Regenerating the Green Revolution

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Paper prepared for presentation at the "Food for the Future: Opportunities for a Crowded Planet" conference conducted by the Crawford Fund for International Agricultural Research, Parliament House, Canberra, Australia, August 8, 2002

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Keynote Address

GORDON CONWAY

'To die of hunger is the bitterest of fates' - Homer, The Odyssey

'A hungry man is an angry man' - African saying

'The Green Revolution was one of the great technological success stories of the 20th century. It greatly increased cereal yields in developing countries, brought down food prices and fed many millions of people. However, there were many who did not benefit, especially in Africa, and there were other undesirable consequences. Today, some 800 million people remain chronically undernourished. There is no single silver bullet solution. It requires a cessation of conflicts, accessible input and output markets, and fair trade for the agricultural exports of the developing countries. But it also needs technologies, both conventional and biotechnologies, that increase yields and are sustainable and environmentally friendly – in short a Doubly Green Revolution.'

It is difficult for us to take a measured and balanced view of the 20th century. We are too close, too involved ourselves in both the tragedies and the achievements. Yet we can make some rough assessments. The wars – world wars and local conflicts – were devastating on a scale that was unprecedented. Nevertheless, by the end of the century people's lives in both the industrialized and developing countries had become much better. Advances in medicine and health care had freed millions from the burden of disease, and people everywhere lived longer. In the industrialized countries housing, employment and improved working conditions provided better lives and livelihoods. In the developing countries the Green Revolution prevented famine and helped feed millions on a sustainable basis. We at the Rockefeller Foundation were significantly involved in providing funding that promoted all of these achievements, and our grantees can take pride in what was achieved.

DR GORDON CONWAY was elected the twelfth President of The Rockefeller Foundation in April 1998. He was educated at the Universities of Wales (Bangor), Cambridge, Trinidad and California (Davis). His discipline is agricultural ecology. He has lived and worked in many countries in Asia and the Middle East. Prior to joining The Rockefeller Foundation, he was vice-chancellor of the University of Sussex and Chair of the Institute for Development Studies. He has authored *Unwelcome Harvest: Agriculture and Pollution* (Earthscan, Island Press), *The Doubly Green Revolution: Food for all in the 21st Century* (Penguin and University Press, Cornell); and *Islamophobia: A Challenge for Us All* (The Runnymede Trust).

Nevertheless, as we enter the 21st century, poverty and inequity remain. Of 6 billion people in the world, more than 1 billion live on less than the equivalent of US$1 per day. Virtually all of these 'poorest of the poor' live in developing countries. The poor in the industrialized countries, such as the USA or Australia, are relatively better off, yet they too live in depressed urban and rural settings, cut off from the economic and social mainstream of their societies.

The challenge for us is simply stated. Can we do even better this century? To our advantage, we are in the midst of great science and technology revolutions – in information technology and the cellular and molecular sciences – that are fuelling the process we know as globalization. We know that these new technologies can make life better for everyone, wherever they live. The issue is whether we have the will, the policies, the institutions and the trained human resources to ensure that this happens.

The war on hunger

The scientific and technological fight against hunger is not new, and much has been achieved. Prior to the Green Revolution, 50% of the population in the less developed countries did not get enough to eat; today the proportion is 20%.

Since the 1970s the greater yields of the new varieties developed by the International Agricultural Research Centers (the IARCs) have helped reduce food prices in real terms by over 70%. This has benefited the poor, who spend the highest proportion of their income on food (FAO 1994).

Yet today about 800 million people live a life of permanent or intermittent hunger and chronic undernourishment (FAO 2001). They lack 'food security': i.e. they do not have access at all times to enough food to lead active, healthy lives (World Bank 1986). A high percentage are women and children; more than 180 million children under 5 years of age are severely underweight, including a quarter of the children under 5 in developing countries. Hunger and health intersect here – children who are malnourished are more vulnerable to infections and disease. In the developing countries, 11 million children under five die each year, and malnourishment contributes to at least half of these deaths (UNICEF 2001). Short of actual hunger, lack of protein, vitamins, minerals and other micronutrients in the diet causes widespread debility. About 250 million children suffer from vitamin A deficiency (ACC/SCN 2000), which causes eye damage – half a million children become partially or totally blind each year. Many subsequently die. Recent research has shown that lack of vitamin A also has a serious pervasive effect, apparently reducing the ability of children's immune systems to cope with infection (Sommer and West 1996). Iron deficiency is common in the developing countries, affecting a billion people. Over 400 million women of childbearing age (15–49) have anemia caused by iron deficiency (Rush 2000). As a result they tend to give birth to stillborn or underweight babies and are more likely to die in childbirth.

