Overview and Priorities for Science and Technology in West Africa: A contribution to USAID West Africa Regional Program Initiative to End Hunger in Africa (IEHA) Action Plan

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1. Executive Summary and Investment Priorities

This document specifies interventions by which to develop and deliver valuable innovations to West African farmers, through targeted investments in science and technology at a regional level. The priorities sketched here can be expected to make major contributions to WARP's objective of a politically stable and economically prosperous West Africa, through the use of improved production techniques and marketing institutions by the region's 115 million farm people, whose rapid population growth and limited migration opportunities cause increased dependence on a fragile natural resource base.

1.1 Priorities for WARP investment in agricultural science and technology

The proposed priorities flow from the bottom up, to enhance what farmers, the private sector, and local governments are already doing. To complement rather than imitate the work of others, the priorities for WARP S&T investments should be:

(1) increased investment in science-based innovation, through specialized networks of NARS, IARC and other scientists whose goal is to develop new plant varieties and complementary soil-fertility and crop-protection technologies that fit West African farmers' changing needs; and

(2) increased investment in policy reform and institutional change, through regional organizations whose goal is to accelerate the multiplication and delivery of seeds and seedlings for new crop varieties, as to expand farmers' access to inorganic fertilizer and crop protection chemicals.

The allocation of resources across the region's diverse agro-ecologies should target those production systems that are of greatest importance to West Africa's farmers and low-income people. In other words, priority setting should begin with the principle of concordance, so that investment shares allocated in proportion to a commodity and region's share of total agricultural output. Concordance is a useful starting point to align WARP investments with farmer needs, but final allocations should also depend on the probably of contributing something new and useful that other organizations do not provide.

Priority-setting across types of technology should target innovations that can be scaled up to reach millions of dispersed, resource-poor farmers. Huge impacts have been achieved with scientific breakthroughs that are embodied in easily replicable, divisible inputs: the initial innovation is difficult, but subsequent applications are relatively easy to copy and spread. The key such innovations in agriculture have been new varieties, inorganic fertilizer and crop protection chemicals. Much of the investment needed for such biochemical breakthroughs is on the research end, to develop new varieties and fertilizer compositions appropriate to farmers' conditions, but regulatory reform is needed to permit competitive private-sector delivery of fertilizer and other agro-industrial inputs, and substantial public investment is also needed for seed multiplication and other activities with public-good characteristics.

1.2 Specific modalities for WARP investment in agricultural science and technology

The specific mechanisms by which to ensure that WARP S&T investments have maximum impact towards USAID's strategic objectives follow from a simple idea: S&T investments should pay for (1) *science-based innovation*, defined operationally as experiments to create and select desirable new plant varieties and associated agronomic techniques; and (2) *technology delivery*, defined operationally as using public-sector institutions to multiply the resulting new varieties while promoting competitive private trading in other inputs and product markets. Allocations across commodities and regions should follow broadly from the principle of concordance, modified by the (subjective) probability of successful innovation. Operationally, the following approach is suggested:

1. To allocate resources in FY03 and for FY04, WARP should:
   - calculate the approximate share of total farm output accounted for by the major commodities in each focus country (Ghana, Mali, Nigeria) and the region as a whole;
   - request proposals from regional networks, institutions and partnerships (including new partnerships), for the conduct of S&T activities that are likely to either:
     (a) increase the quantity and quality of scientific innovation, producing a larger number of potentially more valuable new plant varieties or other inputs that embody new knowledge and can readily be multiplied and delivered to farmers; or
     (b) multiply and deliver the results of previous innovations, expanding the number of farmers who have access to the inputs which embody that innovation, so that farmers can choose to use them to the extent that they serve farmers' needs.
   - expect to fund proposals roughly in proportion to their output shares, subject to the probability of successfully raising farmers' productivity as specified below.

2. To choose among competing proposals, the probability of success should be scored with the following criteria:
   - for the innovation of new techniques, the proposal's budget and operational plan should show a high probability that funds will be used either to conduct laboratory and field experiments that generate new varieties or inputs, or will be used to conduct tests, trials, surveys or other procedures to determine which new inputs are most likely to be most valuable under farmers' conditions, with what accompanying techniques.
   - for the delivery of existing techniques, the proposal's justification should summarize the scientific data demonstrating the technique's potential value to farmers, and the economic rationale for why the private sector is unable to multiply and deliver the needed inputs in question; then the proposal's budget and operational plan should show a high probability that the funds will be used to multiply, control quality and deliver the seeds or other inputs in a cost-effective manner.

3. Given the costs of contracting and administration, it is likely that the most successful proposals will involve, in probable order of relative magnitudes:
   - The existing commodity networks, proposing seed-multiplication programs to accelerate the spread of their most promising varieties, in which NARS scientists might work with NGOs and private firms to improve seed production and quality control systems within and across countries. It seems likely that several good proposals in this area could be generated quickly, involving expenditures on the order of $150,000 to $300,000 each, with each one reaching

several thousand farmers in the first year and generating sustained benefits thereafter far in excess of investment cost.

- The existing commodity networks, proposing coordinated trials of promising techniques across countries, to ensure that any variety or technique known to be promising in one WARP country is also being tried in others with similar agroecological conditions. It seems likely that several good proposals in this area could be generated quickly, involving expenditures on the order of $100,000 to $200,000 each, with each one promising to accelerate the spread of several varieties across several countries, eventually feeding new seed multiplication projects.
- New partnerships between institutions including regional bodies (CORAF/WECARD, INSAH, or others), NARS, IARCs, NGOs and Universities, to go beyond the two kinds of proposals above, conducting discovery and delivery programs across countries for a range of innovations in plant genetics, soil fertility management, crop protection and post-harvest handling, or animal genetics and care. Such innovations are most likely to become fundable only in late FY03 or FY04, as WARP gains experience with the funding of specialized S&T activities.

2. Introduction to S&T investments in West Africa

This document describes the setting and priorities for USAID investments in agricultural science and technology at a regional level in West Africa. The “infrastructure for innovation” sketched here can be expected to make major contributions to WARP’s objective of a politically stable and economically prosperous West Africa, by facilitating the development and delivery of improved seeds, fertilizer and other inputs for the region’s 115 million farm household members.

West Africa is a region with exceptionally rapid rural population growth, due to a late and sudden onset of the demographic transition in the 1950s, and limited opportunities for migration to urban or foreign centers of non-farm employment. With more and more people depending on a fixed natural resource base, the use of modern science to improve productivity is crucial for sustainable economic growth.

The development and delivery of appropriate science-based inputs alleviates poverty by raising the productivity of poor peoples’ assets, and lowers the real cost of producing food, industrial inputs and goods for export. In the absence of science-based innovation, West Africa’s rising rural populations will remain trapped in a cycle of resource degradation, worsening poverty, and social instability.

