

Evolving a plant breeding and seed system in sub-Saharan Africa in an era of donor dependence



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A report for the Global Partnership Initiative for Plant Breeding Capacity Building

**Prepared by John Lynam, with assistance from Elon Gilbert, Howard
Elliot and Fred Bliss**

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Abbreviations and acronyms

AfricaRice	Africa Rice Center
AET	agricultural education and training
AGRA	Alliance for a Green Revolution in Africa
AISP	Agricultural Inputs Subsidy Program (Malawi)
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
AVRDC	The World Vegetable Center
CAADP	Comprehensive Africa Agriculture Development Programme
CARDESA	Centre for Agricultural Research and Development for Southern Africa
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture
CIDA	Canadian International Development Agency
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	Centre for International Cooperation in Agricultural Research for Development (France)
CORAF/WECARD	West and Central African Council for Agricultural Research and Development
CRI	Crops Research Institute (Ghana)
CRSP	Collaborative Research Support Program
DARS	Department of Agricultural Research Services (Malawi)
DFID	Department for International Development (UK)
DGIS	Netherlands Directorate-General for International Cooperation
DTMA	Drought Tolerant Maize in Africa (initiative)
EAAPP	East Africa Agricultural Productivity Program
EARRNET	Eastern Africa Root Crops Research Network
ECABREN	East and Central Africa Bean Research Network
ECAMAW	Eastern and Central Africa Maize and Wheat Research Network
ECARRN	Eastern and Central African Rice Research Network
ECOWAS	Economic Community of West African States
EU	European Union
FAAP	Framework for African Agricultural Productivity
FARA	Forum for Agricultural Research in Africa
FIAAC	Fund for the Improvement and Adoption of African Crops
FLAR	Latin American Fund for Irrigated Rice
GDP	gross domestic product
G×E	genotype by environment (interaction)
GGDP	Ghana Grains Development Project
IARC	international agricultural research centre
IFAD	International Fund for Agricultural Development
IITA	International Institute of Tropical Agriculture
INGER	International Network for Germplasm Evaluation in Rice
IRD	Institut de recherche pour le développement
IRRI	International Rice Research Institute
KAPP	Kenya Agricultural Productivity Programme

KARI	Kenya Agricultural Research Institute
KSC	Kenya Seed Company
MAPP	Multi-Country Agricultural Productivity Program
MAS	marker-assisted selection
NARI	national agricultural research institute
NSCM	National Seed Company of Malawi
OPV	open-pollinated variety
PABRA	Pan-Africa Bean Research Alliance
PASS	Programme for Africa's Seeds Systems (AGRA)
QPM	quality protein maize
RCoE	regional centres of excellence
RIU	Research Into Use (DFID)
ROCARIZ	West and Central Africa Rice Research and Development Network
RTIP	Root and Tuber Improvement Programme
RTIMP	Root and Tuber Improvement and Marketing Programme
SABRN	Southern Africa Bean Research Network
SACCAR	Southern African Centre for Cooperation in Agricultural Research and Training
SADC	Southern African Development Community
SAFGRAD	Semi-Arid Food Grains Research and Development project
SARI	Savannah Agriculture Research Institute (Ghana)
SARRNET	Southern Africa Root Crops Research Network
SDC	Swiss Agency for Development and Cooperation
SIDA	Swedish International Development Cooperation Agency
SPAAR	Special Programme for African Agricultural Research
SRO	subregional organization
STAM	Seed Trade Association of Malawi
TIP	Targeted Inputs Program (Malawi)
USAID	United States Agency for International Development
vBSS	Vegetable Breeding and Seed Systems (AVRDC)
WAAPP	West African Agricultural Productivity Program
WECAMAN	West and Central Africa Maize Network