Hunger in Africa

The situation in Sub-Saharan Africa is especially dire. Food production per capita in most African countries has declined over the past decade, reflecting rapid population growth (averaging 3% yr^{-1}) and low yields resulting from rates of depletion of soil nutrients that far exceed those of replenishment (average losses in many countries exceed 60 kg NPK ha^{-1} yr^{-1}) and crop losses caused by pests, diseases and abiotic stresses, such as drought (Henno and Baanante 1999). Unlike in Asia, where average crop yields have increased substantially, in Africa average cereal yields have remained stagnant at only about 1 ton ha^{-1} for the last three decades (Fig. 1).

How do we reverse these trends? One answer is political. The famines now sweeping southern Africa are partly a consequence of drought, but also due to inappropriate policies and mismanagement. In several regions, conflict takes a severe toll. Food aid – currently running at 3.23 million tons yr^{-1} in Africa – helps prevent starvation in these extreme situations but can create dependency (WFP 2001).

Most of the hungry in Africa, however, are not the victims of wars or incompetent governments. Hunger is widespread in Africa. Some claim there is enough food in the world for everyone if it were evenly distributed. True, but this argument ignores reality. Africa does not produce enough food to feed itself even if it were more evenly distributed.

Rather, Africa must rely on massive purchases, using precious foreign exchange, and on equally large shipments of food aid with the accompanying disincentives for local production, and still over 30% of the population remains undernourished.

Others argue that hunger is simply a matter of poverty. If the poor had higher incomes, they could purchase the food they need, and it would be produced to satisfy their demand. Again there is truth in this. But there are no signs of large-scale manufacturing investments in Africa that would dramatically increase incomes. The reality is that most African families are farm families. It is only through greater agricultural production (and the development of natural resources generally) that poor Africans can produce enough food and other

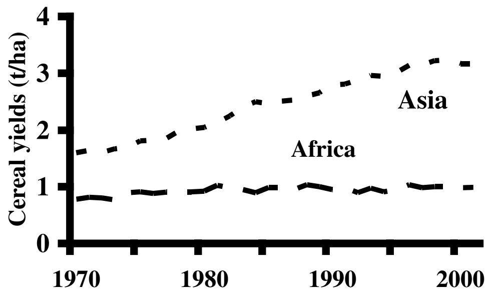

Figure 1. Cereal yield trends; developing countries of Asia compared with sub-Saharan Africa, 1970–2000[1]

[1] FAO Internet Database

farm products to stimulate rural economies and so achieve higher incomes. As numerous studies have shown, agricultural development is a necessary precursor to larger economic and social development (Delgado *et al.* 1998).

The question is: what kind of agricultural development? I argue that, like the Green Revolution of the 20th century that was so successful in feeding much of Asia, it has to be based on science and technology. Yet it has to be different in the technologies that are used, in part because science has advanced and because the circumstances in Africa demand a different set of technologies.

A doubly green revolution

The challenges are daunting. Most econometric models forecast that world population growth rate will be matched by the growth in food production and that food prices will continue to decline (Queen Elizabeth House 1996). Even so, the developing countries as a whole will not be able to meet their food demand. In the IFPRI (International Food Policy Research Institute) model, the total shortfall by 2020 is some 190 million tons, which would have to be imported from the developed countries (Rosegrant *et al.* 1995). Much of this imported grain will go to livestock feed; only 50 million tons will go to satisfy the demand for human food in Sub-Saharan Africa and South Asia. In these regions, food production will be hard pressed to keep up with population increase for a long time to come. According to the IFPRI model, by the year 2020 the excess of market demand for grain over production in Sub-Saharan Africa will be nearly 26 million tons; this compares with current net imports of 9 million tons.

In addition there will be a 'hidden gap' between the market demand and the physical demand that has to be met if food security for all is to be attained. In human terms this can be translated into a persistence of large numbers of malnourished children. By 2020 the total numbers will have declined slightly from the current 180 million to 155 million, but in Sub-Saharan Africa they will have increased by nearly 50%. And, probably, there will still be close to three quarters of a billion people chronically undernourished (Alexandratos 1995).

Yields

The prognosis for filling the gap is not good. Recent data on crop yields and production suggest a degree of stagnation that is worrying. There is widespread evidence of declines in the rates of yield growth (Fig. 2).

A combination of causes is responsible (Pingali and Rosengrant 2001). On the best lands many farmers are producing yields close to those in experiment stations, and there has been little or no increase in yield ceilings of rice and maize in recent years. Another contributing factor is the cumulative effect of environmental degradation, partly caused by agriculture itself. Long-term cereal production experiments in many developing countries exhibit marked downward trends in yields.