Agricultural S&T is inherently both international and location-specific. It makes progress by moving materials and techniques over long distances, to make innovative combinations – which must then be tried locally to determine their usefulness. WARP can play a key role by accelerating the flow of materials and techniques into and within West Africa, among the focus countries (Ghana, Nigeria and Mali) and throughout the region.

Agricultural S&T is inherently multisectoral. With new science-based inputs, farmers can meet subsistence needs with fewer resources, and invest more in market-oriented activities. The lower cost of food and raw materials raises the payoff to investment and trade around the region, giving people a greater stake in their own futures and in that of their communities.

3. Priorities for WARP investment in agricultural S&T

In sum, the regional S&T priorities sketched here promise high impacts in themselves, and also promise to facilitate progress in the other domains targeted by WARP, as higher productivity fuels the region's markets and trade, raising demand for market information and empowering people through trade associations.

The purpose of USAID investment in agricultural S&T is to permit sustainable increases in farm output, through the creation and spread of improved production technologies and market institutions. Doing so requires both targeted investments and a more favorable policy environment.

The proposed priorities flow from the bottom up, being chosen to complement what farmers, the private sector, and local governments are already doing or will do in response to the WARP's investments. These priorities specify the principles by which WARP should choose institutional channels, sub-sector weightings, and delivery mechanisms to achieve maximum impact. These priorities are sketched briefly below in section 3.1, with details of the context and rationale for these priorities in section 3.2

3.1 Summary of priority-setting approach and results

Institutional channels: The highest-priority institutions through which WARP should invest are those which will enhance the activities of others, rather than replace them. In particular, WARP should target: (1) networks of researchers across countries, through which they can share materials and techniques used in research, as well as the final products of research activities, and (2) regional institutions that serve multiple countries, to provide services with large scale economies such as biotechnology research or policy harmonization across countries to permit the flow of technical inputs such as seeds and fertilizer.

Sub-sector weightings: The highest-priority commodities and environments to target in WARP-funded regional networks and other institutions are those which are of greatest importance to West Africa's farmers and low-income people. Priority setting across commodities and regions should begin with the principle of concordance, so that investment shares allocated in proportion to a commodity and region's share of total agricultural output.[1] This implies a larger allocation to basic food crops and resource-poor production systems than is actually given in many agricultural S&T programs.[2] Concordance is a useful starting point to align donor investments with farmer needs, but final allocations should also depend on the probably of contributing useful innovations in that area –

[1] For details on priority-setting, see Alston, Norton and Pardey (1997). For detailed case studies of actual S&T impacts in West Africa, see Masters, Bedingar and Oehmke (1998) or Masters and Ly (2002). These case studies attest to the practical importance of concordance: investments that target small production systems have small impacts.

[2] Annex Table 1 provides some guidance as to the relative importance of key crops in the continent as a whole; Annex Table 2 provides an example of a real concordance analysis across commodities, showing Mozambique's continued under-investment in S&T for basic food crops.

which requires highly specialized, scientific judgment, and depends also on the serendipity of scientists' particular interests, experience and motivation.

Innovations and delivery mechanisms: The highest-priority innovations are those that can readily be scaled up to reach millions of dispersed, resource-poor farmers. Huge impacts have been achieved with scientific breakthroughs that are embodied in easily replicable, divisible inputs: although the initial innovation is difficult, subsequent applications are relatively easy to copy and spread among even among small and remote users. In agriculture, the key embodied inputs have been seeds and seedlings with improved crop genetics, complemented by inorganic fertilizer and crop protection chemicals.[3] Although much of the investment needed for such biochemical breakthroughs is on the research end, to develop new varieties and fertilizer compositions appropriate to farmers' conditions, substantial innovation is also needed on the technology-delivery end. Some innovations needed for better technology delivery involve policy reform to promote private-sector input delivery, but they may also require large public investment in seed multiplication and other activities with public-good characteristics.

3.2 Context and principles for priority-setting

The context for the priorities specified here is sketched in the annex figures, which tell the story of Africa's unique position in the world economy.

The story begins with people, and the fact that Africa is lagging a full generation behind Asia in the demographic transition. Annex Figure 1 shows that Africa's population growth rate did not begin to fall until the 1980s, while Asia's began to fall in the 1960s. Among other consequences, the delay is giving Africa's demographic transition a higher peak population growth rate than occurred anywhere else in the world. And although Africa has the world's fastest-growing cities, these still employ relatively few people, so Africa's rural population has been growing very rapidly – about 2 percent per year from the 1960s until the 1990s (Annex Figure 2). This rural population growth is slowing as the cities absorb more and more people, but it is increasingly becoming by far the faster rate of rural population growth in the world.

A related fact is that Africa's delayed demographic transition gives it the world's youngest population, with roughly 85 children for every 100 adults (Annex Figure 3). This demographic burden will eventually become the "demographic dividend" of falling dependency ratio that has contributed heavily to Asia's rapid growth (Williamson and Bloom 2001). But in the meantime, the demographic fact of a rising rural population on the fixed land base provides a powerful prediction about Africa's economic performance: unless agricultural productivity rises sharply, living standards will continue to fall.

Africa's rising rural populations have, until recently, been accommodated by rising area planted and a decline in fallow periods. As long as the land frontier was open, farmers had little incentive to invest in higher yields, so there was no yield growth (Annex Figure 4). Governments shared this lack of interest in increasing yields, as there were low levels and little growth in agricultural research

[3] Perhaps the most useful agronomic history of productivity improvement is Evans (1993), the most recent and exhaustive economic study of its value to society is Evenson and Gollin (2003). Looking forward, an important assessment of the research frontier in Africa is DeVries and Toenniessen (2001).

expenditure (Annex Table). The result is that Africa's rate of new variety generation and adoption is about 30 years behind Asia's, and is 20 year's behind Latin America, which is the world's other relatively land-abundant region (Annex Figure 5). And, while fertilizer use rates in the rest of the world have converged to an equilibrium rate on the order of 100 kg per hectare of arable land, Africa's use rates rose in the 1960s and 1970s but have since stabilized at one-tenth that level (Annex Figure 6).

3.3 Complementing household and community actions

West Africa's uniquely rapid rural population growth has forced people to expand cropped area onto drier and less fertile lands and to reduce fallow periods, leading to a sharp decline in average soil fertility and in moisture availability. Households are actively responding to the change by investing in soil and moisture retention, to save their increasingly scarce natural resources by using more of their increasingly abundant labor. NRM techniques which once were confined to the most overpopulated parts of West Africa are now spreading widely and rapidly across the region.

Many of the key NRM techniques can best be designed and implemented by the household itself, such as changing seed rates and crop mix; constructing field bunds, ridges, and microcatchments; and managing the flow of crop residues and animal manure. These innovations typically emerge relatively quickly in response to changing circumstances.[4] Farmers are well-known to experiment continuously with the resources they have, to learn from their neighbors and to adopt profitable innovations quickly as long as they have reasonably well-defined user rights over the resources involved.[5] As a result, it is difficult for an outside researcher to improve on farmers' application of such household-level techniques—and collective actions may be counterproductive.[6] The role of research here is to document and anticipate farmers' choices, and assess their implications for outsiders.

