Agricultural Biotechnology for West and Central Africa:

A Strategy Document

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Summary

Agricultural biotechnology offers the prospect of dramatic breakthroughs in poverty alleviation and sustainable economic growth across West and Central Africa. The region is in desperate need of improved food crop productivity, which could be achieved with well-targeted investments at a suitable scale. This document aims to inform USAID interventions in this area, with respect to the targeting and the scale of appropriate investments.

The approach described in this strategy document sets investment priorities so as to enhance what farmers, the private sector, and local governments are already doing. Part 1 of the document details the principles used to set priorities, while part 2 provides detailed data to put those principles into practice. An annex provides a separate paper on the scale and institutional mechanisms that might be needed for Africa as a whole.

The strategy proposed here begins with *concordance* and *probabilities of success*, to characterize the technologies needed by the region's farmers and most likely to be developed through R&D; and then considers *complementarity* between the particular investments contemplated by USAID and the innovations that others are likely to develop in response.

The strategic implications of this approach are that, if agricultural biotechnology investments are to be focused, some of the most worthy targets would be maize for the whole region, plus sorghum and millet for drier regions and cassava for the humid tropics. In the cereals, the principal challenge is to embed biotechnology in the development of hybridization programs for maize, sorghum and millet, magnifying the value of specific biotech traits by inserting them in a broader range of improved varieties, and then developing the seed-multiplication systems needed for dissemination. In cassava, there are already well-established programs pursuing disease resistance and other traits, but they face an even greater need for public-sector dissemination since cassava planting material is more difficult to spread than cereal-crop seeds.

The targets suggested here do not exclude other activities, but they are poor peoples' crops that have been neglected in Africa and yet have experienced sustained productivity growth in South Asia and elsewhere. In raising their productivity, biotechnology can help raise the payoff to farmers' investments of labor, land and purchased inputs, without which growing numbers of rural people will remain trapped in a cycle of resource degradation, worsening poverty, and social instability.

Agricultural Biotechnology for West and Central Africa: A Strategy Document

This document is intended to inform the strategic interventions by which the United States government could help reduce poverty in West Africa, through targeted investments in agricultural biotechnology. Such interventions, if undertaken at a sufficient scale, can be expected to make a major contribution to political stability and sustainable economic growth across West and Central Africa.

Part 1 of the document sets out some general principles to help target USAID biotechnology investments, while Part 2 provides detailed data on the nature and magnitude of the region's agricultural technology agenda. An annex provides a separate paper on the broader context for this agenda in Africa as a whole. The document makes no attempt to summarize the state of agricultural biotechnology research or farmers' adoption of biotechnologies, which has been amply documented elsewhere (e.g. Cabanilla, Sanders and Baquedano 2004), and makes no attempt to document the state of African R&D systems which has also been the subject of extensive study (e.g. DeVries and Toenniessen 2001); the purpose of this document is to compute and present data from outside the research system, to inform the biotechnology agenda and facilitate the strategic targeting of new investments.

With appropriate targeting and sufficient scale, agricultural biotechnology can help African farmers overcome the obstacles they face and achieve their development goals through higher real farm incomes, improved nutrition and health, and more sustainable use of the region's fragile natural resources. Success requires not only the creation and spread of improved production technologies, but also more favorable policies and institutions at the local and global scales. The analysis presented here focuses on R&D investment, in part because those are the choices at hand, but also because the dissemination of new technologies will help improve the payoffs to policy change and institutional development. McMillan and Masters (2003) documents the interaction between farmers' technological opportunities and governments' policy choices, showing how improved technologies have been associated with better governance in Africa. More responsive technologies have and will continue to make it more likely that those more favorable policies will be instituted, initiating a virtuous cycle of self-sustained economic growth.

1. Principles for priority-setting

The targeting of investments begins with careful analysis of what farmers, the private sector, and local governments are already doing, so as to complement those activities and avoid either a duplication of effort or a substitution of one funding source for another. To determine exactly what data we want to look for, it is useful to consider what principles might help us in targeting new investments.

The most complete recent analysis of priority-setting in research is the textbook of Alston, Norton and Pardey (1997); various applications of the methods they propose have been used across the African continent. An early summary of many case studies of actual R&D impacts in West Africa is provided in Masters, Bedingar and Oehmke (1998), and these methods were used in a sequence of seven regional workshops across West and Central Africa as summarized in Masters and Ly (2003). These case studies attest to the practical importance of the principles sketched below. Our summary of their implications for agricultural biotechnology in West and Central Africa begins with the general principle of concordance subject to researchers' odds of success, and then considers the degree to which USAID's particular research investment successfully complements rather than duplicates or substitutes for others' work.

1.1 Concordance and researchers' odds of success

Perhaps the most general principle for successful priority-setting is *concordance* between R&D investments and the resource allocation decisions of farmers in the target region, subject to the researchers' *probabilities of success* in the light of breakthroughs that may have been achieved elsewhere. Concordance implies that the size of R&D investments should be proportional to the size of the target; in particular, the magnitude of USAID's investments in agricultural biotechnology should be proportional to farmers' own investments of their labor, land and other assets. By the concordance principle, if a given farming system occupies 20% of target farmers' assets or produces 20% of their revenue, it should also occupy 20% of the R&D budget.

The rationale for concordance is that total impact is directly proportional to the size of the system affected by a new technology. A great technological success that is adopted in a small system will have a small impact, perhaps smaller than even a marginal improvement that is adopted over a very large system. If one had *no* other information about the probabilities of success, and no differences in the expected payoff for each dollar of R&D investment in raising the productivity of farmers' assets, then the principle of concordance would provide an exact guide to the optimal investment portfolio. In reality, of course, one might have some information about the odds of success, which should be used to modify the concordance principle. Those considerations will be discussed below, but first it is important to consider some of the other reasons why the principle of concordance is not followed in practice.

An example from outside of the West and Central Africa region illustrates the problem, and allows us to discuss the principles involved without having a specific interest in the outcome. Table 1, drawn from a recent study in East Africa, shows each major crop's share of farm output and of national R&D expenditure, and the ratio between them. In that country, the most important crop, cassava, turns out to be among that country's most important subjects of research – but almost as much research attention is devoted to cotton and sweet potato, which are much less important for farmers. Only rice receives exactly the same share of R&D as its contribution to output.

The research intensity ratio captures the degree to which a given target is favored by researchers, and the pattern of resource allocation shown in Table 1 turns out to be fairly typical. Research managers tend to follow concordance only to a very limited degree, and tend to favor particular targets in systematic ways. In particular, aggregate R&D budgets are typically much less concentrated than is farmers' investment. In the example shown, two crops (maize and cassava) account for more than half of all farm income, whereas researchers give roughly equal attention to four or five different crops.

Table 1. Concordance and the allocation of R&D investment in Mozambique (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).