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Executive summary

Because of the complexity of crop breeding in sub-Saharan Africa, the dependence on public sector institutions in producing improved varieties, the often constrained capacity of public sector institutions and reliance on donor funding for operational capacity at national, subregional and continental level, this report argues for better integration of breeding capacities within what might be termed a plant breeding and seed system for sub-Saharan Africa. A plant breeding system conceived at a continental level both captures the scale economies inherent in plant breeding but also meets the requirements of local adaptation so critical in low-input farming systems. To achieve this there will need to be changes in institutional arrangements at national, subregional and continental level and greater coherence in donor funding of plant breeding on the continent. To substantiate this argument, the report reviews the history and current status of plant breeding and seed-system development on the continent. This is done by focusing on plant breeding in rice, maize, cassava, beans (*Phaseolus vulgaris*) and vegetables and reviewing plant breeding capacity in Ghana, Kenya and Malawi based on the most important crops in each country.

However, subregional breeding networks are also reviewed, as is the development of breeding programmes of the international agricultural research centres (IARCs) of the Consultative Group on International Agricultural Research (CGIAR). All of these are primarily funded by international aid and funding priorities have shifted over time, with significant impacts on capacities at all three levels as well as on their functional integration.

Since the Asian Green Revolution, plant breeding has been seen as a core capacity in agricultural research institutes, and as such is in many ways an important indicator of both overall capacity in national agricultural research institutes (NARIs) and the productivity of those institutes. Compared with most other technical innovations, improved crop varieties are relatively easy to track through the research and extension system to adoption by farmers. That said, NARIs in sub-Saharan Africa face challenging capacity and budgetary constraints and wide-ranging demands on a relatively limited capacity. This produces a complicated investment problem where NARIs must decide for which crops to develop a crossing and selection programme (rather than just a testing system for imported varieties), for how many agro-ecologies to develop crossing and evaluation programmes for a given crop, and how much genetic variation to develop and evaluate within a crossing programme. Organized spill-ins of either finished varieties or segregating materials will significantly influence these investment choices, which makes regional and international breeding capacity important in how NARIs invest in and organize

their breeding capacity. A number of principal conclusions are drawn in the report that support the argument for the development of a more integrated and sustainable plant breeding capacity for sub-Saharan Africa. These are set out in summarized form below.

The scope of the breeding challenge requires both scale economies in prebreeding and decentralized capacity necessary for local adaptation. Increases in agricultural productivity are essential in achieving agricultural growth and reduction in rural poverty in sub-Saharan Africa. Improved crop varieties are one important component in achieving such increases in yields. Nevertheless, plant breeding in sub-Saharan Africa presents a daunting challenge given the agro-ecological heterogeneity, the relatively low level of input use, underdeveloped input markets, the dependence on the public sector in producing and disseminating new crop varieties, and the crop diversity from plot to national level. Successful spill-ins of improved varieties have been rare, and have been largely restricted to horticultural crops where input use is high. The history of plant breeding in Africa in the post-independence period has demonstrated the critical importance of developing germplasm pools adapted to the broad array of yield constraints under African conditions as well as varieties locally adapted to farmer requirements. The evolution of plant breeding capacity on the continent has been towards CGIAR centres developing prebreeding populations in target ecologies, relying on scale economies, drawing on traits from molecular breeding programmes at headquarters, and depending on developing finished varieties through decentralized crossing and testing programmes in national programmes. However, functional integration at these three levels was rarely achieved due to shifting priorities in donor support to agriculture in general and plant breeding in particular.

Donor support for developing national agricultural research capacity, including plant breeding capacity, in the 1980s and early 1990s shifted to broader rural development programmes and agricultural research through regional approaches. Few African governments have had the resources to invest in long-term support to agricultural research, especially given the more pressing immediate needs in the sector and the relatively low level of the budget invested in agriculture. In the 1980s through the early 1990s, donors invested both directly in building capacity in newly formed, autonomous NARIs and through the well-funded capacity building programmes and subregional crop research networks of the CGIAR centres. This was also a period of investment in overseas training of scientists and the improvement in capacity was reflected in the release of a significant number of crop varieties and their uptake by farmers. In the 1990s the focus shifted to policy reforms under structural adjustment and market liberalization, with an attendant decline in support to agriculture and particularly agricultural research. The practicality of supporting myriad small agricultural research institutes gave way to donor support for subregional approaches through the subregional organizations (SROs). Initially the focus was on achieving greater coherence across the research networks in each of the regions, but in the last five years the SROs developed their own programme structures, primarily around competitive grants, and donor support to the CGIAR research