Some very important NRM techniques require collective action at the local level, such as restricting access to communally-owned grazing or forest resources; or investing in common assets such as improved wells or retaining walls. The institutional innovations needed for these actions are much more difficult for an individual community to discover and implement, so it can be extremely valuable for outside researchers to analyze the performance of alternative institutional arrangements and to help spread the most successful ones.[7] This kind of technology development and transfer has often been most successfully implemented by NGOs, since they move freely across administrative boundaries to organize communities on a voluntary basis.

[4] The dynamics of this process in Niger, where farmers are investing in progressively more costly soil conservation techniques over time, is in Abdoulaye and Lowenberg-DeBoer (2000).

[5] Kazianga and Masters (2001) show that across farmers in Burkina Faso, those with more security of tenure tend to invest more in soil conservation.

[6] An example is the relatively low labor productivity found for community work days in building rock bunds in Burkina Faso, in a context where farmers are already making high-productivity NRM investments on their own fields, as documented by Zougmoré, Kaboré and Lowenberg-DeBoer, 2000). The value added of collective action would have to be in common-property resources such as groundwater recharge.

[7] An example here is the use of grazing fees to encourage confinement-feeding of animals, which in turn raises the quantity and quality of manure for use on crops. A detailed biophysical simulation model of the long-term effects of such arrangements on natural-resource sustainability is Dalton and Masters (1998).

A few environmental innovations are best implemented at the national or supra-national level. Such actions include the development and enforcement of biosafety and food safety rules,[8] or the management of large-scale resources such as river basins and coastal fisheries. This is the domain of government-to-government exchange, at a relatively high level of technical expertise. WARP may be able to support such initiatives, as well as the NGOs that provide community-level NRM actions, but many other outside donors are focused on these kinds of investments.

For the purpose of priority setting, it seems clear that WARP's unique comparative advantage is to provide farmers, local communities and governments with the science-based innovations that make their actions more productive, raising the payoff from investment and trade. The most important single kind of innovation is crop genetics, followed closely by animal genetics and animal health. The genetic "blueprints" for plants and animals are beyond the control of farmers, communities or African governments, but can be adapted to changing local conditions by researchers connected to global science. Developing the appropriate genetics, however, must be financed and organized by an outside agency, since it draws on worldwide scientific capacity and produces benefits that spread widely beyond the interests of any one institution or group.

3.4 Complementing private-sector and government actions

Beyond the natural resources discussed above, many key elements of the agriculture and food system are man-made, provided by the private sector beyond the farm gate. Decades of agricultural economics research have shown clearly that, wherever property rights are reasonably well defined and enforced, people will invest and trade in an astonishing array of goods and services. Africans are no exception.

The high density and relative efficiency of private sector trade and investment in West Africa, despite an almost complete absence of written contracts, was exhaustively demonstrated in the 1950s and 1960s, by Peter Bauer (1954), William O. Jones (1959, 1972) and many others. But this work also shows that, in Africa as elsewhere, the private sector invests in and trades only *proprietary* things, whose benefits are *excludable* so that costs can be fully recovered from active customers. "Public" goods or services, whose benefits are not excludable, have been notoriously under-provided in Africa for many decades. It is this under-provision of public goods – that is, the weakness of collective institutions capable of raising taxes, providing services and regulating trade in an economically efficient manner – that is now seen as the ultimate cause of low economic growth in Africa as in other low-income regions.[9]

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[8] A case in point would be the introduction of quality-certification systems to permit a competitive market for manufacturer infant foods, as described in Masters and Sanogo (2002).

[9] See Douglass North (1990) for a descriptive analysis, and Easterly and Levine (2002) for a recent econometric test of this proposition. Masters and McMillan (2001) show that political-economic performance is closely correlated with physical geography, implying that external interventions to alleviate geographic constraints are needed to "jump-start" the system of positive feedback between successful public institutions and a successful private sector. In particular, outside agencies can play a large role in providing S&T to overcome location-specific constraints on farm productivity and public health, which otherwise limit economic growth in the areas where those constraints apply.

Research on such institutions underlines the fundamental importance of their legitimacy and accountability to local people (Berkowitz, Pistor and Richard 2003): it is not possible for USAID or any other outside entity to create the grass-roots political activity necessary for legitimacy and accountability. But USAID can help raise the payoff to private investment and trade, and in so doing to raise the payoff for improved government institutions. Recognizing this comparative advantage, the key intervention by which USAID can empower the poor is through improved technologies that make more productive use of their limited assets. (For a detailed analysis and statistical test of how improved technologies lead to better governance, see McMillan and Masters 2003.)

WARP's comparative advantage in the S&T area involves both the regional spread of inputs to innovation, such as the genetic material and research techniques used for crop breeding, and also the regional spread of final innovations, such as new varieties and fertilizer compounds. Once developed, many of the final innovations are in fact proprietary inputs which can most efficiently be delivered to farmers through an appropriately deregulated competitive private sector. Gisselquist, Nash and Pray (2002) document the conditions under which relatively successful deregulations in four countries (Bangladesh, India, Turkey and Zimbabwe) have permitted the rise of private inputs-supply chain. In these settings, innovations originally developed by public-sector researchers are then turned over to private firms, subject to public-sector regulation for quality assurance and food safety. Competition among rival firms then makes for energetic and low-cost manufacture or multiplication and then delivery of the input to farmers.

A few inputs, however, are in fact not proprietary – so the public sector must reach further out to farmers with input multiplication and delivery, before the private sector can take over. This turns out to be the case for many kinds of crop seeds and seedlings. All across West Africa, improved varieties developed on research stations are now spreading from farmer to farmer, but they do so very slowly because private investment in seed multiplication or plant nurseries is not forthcoming. For the private sector to be efficient, appropriable benefits from product sales must be sufficient to cover investment costs. Among basic foods, this is really the case only for hybrids of maize, sorghum and millet, whose grain cannot be replanted in future years (so farmers are willing to pay high prices for the seed), but whose seed can be produced uniformly in a centralized manner at relatively low cost (so firms are able to invest in hybrid production). Almost all other kinds of genetic improvement must be delivered to farmers through the public sector, or it will be delivered slowly if at all.

One fundamental obstacle to private-sector delivery for most genetic improvements is that farmers in a particular location need to buy the improved variety only once -- and thereafter the farmers in that location can retain and share among neighbors. Thus, introducing an improved seed to a particular location has a huge payoff: for example, the discounted net present value of bringing a kilogram of improved cowpea seed to an area may run into the thousands of dollars. But this benefit is spread among many farmers over several years. Given farmers' transaction costs and discount rates, it is impossible for a private seller to obtain enough of the total benefit to justify their investment in seed production – even if everyone is fully informed about the value of the new seed.