There are several common reasons why crops may be of more importance to researchers than to farmers. Most generally, research is not easily divisible, so simply maintaining a presence in a given area often implies giving it a disproportionate fraction of all resources. This problem is especially acute for the very small programs that are widespread in Africa; for example, in a program with five PhD-level scientists, to have one of them work half-time on a project occupies 10% of its top staff. And there are many reasons why research programs should be called on to do *something* in a given area, all of which may pull them away from doing *enough* in the areas that are most important to farmers. These might include a desire to address crops that are exported or highly visible in the marketplace, a desire to work in areas that are of particular interest to scientists or donors, and of course a desire to serve particular geographic areas and political constituencies.

Perhaps the most fundamental reason for a lack of concordance with farmers' priorities is that farmers have relatively little ability to influence research resource allocation. Farmers tend to be geographically dispersed, and in low-income settings they tend to be the poorest people in society, whose resources are devoted mainly to locally consumed staple foods which do not appear in markets. The lowest income farmers' activities have low productivity, but are still the best use of their household's very limited resources. In effect, farmers have voted with their effort, indicating what is most important to them. The principle of concordance is often the best way for researchers to listen to farmers. Indeed, if farmers' preferences were the *only* information available to researchers, there would be no justification for any resource allocation other than concordance.

One important feature of concordance for R&D strategy is that it remains valid even if commodities differ in their market prospects, demand conditions and supply response. Technological improvements in a staple food such as cassava, for example, rarely produce large increases in total production, because demand is relatively fixed and transportation is costly, so increased production leads to large price declines and consumption needs are met with a smaller area planted. Similarly, technological improvements in resource-constrained systems such as semi-arid agropastoralism or rainforest cultivation rarely produce large increases in their total output, because supply response is constrained by low moisture or fragile soils.

Whatever the reason for limited expansion, technological improvement allows consumption needs to be met with less use of scarce resources, and the economic gains from this change are proportional to the size of the system *before the innovation occurs*. Gains do not depend on increased sales or a growing market for the target commodity in that region; indeed, a major purpose of such research is to help people escape from subsistence-production/resource-degradation poverty traps, by helping them meet their nutritional needs with fewer resources, so they can invest the savings in other activities such as livestock, schooling, and eventual out-migration to regions with a more elastic supply of valuable resources.

The use of concordance to predict the economic gains from innovation applies only to social or *economic* gains, of course: the private profitability of investments in new technologies depend very heavily its market prospects, which is an important reason why the technologies most needed by poor people are often not produced or disseminated in the private sector. Even when the total market size of what the poor people are producing is very large, private investors may ignore it because it will not grow – whereas public-sector innovations could be valuable precisely because they help it to shrink. Private investors naturally focus on growth prospects, whereas concordance helps public-sector decision-makers focus on market size.

The validity of concordance for public-sector R&D does not depend on "picking winners" in terms of market prospects, but it does depend on picking winners in terms of what productivity gains might be achievable through research. Concordance would yield an optimal research portfolio if researchers had no information about differences in the probability of research success, but by definition researchers do have more information than farmers about certain things. In particular, what trained researchers typically have is knowledge about the kinds of technological breakthroughs that have previously occurred in other environments, and the kinds of R&D methods by which those breakthroughs were achieved. Thus, even where the final technology itself is not appropriate, specialized researchers can reconstruct the innovation pipeline, produce entirely new technologies using similar R&D methods. In a sense, concordance itself provides a static "snapshot" of farmers' resource allocation at the present time. Strategic targeting of research priorities begins there, and adds a forecast of how R&D could accelerate the process of technological catch-up and convergence to the technological frontier established by previous R&D efforts in other regions.

1.2 Complementarity between USAID's investments and others' actions

The principle of concordance, subject to researchers' odds of success, describes the optimal R&D portfolio for *all* innovative activity. The most effective strategy for a particular funder such as USAID may not be to "follow the herd", however. There is information value in knowing what others are doing, but for maximum impact it is also important for USAID to consider its differences from other actors in the innovation system, to ensure that its investments complement rather than duplicate or displace the investments that would otherwise be made by farmers, local communities, the private sector and other actors.

To the extent that USAID's distinctive perspective includes an interest in the long-run welfare of all Africans, its targeting strategy should include examining data from across the continent to see what regions and which people are currently being *most neglected*, relative to the magnitude of human needs. USAID's investments can then be tailored to meet those needs as quickly as possible. The rationale for targeting pockets of poverty is that, by definition the people in those areas have few resources of their own, have been unable to migrate to regions with more resources, and have been unable to attract much inward investment from elsewhere. Targeting incremental investments to those otherwise-neglected locations helps to unlock the economic potential of those people, and offer them a sustainable way out of poverty.

Even within the otherwise-neglected areas, it can be very valuable to focus on otherwise-neglected activities, to offer innovations and investments that have had a high payoff in other perhaps-similar regions but are not yet available to farmers in the target region. Strategic targeting in this sense can begin at the farm level, by recognizing that rural households and local communities are constantly experimenting with the resources at their disposal, adjusting their use of labor, land, livestock and other locally-available inputs to meet their evolving needs. Similarly, entrepreneurs within Africa and outside are constantly looking for opportunities to invest in potentially proprietary, marketable enterprises. Thus, the crucial task for outside intervention is to focus on that which local people and entrepreneurs cannot do, including in particular science-based R&D to develop improved crop varieties and other technologies that require long-distance and large-scale exchange of ideas and materials, and whose value is demonstrable but cannot be captured by a private entrepreneur.

For example, at the farm level all across West Africa one can observe farmers making unprecedented investments of labor and locally-available materials in soil and water conservation. This type of change arises from farmers' own learning process in response to changing circumstances. There is abundant evidence that farmers experiment continuously with the resources they have, imitate successful neighbors and adopt profitable innovations quickly as long as they have reasonably well-defined user rights over the resources involved (for a detailed study of this process in Burkina Faso, see Kazianga and Masters 2001). As a result, without additional resources it turns out to be difficult for anyone to improve on the farmer's own choices with respect to actions such as seeding rates, planting dates, crop mix, field preparation and weeding practices, the use of mulch, manure and compost, or the construction of field-level soil and water catchments. These are actions for which the requisite inputs and resulting outputs are visible to the farmer, who is highly motivated to make appropriate choices.

Since farmers' circumstances are constantly changing, outside observers must constantly monitor and understand what choices farmers are making if they are to diagnose the nature of the obstacles that farmers face and provide appropriate new technologies. Agricultural biotechnology in particular can improve the genetic material embodied in plant varieties, to change how plants respond to farmers' investments and change the investment opportunities available to entrepreneurs in the emerging private sector. Once developed, these technologies are often embodied in 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.

