Benin, Liberia, Mozambique, and Tanzania where rice is grown; the lowland humid tropics of West African forest zones, the Congo Basin, and Mozambique where cassava harvesting is significant; the marginal lands of the northern Guinea savannah, Sudan savannah, and Sahelian zones where cowpea is raised; and the mid-altitude late-seasonal, maize-harvesting areas of Nigeria, Cameroon, Zambia, eastern Angola, Tanzania, Uganda, Kenya, and Ethiopia. The breeders who work within the varied agroecologies of Africa play a central scientific role on the frontline of the biological challenges of African agriculture. They work not so much with hypothesized concepts or untested technologies, but with proven processes that spawn genetic and phenotypic innovations.

Stanley Nkalubo is a bean breeder in Uganda who earned his PhD in breeding with support from the Rockefeller Foundation. "The role of breeder in Africa is quite different from [that in] the developed countries," Nkalubo says. "An African breeder has to breed for small-holder farmers dispersed over an agroecological landscape that is more heterogeneous than those in developed countries. Also, the farmers in Africa have varying demands, which are not easily met by one or two new varieties but [require] a range of varieties.... To come up with a range of varieties to fulfill all these

Maize.

Maize is particularly sensitive to abiotic stresses such as drought. The biotic stresses afflicting maize vary between regions and agroecologies. They include the weed *Striga*, maize streak virus, and pest stem borers in lowland tropical areas; common rust (*Puccinia sorghi*) and the Turicum leaf blight significantly afflict maize in highland agroecologies. According to DeVries and Toenniessen, "outbreaks of important pests and diseases of maize are related to complex egg-laying and sporulation responses, which are in turn dependent upon difficult-to-predict responses, global environmental factors,...and human activity." Notwithstanding these stresses, DeVries says, for AGRA "maize is a crop of strategic importance." Hybrid maize varieties, in particular, offer great potential for overcoming stresses and increasing yields.

requirements, breeders have to be equipped with vast quantities of germplasm and technologies. And considering the rate at which stresses are overcoming the new and indigenous varieties, breeders will have to think of utilizing the new and easily acceptable technologies, like marker-assisted selection, to reduce the time within which new genes are incorporated into the preferred varieties."

Marker-assisted selection (MAS) is a biotechnology for locating the genes and genetic organization of desirable characteristics, Toenniessen explains, without resorting to transgenic modifications. MAS "enables breeders to follow the inheritance of genes or traits in the laboratory rather than the field.... For traits that are difficult to score in the field, MAS speeds the breeding process." MAS has benefits for many African crops in addition to beans.

Another breeder, Chrispus Oduori Adeti, focuses on finger millet in western



A farmer stands in his maize field near the town of Bungoma, in western Kenya. The hybrid white maize growing in this field produces about three times the average yield. It is most commonly used for porridge. Maize and cassava are the two most important crops in Africa, with the highest maize consumption in eastern and southern Africa. Photograph: Joe DeVries.

Sorghum.

Sorghum is an indigenous African crop that grows in semiarid areas. Although sorghum was taken to India from Africa, India has become a secondary source for the crop; in India, unlike in Africa, hybrid varieties have been cultivated. However, this is changing. DeVries comments, “The most exciting—from AGRA’s perspective—developments on sorghum are the on-farm tests being conducted in Mali this year of hybrid guinea sorghum varieties. These hybrids are partially derived from local landraces.” As different agroecologies require different hybrids, AGRA is “funding hybrid breeding efforts in Kenya, Uganda, Mali, and soon in Malawi.” Sorghum is prone to significant stresses, including the pathogen anthracnose, downy mildew fungus infestations, and many panicle pests. However, for the most important biotic stress of sorghum in Africa—the weed *Striga*—there have been breakthroughs, especially in the development of *Striga*-resistant sorghum.

Kenya while also working on a PhD from Kwazulu University, in South Africa, with Rockefeller Foundation support. “A plant breeder,” he says, “is a scientist who applies his skills...in mining the genetic potential of the crop he or she is working on for maximum benefit to humanity at any given time. The breeder is challenged with the responsibility to provide genotypes that will optimally yield under the prevailing conditions of African agriculture.” Like Nkalubo, Oduori Adeti emphasizes that, for breeders in Africa, it is especially important to involve the participation and preferences of the local farmers. “Farmers are the people who grow this crop, especially the peasant farmers, and they are the ones who know their problems and needs,” comments Oduori Adeti. “In fact, the work I am doing started with a PRA [participatory rural appraisal] to [learn] from farmers what they look for in a finger millet variety. Then from what the farmers describe, and probably with some of their germplasm or landraces, we start developing the desirable varieties through crosses and selection.”