The public good quality of new genetics makes for a large payoff to public investment in seed multiplication, to make successful new varieties spread faster than they could move from farmer to farmer. This payoff is particularly large in the case of vegetatively-propagated plants, where farmer-to-farmer movement is even slower than it is in the case of open-pollinated cereals, and in the case of tree crops, where the payoff to adoption is delayed but potentially very large.

The public role in seed multiplication is partly to accelerate the spread of new genetics, and partly to guarantee that a particular batch of planting material is actually the variety it is claimed to be. Since the buyer cannot observe whether a particular batch of planting material will in fact have the germination rates and other characteristics expected of well-prepared seeds, the provider of the seed must offer some sort of quality guarantee. In some cases, this can be provided by a third-party inspection and testing service, as for example the "Underwriters' Laboratory" inspects and certifies the safety characteristics of electrical appliances in the United States. (A detailed example of this kind of scheme for West Africa is provided in Masters and Sanogo 2002.) In other cases, it is preferable to assure quality by providing the good on a non-profit or government-supplied basis, as is often done with health care and education.

3.5 Gender dimensions of agricultural S&T

West Africa has some of the most unequal gender relations in the world, due largely to the region's poverty and natural-resource dependence (Galor and Weil 1996). But the gender gap is a cause as well as a consequence of continued poverty, because it limits girls' access to education and health services, and limits women's access to property rights and contract enforcement, so that women have limited resources with which to work. In this context, targeting donor investments to girls and women may make above-average contributions to growth as well as equity, precisely because girls and women are starved of resources from other channels.

Developing and delivering improved food crop technologies – particularly biochemical innovations that are divisible and low-cost to adopt – is particularly beneficial to women because it raises their productivity in food production and procurement. Improved seed varieties and management techniques, being technologies that can be adopted without access to credit or formal markets, are therefore among the most successful interventions by which to empower women, by reducing the land and labor they need to feed their families.[10]

In some cases, the introduction of new technology that women can use does increase women's bargaining power and reduces gender disparities, but in general new technology does not directly help close the gender gap. Other interventions are needed as well, in areas outside of the S&T agenda. But in the absence of higher food crop productivity, most Africans will continue to be forced by necessity to devote huge amounts of time and resources to obtaining food – which clearly does weaken the relative power of women in society. So although food-crops research is clearly not sufficient to help West African women reduce discrimination against them, it is probably a necessary element of any successful empowerment strategy.

3.6 Natural-resource sustainability dimensions of agricultural S&T

The principal threat to natural resource sustainability in West Africa is soil degradation, from the mining of soil nutrients by crop growth. Successive plantings combine with the effect of soil micro-organisms to draw nutrients and break down soil organic matter, reducing its moisture-retention potential and cation-exchange capacity. Low soil moisture and low fertilizer-use efficiency make it economically very costly to raise yields by simply adding fertilizer: this is profitable only in a few

[10] One of many studies addressing such mechanisms is Fisher, Warner and Masters (2000).

places, where there is better rainfall or irrigation and higher organic matter in the soil, as well as relatively favorable relative prices (from low transport costs to bring fertilizer in and then ship the crop out, and relatively low interest rates to pay for fertilizer before planting with funds obtained after harvest). John Sanders and his co-authors have focused on this issue for many years, documenting the rapid increase in farmers' use of agronomic improvements to increase moisture retention and soil organic matter, and thereby raise the return to fertilizer adoption (e.g. Shapiro and Sanders 2001, Sanders and Shapiro 2002). They find that farmers typically undertake out-of-season improvements first, such as retaining walls and field bunds, and as labor-land ratios increase they later adopt even more labor-intensive techniques that involve work during peak seasons to maintain ridges and other soil constructs, and to control the timing and placement of manure and inorganic fertilizers for additional phosphorus and nitrogen.

In terms of crop genetics, the short and uncertain duration of Africa's rainfall puts a premium on early-maturing varieties, which allow farmers to stagger their plantings and in some cases actually re-plant a failed stand.[11] Of course, shorter-duration varieties tend to have lower yield potential, simply because they have less time to grow -- but this works only when there is enough soil moisture and nutrients to permit continued growth. Soil degradation has therefore increased the premium for earliness, by reducing the moisture-holding and nutritional quality of soils. In some areas, African farmers' investments in better agronomy could so much enrich their soils that longer growth periods become possible, reversing the past trend towards a preference for shorter-season varieties. The net result is that almost all regions would benefit hugely from an increasing "variety of varieties", providing plant qualities that fit increasingly well into an increasing range of agro-ecological niches.

3.7 Molecular biology and transgenics in the West African S&T

A recent assessment of biotechnology interventions in West Africa is provided by Alhassan (2002). It is clear that, where genes for certain traits (e.g. disease or insect resistance, drought tolerance) cannot be crossed into desirable varieties through classical breeding techniques, it may be useful to introduce those genes using the techniques of molecular biology. Perhaps the most immediately valuable, high-impact application of biotechnology in the region would be the introduction of Bt genes to deal with pod sucking bugs on cowpeas. The Network for Genetic Improvement of Cowpea in Africa (NGICA) has done some work on this already: these pests currently cause yield losses of 50 percent or more, and with very conservative assumptions, successful development of appropriate Bt varieties would generate benefits far in excess of program costs (for a case study from Senegal, see Faye 2000).

For small farmers to benefit from biotechnology requires not only a scientific investment, but also regulatory change – and too often, policy-makers have little knowledge of the technologies in question. In West Africa, NGICA has contributed to both the science and the policy environment, contributing significantly to development of biosafety regulations in several countries. And even where regulatory oversight facilitates appropriate innovation, seed multiplication and quality control remains a critical constraint -- an initial assessment of the ability of West Africa seed systems to deal with biotechnology can be found in Lambert and Khonde, 2002.

[11] Earliness has even more value in irrigated or very high-rainfall areas, where it permits double-cropping. Many of Africa's irrigated rice farmers have only recently had access to the appropriate varieties needed for double-cropping, whereas in Asia many farmers already have varieties that permit triple-cropping.

3.8 Implementation and the supply of scientists

A key issue in the implementation of any S&T program is the small number and advanced age of PhD-level scientists actually engaged in crop improvement. One of the fundamental facts about Africa is its lack of human capital: relatively few people have scientific educations, and since most benefits of investing in scientific education are not appropriable by individuals, their families or even their governments, the vast bulk of it has been and probably will continue to be donor-funded. After an initial boom in the post-independence period, funds for graduate training fell off, so relatively few scientists are now starting their careers – and the need for African scientists to compete and account for funds from many outside donors makes for an unusually large administrative load, so African scientists typically move from research into administration at relatively young ages. (A particularly dramatic case in point is this year's movement of Africa's best-known rice breeder from active research at WARDA to administration at FARA.) Thus the total number of NARS scientists actually working on crop improvement is astonishingly small. On average, there is probably less than one NARS breeder actually working full time on crop improvement for every million farmers [this fact should be verified—ASTI data give only a limited sample; are there other sources?]. And in the IARCs, there are only 76 scientists doing so for all of Africa (DeVries and Toennissen 2001, p. 49), or one per 8.5 million Africans.[12] The total number of researchers is of course much larger, and they may be doing very valuable work, but the amount of crop improvement that occurs is heavily supply-constrained.