Environmental degradation

The litany of environmental degradation is familiar (Conway and Pretty 1991). Soils are eroding and losing their fertility, precious water supplies are being squandered, rangeland overgrazed, forests destroyed and fisheries overexploited. The heavy use of pesticides has caused severe problems. There is growing human morbidity and mortality while, at the same time, pest populations are becoming resistant and escaping from natural control. In the intensively farmed lands of both the developed and developing countries, heavy fertilizer applications are producing nitrate levels in drinking water that approach or exceed permitted levels, increasing the likelihood of government restrictions on fertilizer use. Increased, and inefficient, use of pesticides and nitrogen fertilizers produces severe pollution, but it is mostly local in its effect.

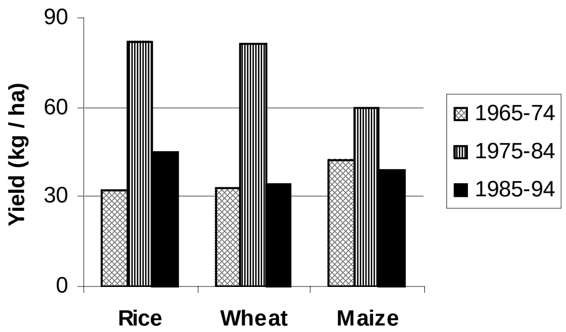

Figure 2. Average annual increase in developing country cereal yields by periods (FAO 1999)

Other agricultural pollutants have the potential for damage on a much larger scale. While industry is often to blame, agriculture is becoming a major contributor to regional and global pollution, producing significant levels of methane, carbon dioxide and nitrous oxide (Fig. 3). Natural processes generate these gases, but the intensification of agriculture in both the developed and developing countries has increased the rates of emission. Individually or in combination, these various gases are contributing to: acid deposition, the depletion of stratospheric ozone, the build up of ozone in the lower atmosphere, and global warming. Each of these, in turn, can have a deleterious consequence on agricultural production.

The way forward

As I indicated earlier I do not believe that the answer lies in encouraging the developed countries to continue to produce food well in excess of their requirements and to subsidize the export of this excess to meet the demand of the developing countries. This would be costly, both in economic and environmental terms, and more important, would exclude a large proportion of the population in the developing world from participating in global economic growth.

The alternative scenario is for the developing countries to undertake an accelerated, broad-based growth, not only in food production, but in agricultural and natural resource development, as part of a larger development process aimed at meeting most of their own food production needs, including the needs of the poor. Implicitly, this scenario recognizes that food security is not a matter solely of producing sufficient food. It depends as much on employment and incomes as it does on food production, and agricultural and natural resource development is crucial in both respects.

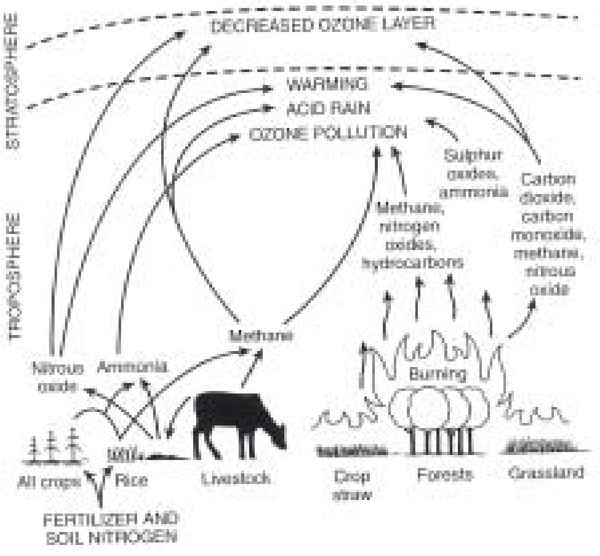

Figure 3. Global pollution caused by agriculture (Conway and Pretty 1991)

I believe these and other arguments point to the need for a second Green Revolution, yet a revolution that does not simply reflect the successes of the first. In effect, we require a Doubly-Green Revolution, a revolution that is even more productive than the first Green Revolution and even more 'Green' in terms of conserving natural resources and the environment (Conway *et al*. 1994; Conway 1999).

Over the next three decades it must aim to repeat the successes of the Green Revolution, on a global scale, in many diverse localities and be equitable, sustainable and environmentally friendly.

A woman on a hill

To bring this concept down to earth I want illustrate by referring to the farm of Mrs Tunai Namurunda. Like so many African farmers she is a single mother struggling to support a family, providing its food, fetching water, gathering fuel, educating the children and treating them when they are ill. She farms a single hectare running up one side of a hill in the Siaya district of Kenya near Lake Victoria. The soils are moderately deep and well drained, but they are acidic, highly weathered, and leached. Shortages of almost everything – land, money, labor and plant nutrients in the soil – mean that she is often unable to provide her family with adequate food. The two youngest children suffer from undernourishment and persistent illnesses.