Some final inputs are themselves not proprietary or marketable, because they generate large "spillover" gains after adoption. To facilitate adoption of this kind of technology, the public sector must reach all the way 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 they will be delivered slowly if at all.

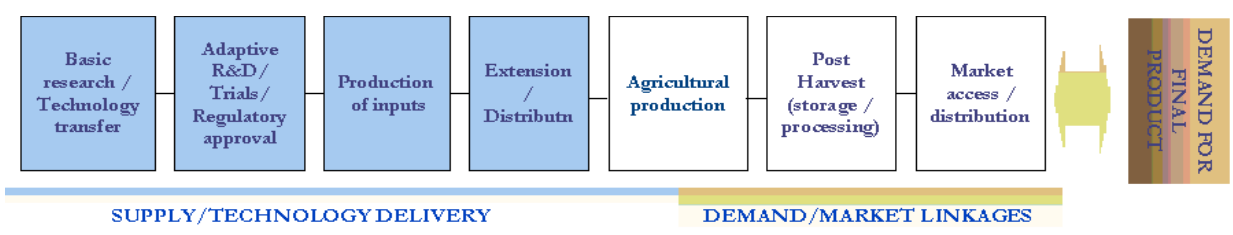
One fundamental obstacle to private-sector delivery for most genetic improvements is that farmers in a particular location need to buy the improved variety only once -- and thereafter the farmers in that location can retain and share among neighbors. Thus, introducing an improved seed to a particular 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.

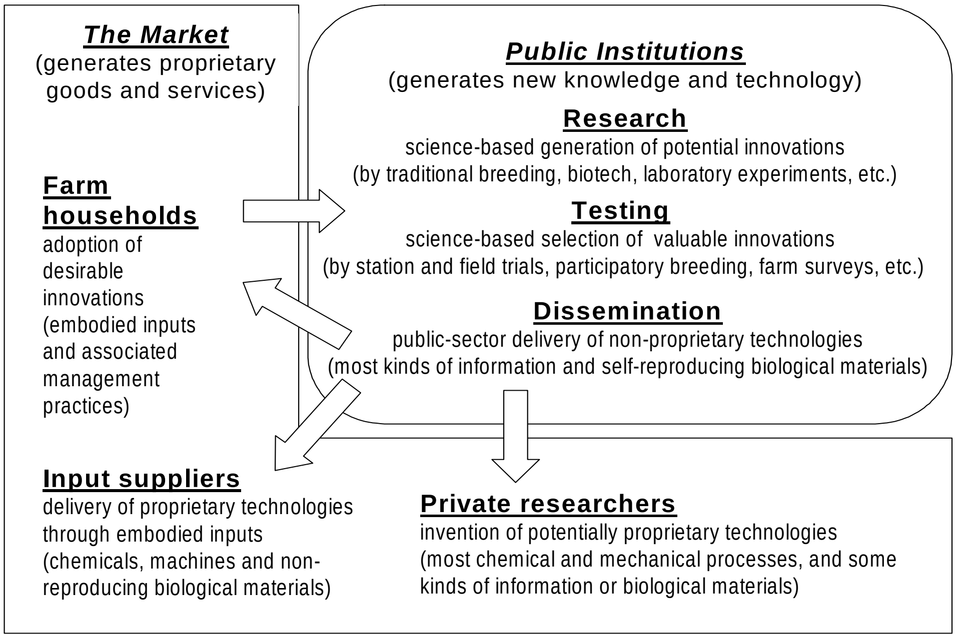
A crucial question in implementation is whether public-sector R&D institutions successfully respond to farmers’ and public needs – and how appropriate or well-adapted the research results really are. The concept of a linear flow from basic to applied research to production and marketing, as illustrated in Figure 1a below, has been substantially modified by the development of increasingly sophisticated scientific methods to something that looks more like Figure 1b.

Figure 1a. Traditional view of technology development and transfer



Source: DFID (RETF Phase 1 Report).

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



When moving from the linear model of Figure 1a to the "embedded" model of Figure 1b, it is necessary for science-based researchers to do more to take end-user needs into account, partly because the technologies developed by more "basic" researchers are increasingly being directly embodied in the inputs adopted by end-users. The next part of this report turns to the data at hand, to characterize what technologies are most needed, what productivity gains are most likely to be achieved, and what would R&D investments are most likely to complement what others are already doing.

2. Data and results

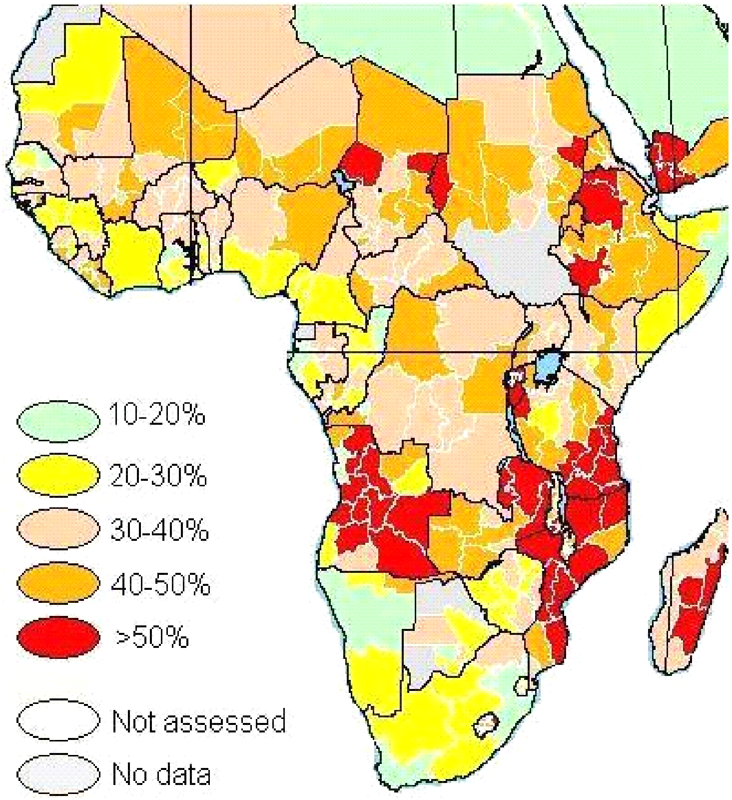
The criteria for targeting sketched above, along with the underlying economic principles detailed in the textbook by Alston, Norton and Pardey (1997), as applied in many West Africa case studies summarized in Masters, Bedingar and Oehmke (1998) and Masters and Ly (2003), provide a useful roadmap to guide to which data are most needed to way to suitable. The relevant data begin with a map to see where USAID's investments might best complement others' actions (or inaction), and then drill in to examine concordance across commodities, and productivity changes over time to examine opportunities for technological catch-up.