Donors have often circumvented the fundamental supply constraint in African science by turning to interventions that require fewer scientists. The small number of African scientists is undoubtedly a major reason why foreign aid typically does not emphasize S&T solutions to Africa's problems: it is far easier to undertake institutional or political kinds of interventions, because such projects can be staffed by people with less education and with a wider variety of backgrounds. But given that new S&T is essential for productivity growth, there is no escaping the need for more PhD-level scientists. These can be "home grown", through long-term training of Africans, but they can also be imported from abroad for full-time work in Africa, through IARCs and long-term projects, or invited to work part-time in collaboration with Africans, through mechanisms such as USAID's CRSPs.

Although the short-term priorities identified in this paper do not address the supply constraint on African science, doing so should be a major long-term priority for WARP in its FY04 and FY05 activities. Providing more scientists is inherently a regional issue, since PhD-level scientists routinely move from country to country to find the best opportunities in their specialty. Thus it is appropriate for USAID's human-capacity investments to be managed at a regional level. Furthermore, it is appropriate for USAID to support training in the context of collaborative programs that bring U.S. scientific capacity to bear on African problems, so that research and training are done simultaneously. This can be done in CRSPs, but it can also be done through other contracting mechanisms such as USDA cooperative agreements and RFAs for longer-term partnerships. These should focus on the delivery of specific subject-matter S&T activities, such as genetics or crop protection, allocated across crops and regions in proportion to their relative output shares.

[12] Of these, DeVries and Toennissen report that almost half (35) are employed by IITA, 15 are at ICRISAT, 9 at WARDA, and the balance spread between CIAT, CIMMYT and CIP.

3.9 Implementation and the flow of innovation

A crucial question in implementation is whether public-sector S&T institutions successfully respond to farmers' and public needs – and how appropriate or well-adapted the research results really are. The concept of a linear flow from basic to applied research to production and marketing, as illustrated in Figure 1a below, has been substantially modified by the development of increasingly sophisticated scientific methods to something that looks more like Figure 1b.

Increasingly, high-level "basic" researchers are able to take end-user needs into account, and are being asked to do so. And typically, the technologies developed by high-level "basic" researchers are embodied in inputs and used, almost unchanged, by farmers – after field trials are used to establish which of many possible techniques works best under each circumstance. A few of the resulting technologies are have appropriable benefits and can be marketed in the private sector, while many others can be disseminated effectively only by public-sector institutions.

In any case, it is only if information on the socio-economic value of the innovations translates into public funding of research that the cycle of innovation and technical change can continue. Without a sustained flow of research, testing and delivery of innovations from public institutions, private-sector productivity cannot grow.

Figure 1a. Traditional view of technology development and transfer

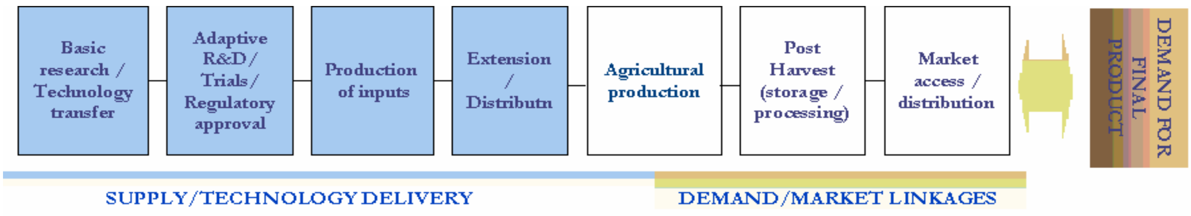
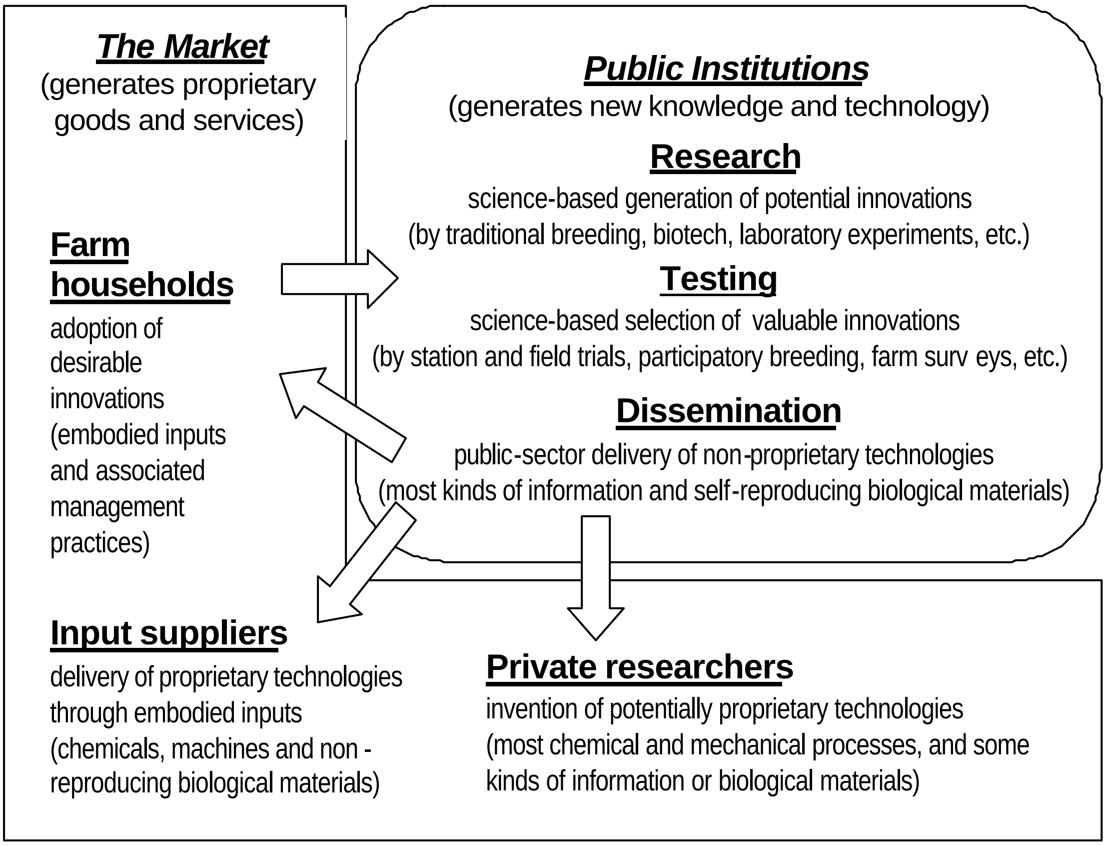


Figure 1b. A new view of Science-based innovation and technology delivery



Bibliographical References

Unpublished documents consulted and available from the author on request

AFR/SD/ANRE, 2001. SO15 Annual Report (Draft). Manuscript revised June 2001 by Michael Johnson.