The soil on her farm is exhausted and Mrs Namurunda cannot afford to buy fertilizer. So she starts each growing season with a maximum potential harvest from her hectare of only about two tons (Fig. 4). Weeds reduce her yield, particularly the parasitic weed *Striga*. Streak virus, fungi and stem borers attack the maize crop, and the cassava, which she regards as her 'insurance crop,' is assaulted by mealy bugs and green mites, joined in recent years by a new super-virulent strain of African cassava mosaic virus.

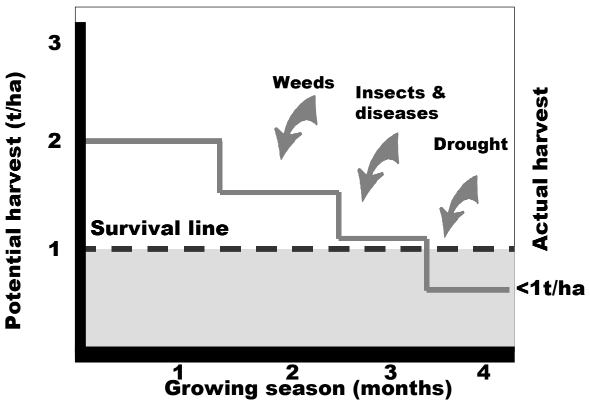

Figure 4. A food-insecure farm in Western Kenya

Her bananas are infected with weevils, nematodes and a fungal disease, black sigatoka, and her beans—which are intended for double use as a source of protein for the family and nitrogen for the soil—suffer from fungal diseases that rot the roots, deform the leaves, shrivel the pods and lower nitrogen fixation. In more seasons than not, her crops suffer from drought.

At the end of most growing seasons, Mrs Namurunda actually harvests less than one ton – less than half of what was achievable on her poor soil. She and her children are often hungry, the two younger children are often sick, and there is no money for schooling or for health care.

The challenge is to help her raise the yield potential to 3 tons per hectare, plant more drought-tolerant crops, and further reduce the toll of weeds, pests and diseases to hope for a final harvest of over 2 tons (Fig. 5). If she could get to this level, she would have enough to feed her family, plus income from selling the modest surplus to help with education for the children and health care. She might also begin to put part of her land into cash crops.

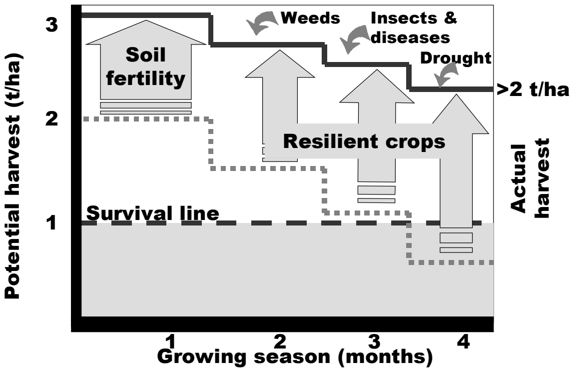

Figure 5. A food-secure farm in Western Kenya

Part of the answer lies in supportive policies – rural credit, more efficient input and output markets and good roads and railways to take her produce to market. In the longer run, Mrs Namurunda and her children will need to earn wages and income from sources other than their small hectare of land (Ashley and Maxwell 2001). At a global level much can be done to improve her prospects by promoting fair competition and access to markets in the developed world. But for the present, her only hope for a better life for her family is to get more from her land. And to overcome the obstacles in her way she requires new technologies.

Integrated nutrient management

At the root of her problems are the low fertility of her soil and the high price of fertilizer. In the absence of subsidies, prices in Western Kenya are \$400 per metric ton of urea *vs.* \$90 in Europe (Sanchez 2002).

African farmers pay the highest fertilizer prices in the world, whether in US dollars or grain equivalents. In Africa, one kilogram of nitrogenous fertilizer can cost a farmer 6–11 kg of grain, compared to 2–3 kg in Asia (Mwangi 1997). On average – and many use none at all – African farmers use only 10 kg ha^{-1} of fertilizer while European farmers use an average of over 200 kg ha^{-1}.