2.1 Geographic targeting and the spatial pattern of investment

One of the clearest measures of where Africans are most in need of productivity-enhancing investment is provided in Figure 2, showing the spatial pattern of child stunting across Africa. The incidence of stunting is a strong signal of local productivity relative to need, because adequate nutrition for young children is an almost universal human priority. Children become stunted only after a fairly long period of extreme deprivation. Child stunting serves as a clear, unambiguous record of the depth and persistence of a family's poverty, and the recent surveys including particularly the USAID-funded DHS data allow comparability across countries and, in many cases, across regions within countries.

The data shown in Figure 2 show a remarkable association between child stunting and climatic patterns within Africa. The areas where more than 50% of children are known to be stunted are located along two belts around 10º North and 10º South of the equator, between Chad and Ethiopia in the north and between Angola and Tanzania to Madagascar in the south. The Sahel region and Central Africa contain a large fraction of regions where more than 40% of children are stunted. And generally, it turns out that the east side of Africa is relatively more deprived than the west, and the region within the geographic tropics (roughly 25º north or south of the equator) is relatively more deprived than Northern Africa or the southern tip of the continent.

Figure 2. Prevalence of stunting in Sub-Saharan Africa (latest available, includes sub-national data)



Source: Redrawn from data compiled by the FAO's Poverty and Food Security Mapping Project, using the most recent Demographic and Health Survey (DHS) data from ORC Macro, Multiple Indicator Cluster Survey (MICS) data from UNICEF, WHO survey data and national government estimates.

Note: Data shown are the percentage of children aged 0-5 whose height for age is at least two standard deviations below the NCHS standard for their age.

The prevalence of stunting gives us some indication of the location of most extreme poverty towards which USAID might target its productivity enhancement efforts. For a more detailed picture of the significance and variation in this kind of deprivation, Table 2 provides data on the progression of stunting as children grow, from each country in the West and Central Africa region for which there exist DHS data. These data also include infant and child mortality rates from those countries where stunting data were not collected.

Table 2. Stunting and mortality among infants and children in West Africa

	Infants (0-12 months)			Children (up to 5 years)				
	Pct Stunted			Percent Stunted				
	0-6 mo.	6-12 mo.	Infant mortality	1-2 yrs.	2-3 yrs.	3-4 yrs.	4-5 yrs.	Child mortality
Benin 1996			10.35					18.39
Benin 2001	5.6	11.4	9.48	39.1	37.2	36.8	38.6	16.27
Burkina Faso 1992/93	4.6	14.3	10.76	39.9	42.6	40.6	43.4	20.45
Burkina Faso 1998/99	5.0	14.8	10.86	45.1	46.4	50.8	46.0	22.41
Cote d'Ivoire 1994			9.13					14.99
Cote d'Ivoire 1998/99	8.2	13.0	11.15	29.1	25.2	29.1	35.0	17.43
Ghana 1988	4.7	13.1	8.09	33.2	42.4	50.0		15.38
Ghana 1993			7.47					13.28
Ghana 1998	2.9	8.8	6.12	27.0	27.5	37.3	35.1	11.04
Guinea 1999	7.0	14.1	10.66	33.0	32.2	34.2	31.3	19.51
Liberia 1986			15.25					23.09
Mali 1987	6.9	16.7	13.12	31.0	33.2	43.0		27.83
Mali 1995/96			13.35					25.22
Mali 2001	5.4	19.5	12.62	45.5	48.9	47.9	41.4	23.82
Mauritania 2000/01	6.4	18.0		41.5	36.1	44.4	43.8	
Niger 1992	7.4	22.2	13.45	49.4	52.7	53.4	42.9	32.62
Niger 1998			13.58					30.26
Nigeria 1990	11.9	22.7	9.16	44.4	53.3	55.3	52.8	19.13
Nigeria 1999			7.07					13.33
Ondo State 1986		10.9	5.70	32.2	47.1	29.8		11.00
Senegal 1986		8.6	9.09	27.2	28.4	37.5		21.06
Senegal 1992/93	5.7	13.6	7.61	27.7	31.3	30.0	30.7	15.69
Senegal 1997			6.94					13.94
Togo 1988	7.3	23.4	8.40	37.4	36.6	40.0		15.97
Togo 1998			8.03					14.38

Source: Compiled from Demographic and Health Survey data, available online from www.measuredhs.com.
Note: Data show the percentage of children whose height for age is less than two standard deviations below the NCHS reference, and the percentage of children who died before their first birthday (for infant mortality) or their fifth (for child mortality).

Looking across the rows of the DHS data reveals how stunting rates become progressively worse as children develop and experience greater cumulative nutritional deficits. Including the rates of child mortality as well as child stunting underscores the close connection between the two, and reminds us that the stunting data refer only to those children who have survived. Even where stunting rates are comparatively low, in the 30-40% range, an additional 10-20% percent of children have died before age five.

The DHS data provide clear evidence that nutrition and health status generally improved in the 1990s – although these improvements were not nearly fast enough to reduce the absolute number of stunted children in the region, and separate data show continued increases in that number throughout this period due to the rapidly rising total size of the at-risk population. The proportional rates clearly worsened in only one surveyed country, Burkina Faso. There is some evidence of worsening in Cote d'Ivoire and in Mali, which has the unusual situation of worsening incidence of stunting while child mortality rates improve. This could be the result of compositional changes (e.g. more child survival among children who were not malnourished in the past, and/or more malnutrition among the poorest children who are most likely to die).

2.2 Concordance and the commodity composition of investment

For USAID investments to help farmers meet the needs highlighted above, it is helpful to target the cropping systems that farmers themselves have chosen. Figures 3 and 4 provide a strong indication of African farmers' priorities and resource allocations, in terms of each crop's share of farmers' total production of dietary energy and protein. These data are derived from the FAO food balance sheet, converting metric tons of farmgate production into comparable units. The underlying data are reproduced in Annex 1, and are shown for Africa as a whole, for West Africa and for Central Africa, contrasting the 1961 and 2002 shares.