African Development Bank, "Agriculture And Rural Development Sector, Bank Group Policy." January 2000.

Alhassan, Walter S., "Agro-biotechnology Application in West and Central Africa – 2002 Survey Outcome." Manuscript revised September 2002. International Institute of Tropical Agriculture, Ibadan, Nigeria

CGIAR, "A Multi-Country Agricultural Productivity Program (MAPP) for Africa." Draft issues paper. Document no. AGM02/6/iii. Washington, DC: CGIAR, October 16, 2002.

Faye, Mbene, "Use of Agricultural Biotechnology to Improve Gain from Cowpea Production in Senegal." Purdue University Department of Agricultural Economics, 2000.

Johnson, Michael and Peter Hazell, "Cutting Hunger in Africa Through Smallholder-Led Productivity Growth." Washington, DC: IFPRI, August 23, 2002.

Lambert, Dayton and Mavuangi Khonde, "Seed Sector Challenges for Bt Cowpea in West Africa," Bean/Cowpea CRSP. Purdue University, Department of Agricultural Economics, September, 2002.

Ndjeunga, Jupiter and Bonny R. Ntare, "Research and development options to reduce poverty and hunger by 2015." Draft for discussion (no date).

Ouendeba, Botorou, Tahirou Abdoulaye, and John H. Sanders, "Food Staples in West Africa: Production and Marketing. A Concept Note" Manuscript revised November 2002.

Shapiro, Barry I. and John H. Sanders, "Natural Resource Technologies for Semi-arid Regions of Sub-Saharan Africa." Manuscript revised June 2001.

Stryker, J. Dirck, "Opportunities and Obstacles for Biotechnology in West African Agriculture." Manuscript revised August 8, 2000.

USAID Africa Bureau, "West African Regional Program (WARP) FY2003 Results Review and Resource Request," April 13, 2001.

USAID Africa Bureau Regional Strategy Team, "Strategic Plan FY2001–2008 for the West African Regional Program (WARP)." March 2000.

USAID/WARP, "West Africa Regional Program Annual Report 2002." Released July 1, 2002.

Workshop on a Collaborative Platform for Agricultural Research in Sub-Saharan Africa. ISNAR, WARDA and CTA, March 2001.

World Bank, Africa Region, "Empowering Farmers in Sub-Saharan Africa: Best Practices." *Findings*, no. 33. Africa Technical Department, February 1995.

References Cited (published)

Abdoulaye, Tahirou and J. Lowenberg-DeBoer, "Intensification of Sahelian Farming Systems: Evidence from Niger," *Agricultural Systems* 64: 67-81, 2000.

Alston, Julian, George Norton and Phil Pardey, *Science under Scarcity: Principles and practice for agricultural research evaluation and priority setting*. Ithaca, NY: Cornell University Press, 1995.

Bauer, Peter T., *West African Trade: A Study of Competition, Oligopoly and Monopoly in a Changing Economy.* New York: Cambridge University Press, 1954.

Berkowitz, Daniel, Katharina Pistor and Jean-Francois Richard, "Economic Development, Legality and the Transplant Effect," *European Economic Review* 47(1): 165-195, 2003.

Dalton, Timothy J. and William A. Masters, "Pasture Taxes and Agricultural Intensification in Southern Mali" *Agricultural Economics*, 19(1-2): 27-32, 1998.

DeVries, Joseph and Gary Toenniessen, Securing the Harvest Biotechnology, Breeding and Seed Systems for African Crops. New York: CAB International, 2001.

Easterly, William and Ross Levine, "Tropics, Germs, and Crops: How Endowments Influence Economic Development." NBER Working Paper No. 9106. Cambridge: NBER: August 2002.

Fisher, Monica G., Rebecca Warner and William A. Masters, "Gender and Agricultural Change: Crop-Livestock Interaction in Senegal", *Society and Nat. Resources*, 13(3, 2000): 203-222.

Galor, Oded and David N. Weil, "The Gender Gap, Fertility, and Growth," *American Economic Review*, 86(June 1996): 374-387.

Gisselquist, David, John Nash, and Carl Pray, "Deregulating the Transfer of Agricultural Technology: Lessons from Bangladesh, India, Turkey, and Zimbabwe." *World Bank Research Observer* 17(2002): 237-265.

Jones, William O., *Manioc in Africa.* Stanford: Stanford University Press, 1959.

Jones, William O., *Marketing Staple Food Crops in Tropical Africa.* Ithaca: Cornell University Press, 1972.

Kazianga, Harounan and William A. Masters, "Investing in Soils: Field Bunds and Microcatchments in Burkina Faso", *Environment and Development Economics*, 7(3, July 2002): 571-591.

Masters, William A., Touba Bedingar and James F. Oehmke, “The Impact of Agricultural Research in Africa: Aggregate and Case Study Evidence”, *Agric. Econ.*, 19(1-2, 1998): 81-86.

Masters, William A. and Margaret S. McMillan, "Climate and Scale in Economic Growth" *Journal of Economic Growth*, 6(3, Sept. 2001): 167-186.

McMillan, Margaret S. and William A. Masters, “An African Growth Trap: Production Technology and the Time-Consistency of Agricultural Taxation, R&D and Investment”, *Review of Development Economics,* forthcoming 2003.

North, Douglass C., *Institutions, Institutional Change and Economic Performance.* New York: Cambridge University Press.

Sanders, John H. and Barry I. Shapiro, “Crop Technology Introduction in Semi-arid West Africa: Performance and Future Strategy.” *Journal of Crop Production,* forthcoming (manuscript revised March 6, 2002).