In Mrs Namarunda's case her input prices began to fall with the arrival in her village of the Sustainable Community Oriented Development Programmed (SCODP), a local Kenyan NGO, who negotiated for cheaper fertilizers and improved seeds (of crops and leguminous tree fallows) and helped get better prices for farm products (Seward and Okello 1998). With the help of scientists from the Kenyan Agricultural Research Institute (KARI), Kenyan universities, the International Centre for Research on Agroforestry (ICRAF) and the Tropical Soil Biology and Fertility Programme (TSBF), they took soil samples in the village that revealed a severe lack of phosphorus and shortages of nitrogen and micronutrients (Nzigheba *et al.* 1998). These results were compared with TSBF's Organic Resource Database, which describes the nutrient content of over 300 locally-available materials that can provide soil inputs (Palm *et al.* 2001). Alternative strategies to enhance soil productivity were developed based on nutrient cycling, livestock-crop interactions, biological nitrogen fixation, rock phosphate, improved fallows and efficient use of small amounts of fertilizer formulated to provide key missing nutrients.

KARI then designed a number of on-farm trials that were conducted by farmers to test the alternatives and to develop agronomic 'best practices'. They found, for example, that sowing a mixture of maize and legume plants in double rows (2 x 2), rather than every other row, provided more light for the legume, allowing more valuable legumes, such as cowpea, to be grown and also providing greater nitrogen fixation (Lan'gat *et al*. 2001). Improved fallows of the genera *Crotalaria, Sesbania* and *Tephrosia*, grown during the dry seasons, provided significant additional nitrogen (100–200 kg ha^{-1} yr^{-1}) for use by the next rainy season maize crop (Sanchez *op cit.*)

Resilient crops

Using such best practices, Mrs Namurunda quickly learned that she could substantially improve soil fertility on her farm, but much of her increased production was still lost to pest, diseases and other stresses.

Integrated pest management is providing some answers: a promising line of attack against *Striga* depends on intercropping maize with the legume *Desmodium uncinatum*; and a South American wasp that is a natural enemy of the cassava mealybug has been successfully introduced into Africa. Mrs Namurunda is also getting benefits from new plant varieties bred by traditional means: a high-quality-protein maize is increasing her family's protein intake; and new cassava varieties based on West African strains that are resistant to the new form of cassava mosaic virus.

But, the new high-quality maize took 16 years to breed and still needs better adaptation to local conditions. The new cassavas are still bitter to the East African taste and require more preparation. Controlling *Striga* requires several different lines of attack at once, and drought tolerance is slow and difficult to breed into crops by conventional means. There are many targets for plant breeders where conventional breeding is too slow or unable to produce the desired results (Table 1). Biotechnology provides a powerful alternative.

Table 1. Crop breeding targets in Africa for which biotechnology is appropriate

Striga-resistant millet and maize
Drought tolerant rice and maize
Pod borer resistant cowpea
Weevil and fungal resistant banana
More nutritious maize, rice and cassava
Stemborer resistant maize and sorghum
Herbicide tolerant crops

The potential of agricultural biotechnology

Agricultural biotechnology consists of three practical processes resulting from basic advances in cellular and molecular biotechnology.

- *Tissue culture*, which permits the growth of whole plants from a single cell or clump of cells in an artificial medium;
- *Marker-aided selection*, based on our ability to detect the presence of particular DNA sequences at specific locations on a chromosome and link these to the presence of genes responsible for particular traits;
- *Genetic modification*, based on recombinant DNA technology, which enables the direct transfer of genes from one organism to another.

Tissue culture

Tissue culture has so far provided the greatest benefits to poor farmers. Tens of thousands of farmers in Africa are now growing food crops produced by this form of biotechnology. In East Africa, where banana is a staple crop, micro-propagation of improved and disease-free banana seedlings through tissue culture is improving food production and generating income for small-scale farmers like Mrs Namurunda (Wambugu and Kiome 2001).

To date the most dramatic achievements have been with rice. Using anther culture and another tissue culture technique, embryo rescue, scientists have crossed the high-yielding Asian rice *Oryza sativa* with the African rice *O. glaberrima*. The progeny of such crosses usually have low fertility, but in the Côte d'Ivoire, using anther culture techniques developed in China, African scientists at the West Africa Rice Development Association (WARDA) have been able to produce crosses that combine the high yields of the Asian rice with the weed-competitiveness and drought-tolerance of African rice (Jones 1999). Last year the new varieties were being grown by over 20 000 upland farmers in Guinea, and more than doubled yields.

Marker-aided selection

With marker-aided selection (MAS) it is possible to identify segments of the plant genome that are closely linked to the desired genes, so the presence of the trait can be determined at the seedling or even the seed stage. This makes it possible to achieve a new variety in four to six generations instead of ten.

Maize streak virus (MSV), the most serious disease of maize in Africa, affects 60% of the planted area and causes an estimated 37% yield loss, or roughly 5.5 million tons yr^{-1} losses in production (Jeffers 2001). Excellent genetic resistance to MSV has been known for over 20 years, but it has not been widely deployed in local maize varieties because few national breeding programs can afford to maintain the insect colonies and other infrastructure necessary to measure for resistance against insect-vectored viral diseases. Now, using genetic markers on the molecular map of maize, it is possible to identify the precise location of the resistance gene, and using the DNA markers flanking the gene, to backcross it into numerous well-adapted local varieties without expensive disease screening.