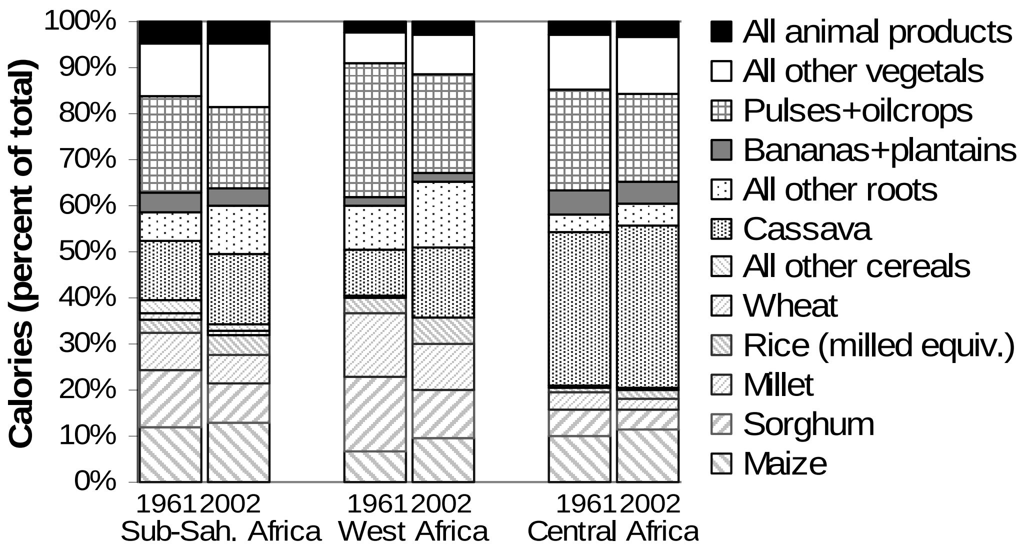
The contribution of each crop to total calorie and protein output captures their relative economic importance to farmers very well – much better than market data, since most of this output is in fact consumed on-farm. The crops' shares of total consumption are slightly different due to the importance of imported cereal grains: wheat and rice together account for 15% of consumption, but only 5% of production.

One remarkable finding in these data is the growing importance of both cassava and other root crops, for all three regions – particularly when measured in terms of dietary energy. These crops have unusually low protein content, however.

Another remarkable point is the spread of maize, which has displaced sorghum as the single most important food produced across Africa as a whole, and in the relatively humid countries of Central Africa is now more important than sorghum and millet combined. In the West Africa region, however, both sorghum and millet continue to be more widely produced than maize.

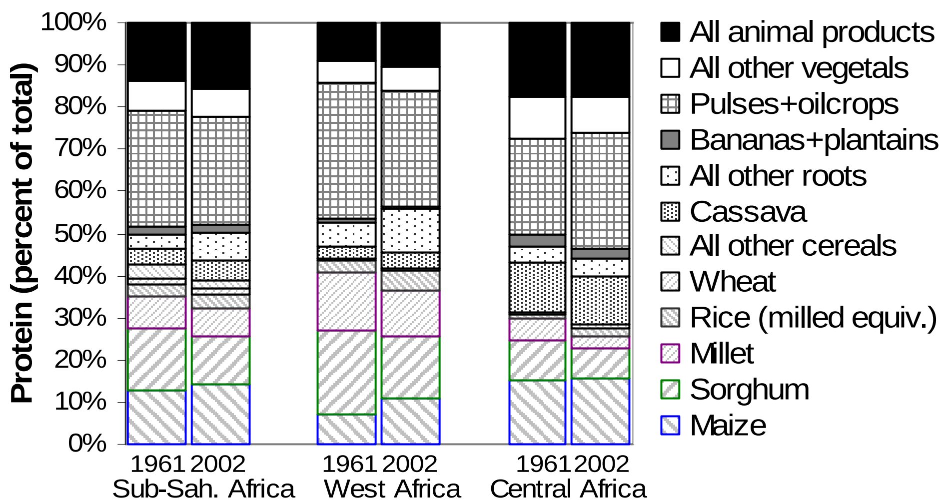
Finally, it is important to note the very large share of pulses and oilcrops. Africa, and West Africa in particular, is actually a net exporter of this class of commodities, and their production share is larger than their consumption share, but crops such as cowpea, groundnuts and sunflower are remarkably well-adapted to Africa's low-moisture, labor-abundant production systems.

Figure 3. Share of food production by crop, 1961 and 2002



Source: Calculated from data in FAOStat (2005), reproduced in Annex 1.

Figure 4. Share of protein production by crop, 1961 and 2002

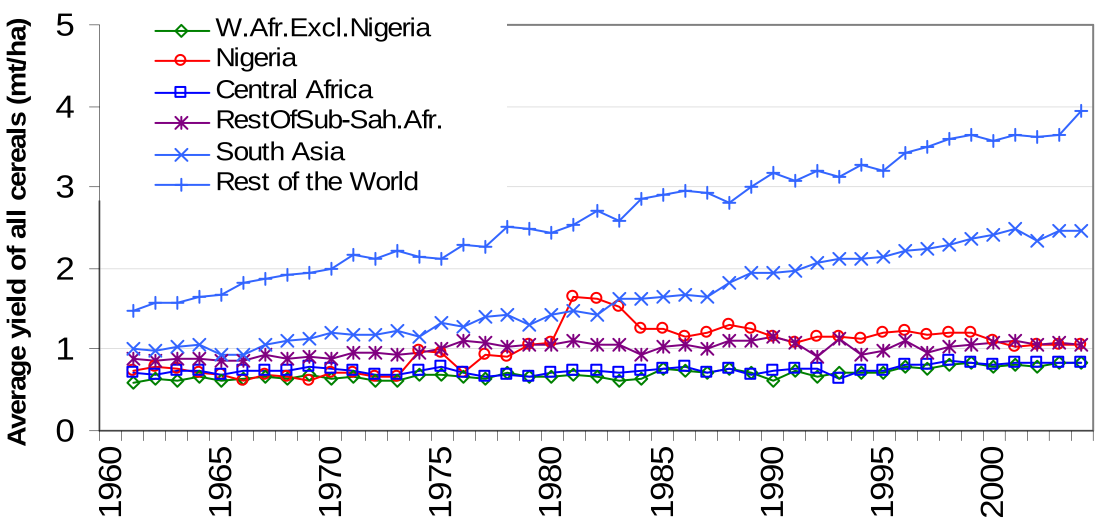


Source: Calculated from data in FAOStat (2005), reproduced in Annex 1.

2.3 Odds of success and technological catch-up
If R&D investments were informed *only* by farmers' priorities, then Figures 3 and 4 would provide sufficient evidence for targeting. But researchers have access to information about the technological breakthroughs that are possible elsewhere. Figures 5-10 provide a useful perspective on the region's avoidable technological lags, by comparing FAO estimates of the average crop yield for major crops over time and across regions. In particular, the figures all compare Central Africa, West Africa excluding Nigeria and then Nigeria, with the rest of Sub-Saharan Africa, South Asia, and the rest of the world. The Nigeria data are omitted from some graphs because they are too variable or otherwise not meaningful, and the rest-of-world data are omitted where the differences in farming systems obviate any comparison.

Figure 5 shows average yields for the sum of all cereal grains. South Asia had somewhat higher yields than Africa in the 1960s, but since then has experienced steady growth paralleling that of the rest of the world. Africa *could* join that growth club. These data refer to an aggregate of several different crops -- some of the yield increase comes from switching among species, e.g. from small grains to maize, and some comes from switching among varieties, e.g. from traditional to improved varieties and hybrids, and in both cases a large part of the value of changing genetic "blueprint" is that doing so makes it more profitable to add additional inputs such as more labor in weeding or soil and water conservation, as well as more fertilizer and other purchased inputs.