Both Oduori Adeti and Nkalubo already see successes with the crops they are breeding. Finger millet, a supplemental cereal crop, is, according to Oduori Adeti, “of particular importance in upland areas of eastern Africa...[and] is productive in a wide range of environments and growing conditions from sea level to altitudes as high as the Ethiopian highlands where it is thought to originate.” Finger millet lacks storage pests and therefore serves food security purposes for otherwise low harvest times. Oduori Adeti says his priority is “to enhance finger millet breeding methodologies, especially hybridization, and improve yield and resistance to abiotic and biotic stresses. This is because in Africa, the breeding potential has hardly been exploited due to the little research attention the crop has received previously.” Oduori Adeti adds that, through his PhD program, “the first finger millet crosses have been made and are promising to go a long way in boosting finger millet yield.” Preliminary tests have been done at research stations, and the next stage is to grow the new varieties in multiple locations and, ultimately, on farmers’ fields. The shared goal, he says, is “to boost farmers’ production for improved incomes and food security and quality.”

Nkalubo also senses great promise with his breeding work with beans. “Dry beans are one of the major food crops grown in Uganda on about 600,000 hectares of land.... The crop is an important source of calories and the most important source of dietary protein for over 80 percent of the population, as the majority, being poor, cannot afford dairy products, poultry, or fish.” Nkalubo adds that beans are “grown in environments that suffer from both abiotic and biotic stresses, including diseases, insect pests, drought, [and] low soil fertility.”

Nkalubo specializes in research on the core pathogen of anthracnoses, destructive plant diseases caused by fungi. He and others are trying “to breed for resistance to key production constraints, especially diseases of widespread importance, and to definitely increase yield. This method helps resource-poor farmers take advantage of improved cultivars, [while] minimizing the risk of spreading patho-



Joe DeVries and Acar Toure, of the Institute of Rural Economy in Mali, stand amidst sorghum. Toure recently developed the guinea-type hybrid varieties pictured in this field test. Sorghum has a very high level of diversity in Africa and is an especially important grain crop in semiarid areas of Africa. Photograph: Yvonne Pinto, of the Bill and Melinda Gates Foundation.



In these test plots at the Kenya Agricultural Research Institute, Chrispus Oduori Adeti is breeding for higher yield and resistance to the fungal disease neck blast. Finger millet is an important food crop because of its long-term storage capacity and its high nutritive value, making it important in the diets of children and expectant and breastfeeding mothers. Photograph: Joe DeVries.

gen populations.” Currently, he says, “work is at the phase of conducting field trials for the lines [246 in number] we have so far established from our various breeding crosses using the conventional breeding methods. We are conducting participatory, variety selection trials with the farmers so as to address the farmer requirements, and at the same time evaluating the lines for the various biotic and abiotic stresses.”

In addition to outreach and breeding operations, Nkalubo points out the significance of enhanced germplasm collection afforded by AGRA. “To a breeder, the most limiting factors are basically germplasm or source of new genes and funds to enable one to play around with these genes to produce desirable products and technologies.... The fact that AGRA has been able to provide funding to enable me [to] manipulate the available germplasm and genes to the benefit of the Uganda farming community, and Africa in general, is one step into the realization of my dreams. For my work in Uganda,

the funds are being used to acquire and upgrade equipment for the screening of anthracnose and also to collect more germplasm.”

The AGRA effort will allow numerous breeders to address some of the most persistent crop problems in Africa. Cassava, which was introduced into Africa by the Portuguese more than 500 years ago, for example, is especially important because it grows in poor soils and across the continent. Pointing to the many initiatives for improving the crop, DeVries says that cassava “is currently one of the most exciting crop breeding challenges in Africa, for a number of reasons. Firstly, it happens that most of the major biotic constraints that seriously reduce cassava yields can be dealt with genetically through conventional breeding, that is, without having to venture outside the *Manihot* genome [the base cassava genome].”

A recent collaborative effort between the International Institute of Tropical Agriculture, headquartered in Nigeria, and the Colombian-based International

Bananas.