Zougmoré, Robert, Daniel Kaboré and J. Lowenberg-DeBoer, “Optimal Spacing of Soil Conservation Barriers: Example of Rock Bunds in Burkina Faso,” *Agronomy Journal* 92:2 (2000)

Annexes

Annex Table 1. Relative importance of key food products in Africa, 1961 and 2000

	1961 (population 208 million)				2000 (population 605 million)			
	Prod'n.	Food availability			Prod'n.	Food availability		
	(kg)	(kg)	(cal.)	(protein)	(kg)	(kg)	(cal.)	(protein)
Grand total			2059	53			2226	54
Vegetable products			1918	42			2087	44
Animal products			141	11			140	11
Cereals - excl. beer	146.2	112.0	46.1%	47.7%	120.5	123.7	47.5%	50.9%
Rice (milled equivalent)	10.1	9.3	4.5%	3.8%	12.4	17.7	7.8%	6.6%
Maize	43.6	31.8	13.4%	13.7%	47.4	40.1	15.7%	16.4%
Millet	31.6	22.4	8.6%	8.2%	21.0	17.4	6.2%	6.1%
Sorghum	46.3	32.2	13.0%	14.8%	29.4	23.7	8.8%	10.7%
Starchy roots	224.1	157.6	20.5%	7.4%	260.2	163.1	19.7%	8.1%
Cassava	151.4	111.8	14.7%	4.0%	155.0	103.1	12.4%	3.5%
Pulses	14.0	10.2	4.6%	11.8%	12.1	9.5	4.0%	10.5%
Treenuts	1.9	1.3	0.6%	0.6%	1.5	1.0	0.3%	0.4%
Oilcrops	35.3	6.7	3.8%	5.9%	22.0	5.3	2.8%	5.2%
Groundnuts (shelled eq.)	15.4	3.5	2.5%	4.2%	9.3	2.5	1.7%	3.0%
Vegetable oils	8.8	5.4	6.3%	0.2%	7.2	7.5	8.1%	0.2%
Vegetables	33.6	30.6	1.2%	2.7%	32.1	29.7	1.0%	2.2%
Fruit - excluding wine	84.1	54.3	4.6%	1.9%	68.0	48.5	3.8%	1.7%
Bananas	13.2	7.2	0.6%	0.4%	9.6	6.5	0.5%	0.4%
Plantains	43.6	23.3	2.8%	1.0%	34.9	22.0	2.4%	0.9%
Alcoholic beverages	39.0	38.8	2.2%	0.8%	35.3	33.6	1.8%	0.7%
Meat	12.8	12.7	3.0%	10.1%	11.0	11.4	2.5%	8.3%
Beef and veal	6.2	6.1	1.6%	4.8%	4.6	4.6	1.1%	3.5%
Mutton & goat meat	2.3	2.3	0.5%	1.7%	2.1	2.1	0.4%	1.5%
Pigmeat	0.6	0.6	0.3%	0.4%	1.0	1.0	0.4%	0.6%
Poultry meat	1.0	1.0	0.1%	0.6%	1.7	2.0	0.3%	1.3%
Milk - excl. butter	30.7	27.9	2.4%	4.9%	26.9	27.1	2.2%	4.8%
Eggs	1.2	1.0	0.1%	0.6%	1.8	1.5	0.2%	0.7%
Fish, seafood	5.4	5.9	0.5%	3.2%	6.8	7.6	0.7%	4.2%
Freshwater fish	2.6	2.4	0.2%	1.3%	3.0	2.8	0.2%	1.5%

Source: Author's calculations from FAO (2002), Food Balance Sheets <apps.fao.org>.
Note: Protein totals are in grams; calorie and protein shares are expressed as percent of the per-capita totals.
Data shown are for Sub-Saharan Africa as a whole, with considerable variation across countries and regions.

Annexes

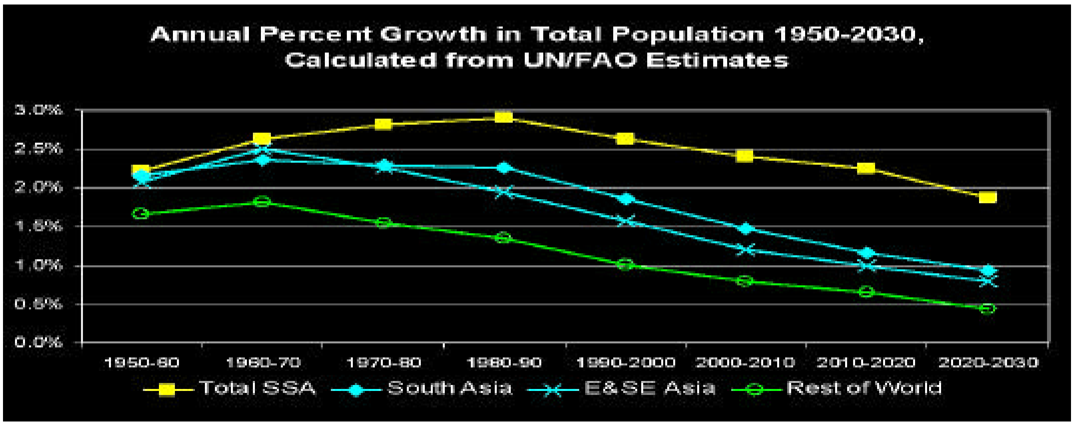
Annex Table 2. (Lack of) Concordance in Mozambique agricultural S&T, 1990s

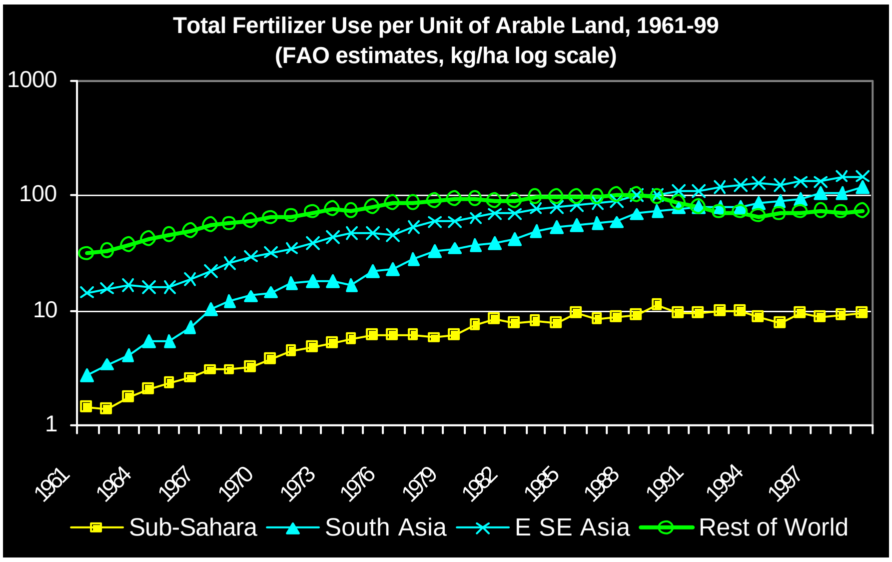
	Share of Agricultural GDP	Share of research expenditure	Research intensity ratio
Cassava	44	15	0.3
Maize	16	12	0.7
Pulses	9	5	0.5
Peanuts	7	5	0.6
Sorghum	6	10	1.6
Rice	4	4	1.0
Cotton	2	15	6.4
Cashew	2	7	3.7
Sweet potato	1	14	14.2

Source: Uaiene, Rafael, 2002. "Priority setting and resource allocation in the National Agronomic Research Institute, Mozambique" (draft, Dec. 2002).