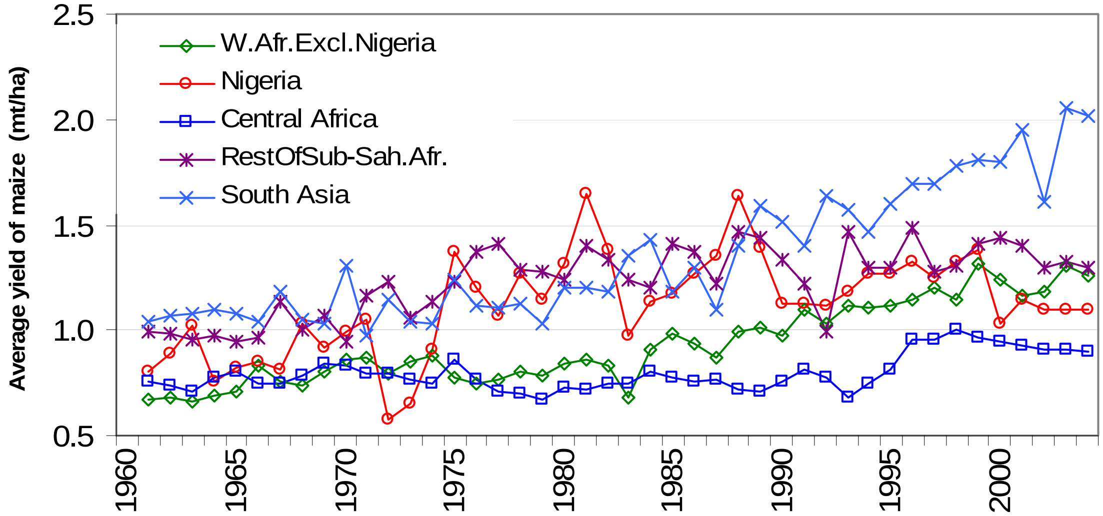
Figure 5. Average yield of all cereals by region, 1961-2004



Source: Figures 5-10 calculated from FAOStat (2005) data

The data below disaggregate the cereal crops, into maize yields (Figure 6) and millet yields (Figure 7). What is most noticeable about the maize productivity data is that African maize yields have grown rapidly, paralleling the growth in South Asia, since 1983 in West Africa outside Nigeria, and since 1993 in Central Africa – but in both cases the growth has stalled since 1997-98. Clearly there is enormous potential for maize improvement to be sustained over time as it has been elsewhere, through a chained sequence of hybrids and associated growth in the use of other inputs.

Figure 6. Average yield of maize by region, 1961-2004



The comparable picture for millet is shown in Figure 7. Here, the African countries have experienced yield growth only very recently after 2000, whereas South Asia has shown some sustained growth since 1985.

Figure 7. Average yield of millet by region, 1961-2004

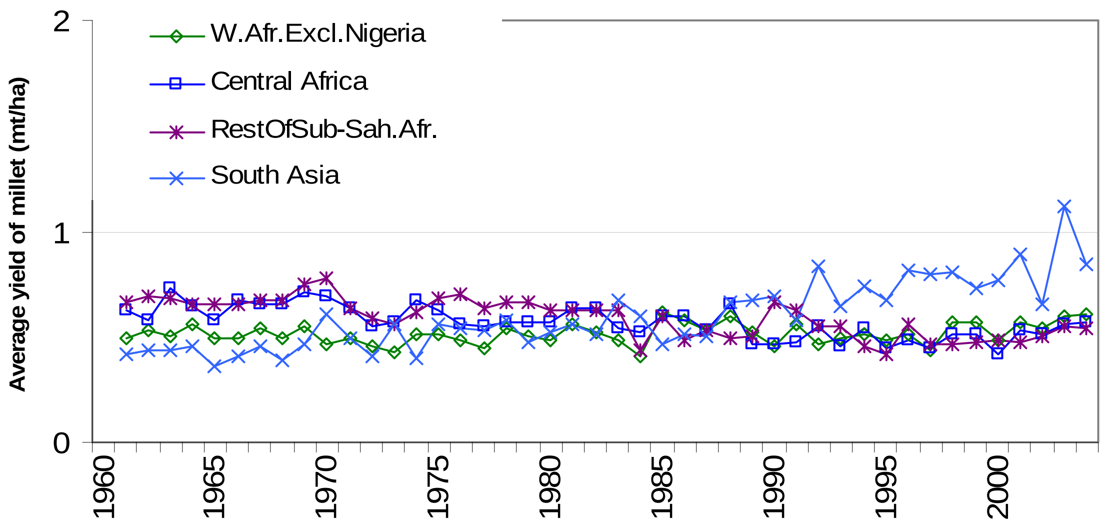
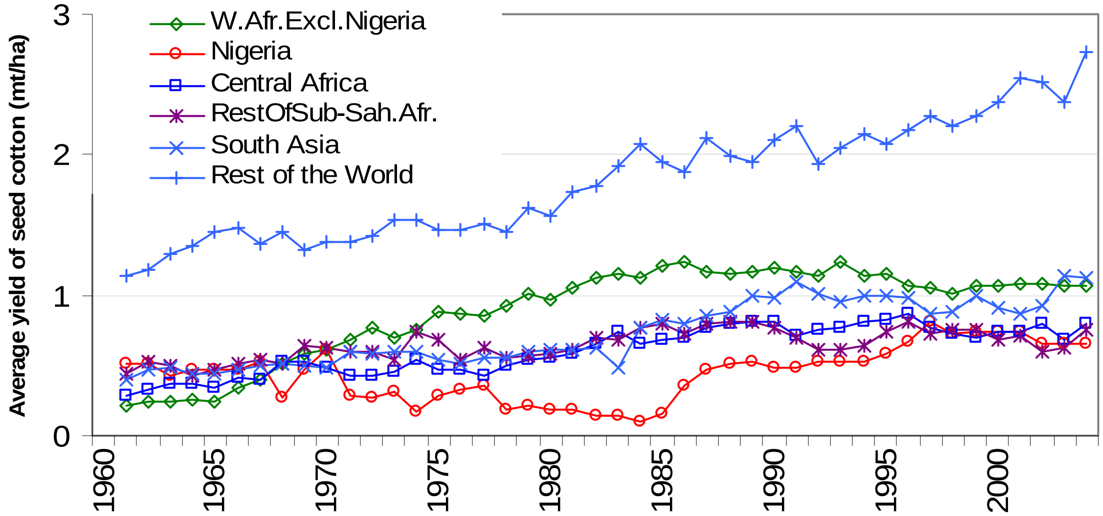