Marker-aided selection is particularly useful for breeding drought-tolerance, which typically occurs as the result of a number of different traits – deeper roots, early flowering, osmolytic changes – working together. Breeding for it is a particularly difficult and slow process using conventional techniques, but markers are now permitting combinations of these traits to be accumulated in new varieties.

Genetic modification

Genetic modification moves genes between organisms, including those that do not cross in nature. The resulting plants, called transgenic, or genetically modified organisms (GMOs), have been the focus of most of the controversy over biotechnology so far. For some good reasons, including those connected with early episodes of corporate haste and arrogance, people in many countries are suspicious of GMOs and hostile to their use, especially in food.

Despite the opposition, since 1996 there has been a steady increase in the worldwide area planted to transgenic crops, with 52.6 million ha harvested in 13 countries in the year 2001 (James 2001). Over 5.5 million farmers grew transgenic crops in 2001, 90% of whom were small-scale farmers in developing countries, with the vast majority in China.

US farmers clearly find this a useful and profitable technology; most of their cotton and soybeans are now GM crops. For poorer farmers the main benefits so far have come from growing cotton that is resistant to insects. The resistance is conferred by introducing gene constructs derived from the bacterium *Bacillus thuringiensis* (*Bt*). Last year in China over 3 million resource-poor farmers grew over 1.5 million ha of *Bt* cotton, over 30% of China's total crop area (Pray *et al.* 2002). They were able to reduce the number of pesticide applications substantially, obtained higher yields and derived benefits estimated at $330 to $400 more per hectare (Huang *et al*. 2002). Reducing pesticides reduces harm to human life and health, as well as to the environment. The benefits to health have been particularly notable for *Bt* cotton in China where pesticides are traditionally applied manually without protective clothing resulting in high incidences of poisoning (Pray *et al*. 2002).

Genetically-modified cotton that utilizes *Bt* genes has been grown in South Africa for three seasons and provides the only practical experience African smallholder farmers have had with GM crops. In the Makhathini Flats region of KwaZulu Natal Province, 95% of smallholder cotton producers grew *Bt* cotton in the 1999–2000 growing season (Table 2). The results have been increased yields, increased profits and significant reduction in pesticide use (Ismael *et al*. 2001). And, the smaller the farm, the greater the benefits received.

Table 2.* Bt *cotton production in Makhathini Flats, South Africa, 1999-2000 (Ismael* et al. *2001)

Attribute	Conventional cotton	*Bt* cotton
Yield (kg ha^{-1})	261	417
Value (Rand ha^{-1})	568	905
Seed cost (Rand ha^{-1})	91	197
Pesticide cost (Rand ha^{-1})	116	72
Gross margin (Rand ha^{-1})	361	638

Genetic engineering is also being used to produce transgenic food plants with nutritional traits important to developing countries.

The best example to date is the successful production of beta-carotene, the precursor of vitamin A, in the grain of rice to produce so-called 'Golden Rice'. Beta-carotene is produced in the leaves of the rice plant, but conventional plant breeding was unable to obtain production in the grain. Scientists at the Swiss Institute of Plant Sciences in Zurich successfully transferred one bacterial gene and two daffodil genes that are expressed preferentially in the grain, and the added transgenes resulted in the synthesis of nutritionally significant levels of pro-vitamin-A (beta-carotene) in the grain (Ye *et al*. 2000). Currently, breeders in several Asian countries are transferring the genes into locally adapted rice varieties.

A secure farm

Over the past three years, by utilizing these technological innovations – in IPM and INM, in conventional breeding, tissue culture and marker-aided selection – Mrs Namurunda has harvested over 2 tons ha^{-1}, which is well above the family's survival line. Last year she even grew vegetables and flowers as cash crops and made enough profit to pay the fees for her three young daughters to go to school along with their brother. Though it is gradual, she recognizes that the fertility of the soils on her farm is steadily improving, and because of the genetic resilience built into her new crop varieties, the extra effort and investment she makes in restoring soil fertility is not lost to pests and diseases (DeVries and Toenniessen 2001).

Her life has changed, and so have the prospects for her family. She has heard that KARI is developing new maize varieties, based on breeding lines from CIMMYT that have already proven to yield better under drought and low nutrient conditions in southern Africa, and that provide effective control of *Striga* (Banziger and Cooper, in press; Kanampiu *et al.* 2002). She is anxious to experiment with these new varieties and to provide feedback about how they perform and how they can be further improved. She has enrolled in KARI's Farmer Field School program to become a farmer trainer, which includes special training in group learning, non-formal education methods, communication skills, agro-ecological analysis and relevant technical matters. She looks forward to sharing what she has learned with other farmers in her village.