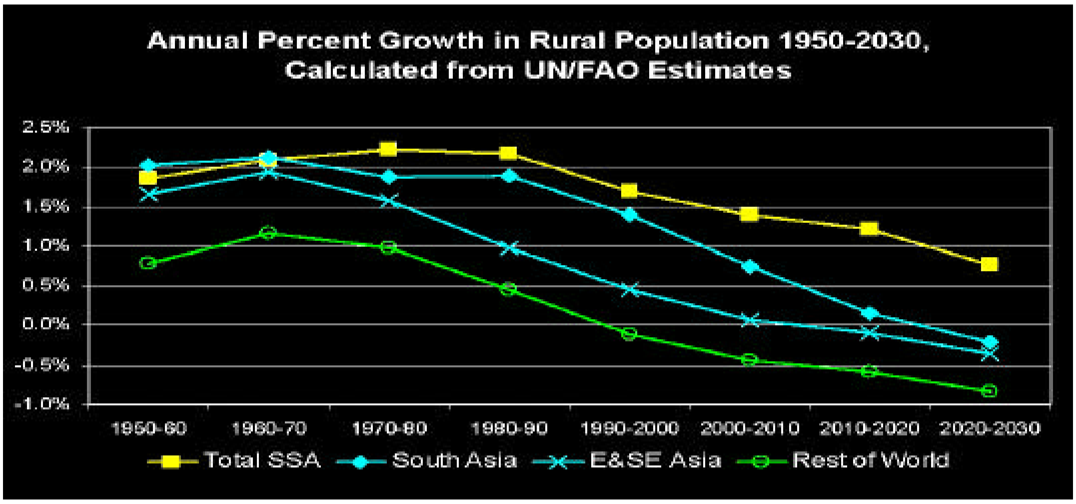
Annex Figures: Annual Percent Growth in Total Population
Total Fertilizer Use per unit of Arable Land
Annual Percentage Growth in Rural Population
Expenditure on Public R&D by Region

Source: W.A. Masters, "Institutions and Technology for Food Security." ACES *Global Connect* Seminar at the University of Illinois, Urbana-Champaign, Oct. 3, 2002.
www.agecon.purdue.edu/staff/masters

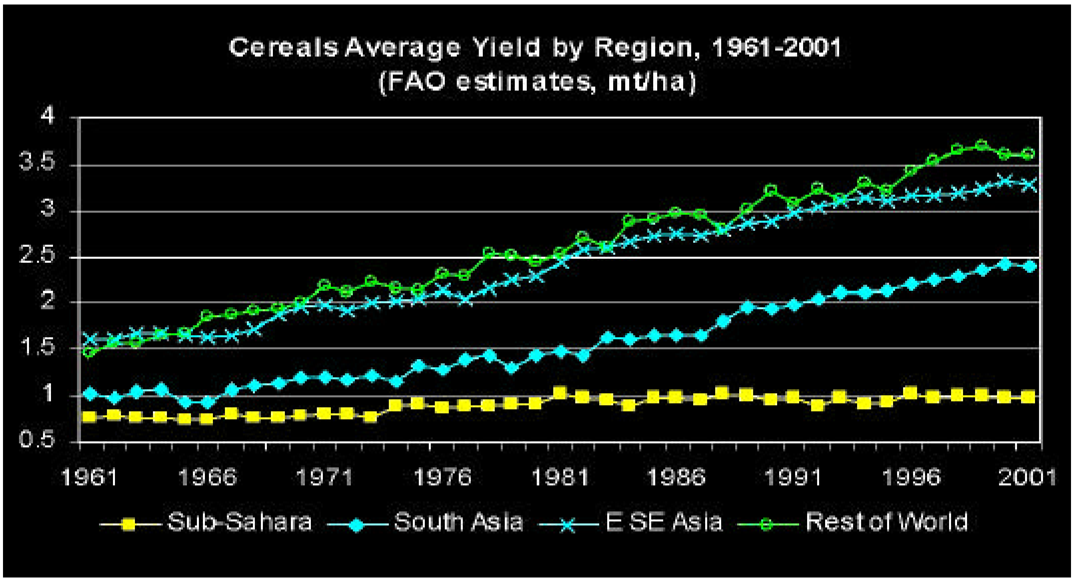


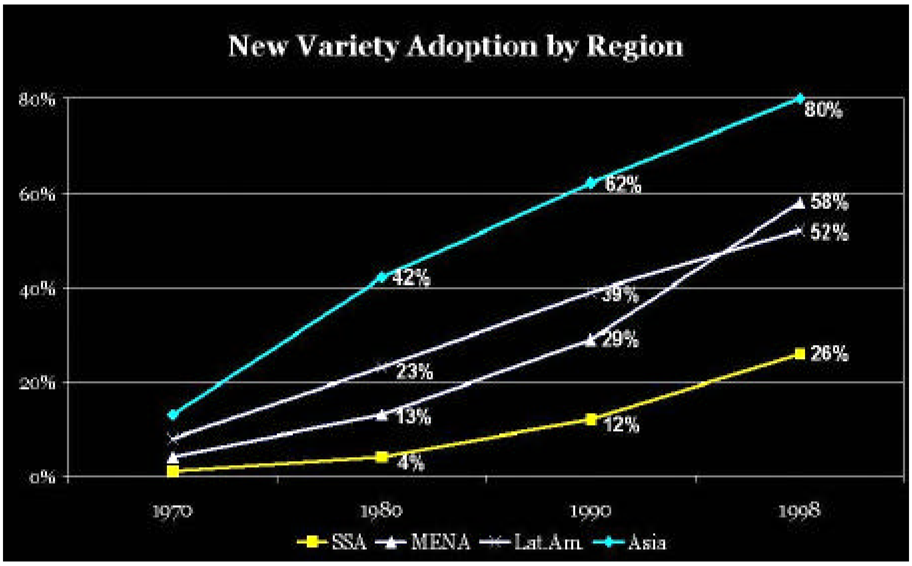


Total Fertilizer Use per Unit of Arable Land, 1961-99
(FAO estimates, kg/ha log scale)
1000
100
10
1
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
Sub-Sahara
South Asia
E SE Asia
Rest of World



Annual Percent Growth in Rural Population 1950-2030,
Calculated from UN/FAO Estimates
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
-0.5%
-1.0%
1950-60
1960-70
1970-80
1980-90
1990-2000
2000-2010
2010-2020
2020-2030
Total SSA
South Asia
E&SE Asia
Rest of World





Source: Calculated from data in Evenson and Gollin, forthcoming 2002.

Expenditure on public R&D by region

	1971	1981	1991
Real US$ (millions)			
World (153 countries)	7,304	11,247	14,966
LDCs (131 countries)	2,984	5,503	8,009
Sub-Sah. Af. (44 co.)	699	927	968
Expenditure growth (%/yr)			
World	4.3%	2.9%	3.6%
LDCs	6.4%	3.9%	5.1%
SSA	2.5%	0.8%	1.6%

Source: Pardey, Roseboom and Craig 1999, p. 56.