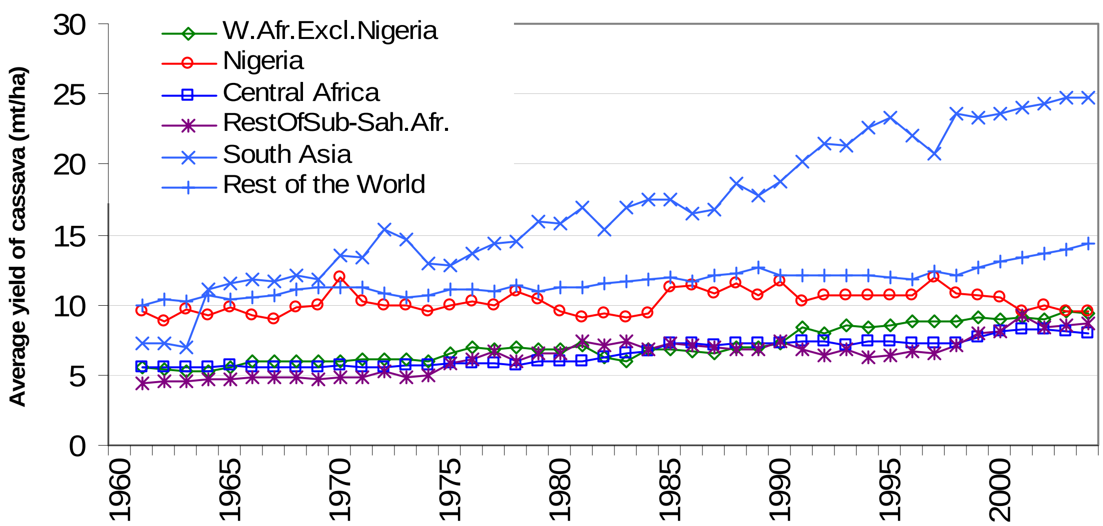
Figure 8 shows similar data for seed cotton, where Africa has done comparatively much better than South Asia – until recently, when its yields stopped increasing while other regions' kept improving.

Figure 8. Average yield of seed cotton by region, 1961-2004



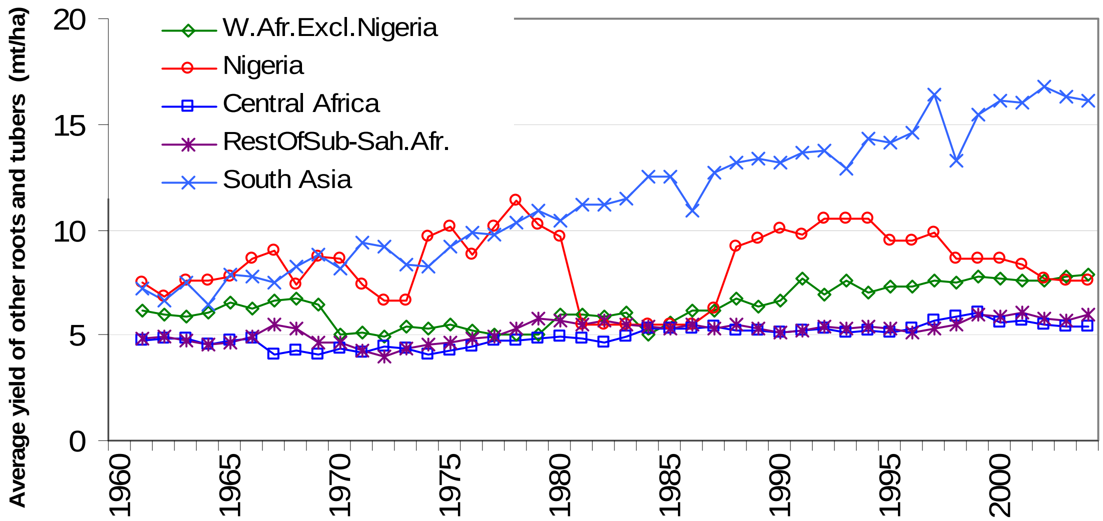
The situation with root crops, shown in Figures 9 (for cassava) and 10 (for all others combined) is quite distinct. In the case of cassava, yields have grown gradually since the 1970s, but much more slowly than the growth that occurred in South Asia, and without significant growth over the past five years.

Figure 9. Average yield of cassava by region, 1961-2004



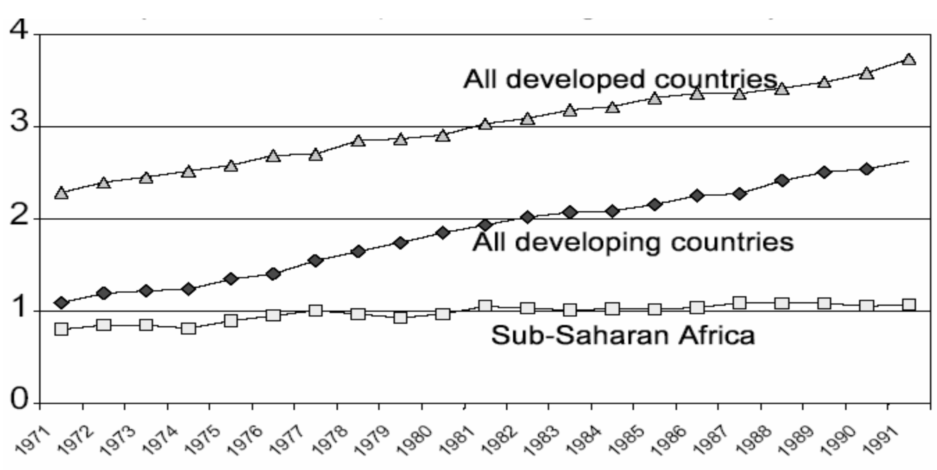
With the other root crops shown in Figure 10, growth in Africa has been more sporadic, but again growth in South Asia has been steady and very dramatic.