In 1998, bananas reportedly provided more than 25 percent of Africa’s carbohydrate needs. Three types of African bananas are grown, derived from two species from Malaysia; they comprise diploid and triploid combinations of the original species. “Bananas are an exceedingly difficult crop to breed,” DeVries says, “so AGRA has to be selective in where it decides to deploy breeding as a strategy to assist Africa’s banana farmers.” The diseases black leaf streak, or black sigatoka, and banana streak virus are the major biotic stresses. In Uganda, the National Agricultural Research Organization has made some early progress on breeding the East African highland banana with resistance to black leaf streak disease. Additionally, varieties propagated by means of tissue culture are anticipated to greatly aid banana breeding. However, the challenges of banana tissue culture’s propensity for the banana streak virus and the relatively steep price for micropropagated plantlets must be surmounted.

Center for Tropical Agriculture, which has amassed a large and varied germplasm collection of Latin American cassava, is working on cassava mosaic disease (CMD). CMD exists only in Africa and seriously afflicts cassava grown there. The two institutes, with the aid of MAS, have introduced a dominant gene for resistance to CMD found in African cassava into Latin American cultivars, says Toenniessen, before their shipment to Africa. He added that increasing cassava biodiversity in Africa by allowing greater use of Latin American germplasm is a significant benefit. “AGRA will fund national breeding programs in Africa using this increased biodiversity.”

Another important crop plant, cowpea, is an indigenous African legume that grows throughout Africa in difficult agricultural conditions, especially semiarid regions. Cowpea is also considered an important “insurance” crop, as it is harvested in otherwise nonharvest periods. It is also, DeVries says, “a crop generally grown and marketed by women, so cow-

pea embodies social equity value, as well.” In Burkina Faso, breeders selecting for cowpea resistance to the weed *Striga* have “identified three genotypes of very different genetic backgrounds that show immunity to the parasite,” he says. In Uganda, AGRA is funding work at the National Agricultural Research Organization to breed and select plants for resistance to the aphid-borne mosaic virus that afflicts cowpea.

However, for cowpea, “insect resistance...has so far proven intractable,” DeVries says. The persistence of insect problems has led some to suggest transgenics—the genetic modification of organisms to carry genes from other species—as a possibility for improving cowpea. In general, however, African governments have yet to implement policies for the release of genetically modified organisms. In the meantime, AGRA concentrates on technologies such as MAS and tissue culture to improve cowpea and other crops.

Other crops, such as maize, rice, sorghum, and banana, will receive breeding support from AGRA, as well. For maize and sorghum, significant work has already been done on producing high-yield hybrids, while other efforts focus on the weeds, pests, and pathogens that have diminished Africa’s food supply.

Future investments and intimations

The greening of African agriculture comes from adding one improvement to another, from new breeding lines to new policies that promote agroecological seed companies to innovations in farmer

participation. The future also depends on educational commitments, and AGRA is proactively supporting the training of diverse agricultural specialists in Africa. “AGRA expects to support the training of several hundred MS and PhD scientists,” Toenniessen said. “For example, the African Center for Crop Improvement in South Africa and a similar program in Ghana will train 120 PhD plant breeders. Other training programs will be in agronomy, soil sciences, economics, business.”

The new breeding efforts are also engendering a sense of optimism. “What makes this such an exciting time for crop scientists and geneticists in Africa,” DeVries said, “is that there is so much yet to be done.” In the autumn of 2007, DeVries traveled through East Africa, where he spoke with fellow scientists. “A virologist in Tanzania was telling me about huge yield losses maize farmers experience every year in the Lake Victoria region of the country due to maize streak virus, and that cassava farmers were suffering similar yield losses from cassava mosaic disease.... I know from experience in western Kenya that until the development of the new maize hybrids, maize, which looked very healthy up to about the mid-grain-filling period in western Kenya, would suddenly begin to wither and turn yellow from foliar diseases....

“But now, you can tour western Kenya and find that the maize looks green and healthy all the way through the season, and the yields, we hear, have improved dramatically. All that was achieved through breeding and seed supply. We know that the same thing can be done in the Lake Victoria region of Tanzania.... It

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is just a question of putting in the funds to run a breeding program focused on controlling those diseases and other factors, and things can change.... We can do it in every situation in Africa where farmers are struggling for larger harvests to feed their families.”

Nkalubo expressed similar sentiments: “AGRA, knowing the way in which the African communities work, is trying to fund and coordinate the different departments within the country, all working for a common goal. These include education sectors, researchers, research institutions, farmers, seed companies, agro-dealers, farming communities, [and] nongovernment organizations...within Africa. This approach I do find very good and creative, and [it] differs from earlier approaches where only a few stakeholders are involved and left loopholes for failure. With this kind of approach, I believe the objectives of the African Green Revolution have an 80 to 90 percent chance of being successful.”

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