Participation

The participation of Mrs Namurunda and millions of farmers like her is going to be critical to success. A Doubly Green Revolution cannot rely on the application of biotechnology or ecology alone. If the first Green Revolution started with the biological challenge inherent in producing new high-yielding food crops and then looked to determine how the benefits could reach the poor, this new revolution has to reverse the chain of logic, starting with the socio-economic demands of poor households and then seeking to identify the appropriate research priorities.

Biologists will have to listen as well as instruct (Conway 1998). There will be no easy solutions and few, if any, miracles in the new revolution. Greater food production will come from targeting local agroecosystems, making the most of indigenous resources, knowledge and analysis. More than ever before, we will have to forge genuine partnerships between biologists and farmers. It will not be enough simply to test new varieties or breeds on farmers' fields at the end of the breeding process. Experiments in many parts of the developing world are showing very effective ways of involving farmers right at the beginning, in the design of new varieties and breeds and in the breeding process itself (Sperling and Scheidegger 1995).

Participation has long been a slogan of development, but for the first time we now have effective techniques to make it a more practical proposition. Under the heading of Participatory Learning Appraisal (PLA) there is a formidable array of methods which permits farmers to analyze their own situations and, most importantly, to engage in productive dialogue with research scientists and extension workers (Conway 1999).

These techniques enable rural people to take the lead, producing their own diagrams, undertaking their own analyses and developing solutions to problems and recommendations for change and innovation. Maps are readily created by simply providing villagers with chalk and colored powder and no further instruction other than the request to produce a map – of the village, or the watershed or a farm. A threshing floor or a cleared space in the village square is all that is needed to produce such a map, often of considerable complexity. People who are illiterate and barely numerate can construct seasonal calendars using pebbles or seeds. Pie diagrams – pieces of straw and colored powder lain out on an earthen floor – are used to indicate relative sources of income.

Although this is, in itself, encouraging, it is the use to which the diagrams are put that is important. These diagrams not only reveal existing patterns but point to problems and opportunities and are seized on by rural people to make their needs felt. The diagrams have become a basis for collective planning and the approach has begun to change the relationship between 'expert outsiders' and village people. In every exercise the traditional position of rural people being passive recipients of knowledge and instruction has been replaced by the creation of productive dialogues. A recent report by ActionAid describes a very sophisticated use of maps and preference rankings by the Sanaag people of Somaliland for community based livestock development (ActionAid 1999).

It has long been the practice to place trial plots in farmers' fields, but often the farmers are simply used as laborers, being given little knowledge of the purpose of the trial. Experience shows that more active involvement produces better, more sustainable results. Breeders from CIMMYT in Zimbabwe have had notable success in introducing new varieties of maize that are more resistant to the stresses of drought and low nitrogen, success that is due in large part to the active participation of local farmers in the breeding efforts (Banziger and Cooper, in press). In Kenya, KARI is also trying out a more fully participatory approach. Farmers are planting out trial plots on their land – investigating varieties, spacing, fertilizer treatments, intercropping, erosion control – mixing treatments suggested by the KARI team with their own. They conduct the trials themselves and use pair-wise ranking to analyze the results. A committee of farmer researchers has been formed and the trial results, and the approach itself, are now being taken up by neighboring farmers. It is possible to see this as a first step towards a radical alternative to traditional extension systems, involving farmer research, farmer to farmer transfers of knowledge, farmer schools and other farmer led activities.

Partnerships

Mrs Namurunda's farm in western Kenya is just one of many places throughout Africa where real progress is being made. Dozens of new crop varieties have been or are about to be released in combination with locally well-adapted strategies for restoring soil fertility. Essentially all of these new technologies have resulted from linking the work of national and international scientists with local NGOs and seed companies, and the collaboration of all of them with farmers. A clear lesson is the importance of 1) combining agro-ecological and genetic technologies; 2) building partnerships that begin and end with farmers; and 3) creating a network of public and private sectors, including non-governmental organizations, national agricultural research systems such as KARI, the international research centres and the advanced laboratories of industrialized countries, as depicted in Figure 6.

Public researchers have traditionally played a key role in agricultural development. Agricultural universities, agricultural research agencies and extension services were established in most countries and charged with developing and delivering new technologies to farmers. The international agricultural research system depicted in Figure 6 was established specifically to develop better products and improved farming methods for smallholder farmers in developing countries.