Figure 10. Average yield of other root crops by region, 1961-2004



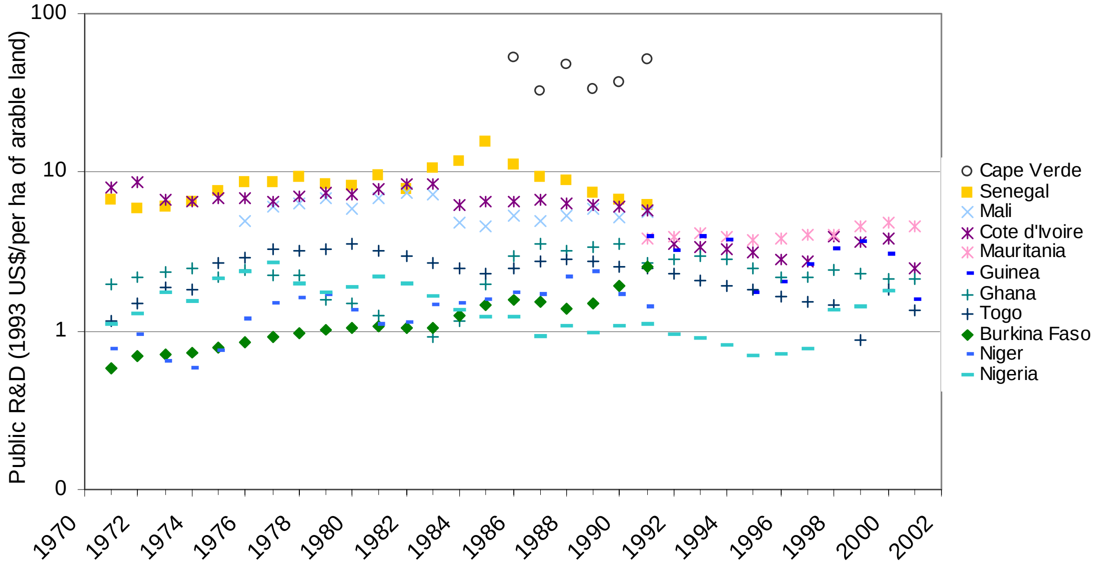
The FAO estimates of average yields, like all such data, are subject to considerable error and can only be taken as suggestive. But what they suggest is extremely plausible, due to the comparative neglect of agricultural R&D investment for Africa in the past. Figure 11 summarizes the available data on this for the 1971-91 period. Comparable data were collected during the 1990s for a much smaller number of countries; these are shown in Figure 12. Clearly, public R&D investments in African agriculture were low and stagnant relative to R&D investments elsewhere, contributing to slow growth in crop productivity.

Figure 11. Public agricultural R&D per unit of agricultural land, 1971-91 (1985 PPP dollars per hectare)



Source: Calculated from IFPRI and FAOStat file data

Figure 12. Agricultural R&D intensity in West and Central Africa, 1971-2001



3. Conclusions: scaling up the impact of R&D

Once appropriate mechanisms for targeting R&D have been instituted, the next priority is to scale up the flow of investment so that the technologies they produce can reach the millions of dispersed, resource-poor farmers who need them. Huge impacts have been achieved in Asia through 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. The exact same technologies as were adopted in Asia can rarely be adopted in Africa, but a similar process of science-based crop breeding and R&D for other techniques, followed by multiplication and dissemination of those results, can generate similar impacts.

The scale of investment needed, as well as the institutional mechanisms by which that investment might best be channeled, has been amply discussed elsewhere; one particular paper is attached as an annex to this report. What is clear from the data presented here is that a careful targeting of agricultural biotechnology to the crops that are most important to the poorest people, and have shown that they can sustain rapid growth in other regions, can and will have a dramatic impact in the African context.

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Annex Table 1. FAO Food Balance sheet data on sources of food by crop, 1961 and 2002

	Sub-Saharan Africa (51 countries)				West Africa (17 countries)				Central Africa (9 countries)			
Year (Population)	1961 (208.5 m.)		2002 (637.1 m.)		1961 (77.4 m.)		2002 (238.2 m.)		1961 (32.4 m.)		2002 (97.4 m.)	
	Cal.	Prot.	Cal.	Prot.	Cal.	Prot.	Cal.	Prot.	Cal.	Prot.	Cal.	Prot.
Total estimated food available	2123	53.2	2270	54.1	2210	52.7	2626	59.6	2267	44	1925	39
Percent of food available												
Maize	13%	13%	14%	16%	7%	8%	8%	10%	11%	15%	12%	16%
Sorghum	13%	15%	8%	10%	18%	23%	10%	14%	6%	9%	4%	6%
Millet	8%	8%	6%	6%	16%	16%	10%	11%	4%	5%	2%	3%
Rice (milled equivalent)	4%	4%	8%	7%	5%	5%	12%	11%	1%	1%	4%	4%
Wheat	3%	3%	7%	9%	1%	2%	5%	7%	1%	2%	6%	8%
All other cereals	4%	4%	2%	2%	1%	1%	0%	0%	0%	0%	1%	1%
Cassava	14%	4%	12%	4%	9%	2%	10%	3%	40%	13%	33%	10%
All other roots	6%	3%	7%	4%	8%	5%	9%	6%	5%	4%	4%	3%
Bananas + plantains	3%	1%	3%	1%	3%	1%	2%	1%	5%	3%	3%	2%
Pulses, oilcrops + veg.oils	14%	18%	15%	17%	18%	13%	17%	15%	12%	19%	17%	20%
All other vegetals	11%	7%	12%	6%	11%	8%	12%	7%	11%	9%	10%	6%
All animal products	7%	20%	6%	19%	4%	16%	4%	17%	4%	21%	5%	22%
Percent of farm-level production												
Maize	12%	13%	13%	14%	7%	7%	9%	11%	10%	15%	11%	16%
Sorghum	12%	15%	9%	12%	16%	20%	11%	14%	6%	9%	4%	7%
Millet	8%	8%	6%	6%	14%	14%	10%	11%	4%	6%	2%	3%
Rice (milled equivalent)	3%	3%	4%	4%	3%	3%	5%	5%	1%	1%	2%	2%
Wheat	1%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%
All other cereals	3%	3%	2%	2%	1%	1%	0%	0%	0%	0%	1%	1%
Cassava	13%	4%	15%	5%	10%	3%	15%	4%	33%	12%	35%	12%
All other roots	6%	4%	10%	7%	9%	6%	15%	10%	4%	4%	5%	4%
Bananas + plantains	4%	2%	4%	2%	2%	1%	2%	1%	5%	3%	5%	3%
Pulses, oilcrops + veg.oils	21%	28%	18%	26%	29%	32%	21%	28%	22%	23%	19%	27%
All other vegetals	12%	7%	14%	7%	7%	5%	9%	6%	12%	10%	12%	9%
All animal products	5%	14%	5%	16%	3%	9%	3%	10%	3%	18%	4%	18%

Source: Computed from FAOStat (2005), <apps.fao.org>.

Note: The Western Africa region is: Benin, Burkina Faso, Cape Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Saint Helena, Senegal, Sierra Leone, Togo. The Central Africa region is: Angola, Cameroon, Central African Republic, Chad, Dem. Rep. of Congo, Congo, Equatorial Guinea, Gabon, Sao Tome and Principe.

ANNEX (30 PAGES)

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Paying for Prosperity: How and Why to Invest in Agricultural R&D for Development in Africa

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for *Journal of International Affairs*, Spring 2005
Special issue on *Finance Challenges of the Millennium Development Goals*