Sixteen International Agricultural Research Centres (e.g., the International Institute for Tropical Agriculture, IITA, based in Nigeria; the International Rice Research Institute, IRRI, based in the Philippines; the International Maize and Wheat Improvement Center, CIMMYT, based in Mexico) play a central role by producing breeding lines and other global 'public goods' that are made

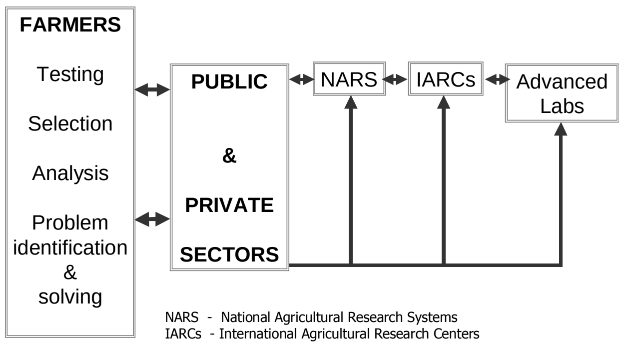

Figure 6. Partnerships involving farmers, public research institutes and the private sector are key to the success of the Doubly Green Revolution

freely available to everyone. Today, the vast majority of improved varieties of staple food crops grown in developing countries are the product of this public sector research system.

Public-private partnerships

But the vision that inspired the Green Revolution and spurred the development of the International Research Centers has faded and national governments and development agencies alike now dramatically under-invest in agricultural research for the poor. Patents in the US are now being issued at a rate of one million every five years, and the scope of what can be patented continues to grow broader. The multiplication of ownership rights that must be negotiated – and paid for – to market a product is so great that some useful ideas are not being pursued. The system encourages companies to warehouse thousands of patents they will never develop, in order to prevent a competitor from developing them or to use as 'trading cards' to gain access to patented materials and processes controlled by other companies. Increasingly only big corporations – not public scientists – are able to assemble the IPR pieces necessary for freedom to operate. This new feature of research has made the work of public agencies, which traditionally were responsible for virtually all of the products made available to the poor, considerably more difficult. As a result, over 80% of the new biotechnology products are being developed in the private sector, and very few of these are targeted to the needs of the poor.

One answer lies in public-private partnerships (PPPs) that address several major constraints to the open flow of knowledge and products that are needed by the poor. The first is the existence of severe market failures, and two others, which are inter-connected, relate to the restrictions posed by intellectual property rights and the need to guarantee proper stewardship of projects involving plant biotechnology.

In collaboration with partners including the Meridian Institute, the Rockefeller Foundation is exploring the potential for establishing such PPPs. The first, the African Agricultural Technology Foundation (AATF), will be an African-based and African-led initiative. It will receive licenses for new crop technologies from corporations and other research organizations. Then, while assuring proper stewardship of the technologies, the AATF will sub-license their use in specific projects by national and international research organizations in Africa. So far, the five major crop-biotechnology corporations and the USDA have agreed to share their technologies with Africa through the AATF.

The second mechanism, which is actually a public-public partnership, is tentatively called the Public Sector Intellectual Property Resource for Agriculture (PSIPRA, pronounced 'sipra'). In this case we are partnering with the McKnight Foundation, which also supports plant biotechnology research in developing countries, and a number of major agricultural research universities (e.g., California, Cornell, Wisconsin, North Carolina State, Texas A&M). Universities such as these are generating much of the intellectual property (IP) in crop biotechnology but often lose control of it through exclusive licensing to corporations. This has limited their freedom to share their technologies with public-sector institutions such as the IARCs and has constrained their own ability to produce genetically modified specialty crops for commercial use. Universities involved with PSIPRA would promote licensing strategies that favor retention of rights to use their own technologies for humanitarian purposes and also for the development of specialty crops where markets are small and do not compete with the large private-sector companies. It could also, through a public database, provide information on technologies that are still available to the public sector and explore IP pooling mechanisms designed to help scientists develop new crops that can truly reach those that are most in need.

With such partnerships in place, there will be reason for optimism. But still, if Africa is to reverse its current trend downward into greater and greater food insecurity, much more needs to be done. The scale of the task is daunting. There is much that African governments can do – through support of indigenous research and extension capacity and through the creation of well-functioning input and output markets and supportive economic policies. African leaders need, in particular, to re-establish their strong commitment to agricultural research and development. But African governments cannot achieve food security alone. The work of the Consultative Group on International Agricultural Research (CGIAR) in recent years has demonstrated what can be done with relatively little investment (the total cost of the 16 CGIAR centers is under \$350 million yr^{-1}, and is one of the most cost-effective investments donors make). The donor community, including the World Bank and the bilateral agencies, needs to explicitly recognize this and commit itself to a decade-long program of support. Only then can we be reasonably confident that the food security now attained by Mrs Namurunda's family will be achieved by small-scale farming families all across Africa.

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