networks largely vanished, except for a few important cases. Competitive grants are not well suited to the needs of an ongoing breeding programme and at the same time the links between CGIAR breeding programmes and national programmes were cut in a large number of cases. However, the entry of the Bill and Melinda Gates Foundation as a significant donor to agricultural research in Africa, the creation of the Alliance for a Green Revolution in Africa, the structural reform of the CGIAR and the consolidation of the Comprehensive Africa Agriculture Development Programme process all offer potential for moving toward a more integrated plant breeding system for Africa.

International and regional breeding capacity is not a substitute but rather a very strong complement to plant breeding capacity at the national level in Africa, even in small and medium-sized countries. The objective of any breeding programme is to produce adapted germplasm with the requisite complement of priority traits that meet the needs of farmers. The issue in a resource constrained environment is how to organize the breeding effort to attain the cost efficiencies in large-scale breeding efforts with the requirements in Africa for significant local adaptation to farmer needs. Various models have been used in subregional breeding networks in attempting to achieve these two objectives through closer integration between CGIAR breeding programmes and evolving capacity in national programmes. The following models have been developed:

1. Centralized cultivar development: The IARC programme develops fixed lines and these are either tested in a regional variety trial or integrated into the national performance trials of individual countries. For countries with a crossing programme, varieties may enter as a parent, but that is relatively inefficient compared to the provision of nurseries and populations.
2. Centralized crossing and dispersed selection: This model is particularly used in rice and is especially useful when priority traits are common to a region but their combination will vary across markets or production systems. Thus, the Africa Rice Center (AfricaRice) can feed traits from wide crosses into its crossing block and work with a significant range of genetic variability, but then the early generations undergo selection across a wide range of conditions in national programmes.
3. A division of labour across multiple breeding projects: This derives primarily from the bean breeding model used at the International Center for Tropical Agriculture (CIAT). Traits such as colour and grain size, where preferences vary by country, must be segregated into different breeding populations and these in turn combined with disease and pest resistances specific to principal agro-ecologies. Each national programme can thus concentrate on the market type most demanded in their country but draw on varieties for more minor market types or agro-ecologies from other countries.
4. Centralized population breeding supporting national crossing and selection programmes: Such a model appears to be particularly applicable to sub-

Saharan Africa, at least in terms of the combinations of traits that need to be assembled for particular agro-ecologies. Such prebreeding within broad agro-ecologies could feed directly into national crossing and selection programmes or into the other three models, depending on capacity at the national level. This model is being pursued in the International Potato Center's sweet potato breeding programme.

Capacity to produce foundation seed is one of the principal limiting constraints in linking breeding programmes to evolving capacity in the seed sector. There is only an emergent private seed sector in sub-Saharan Africa; the vast majority of seed is provided by the informal sector and the public sector supports much of the formal seed sector, outside of hybrid maize and vegetable seed. However, a persistent gap exists in the multiplication of foundation seed, due to lack of clear lines of authority for this activity, budgetary constraints, lack of follow-through by plant breeders after the variety release process, and the lack of sufficient land and irrigation capacity. This lack of clear responsibility for foundation seed production is being further confused by the attempts to make this a private-sector activity, when market size is not sufficient to attract private-sector entry. In many cases the IARCs have had to fill this vacuum, just to ensure that new varieties start to move through the seed system.

Private-sector seed companies are developing, especially in East and southern Africa, but they must now operate in an uncertain policy environment with the recent introduction of input subsidies. Market liberalization in the 1990s, moves towards regional harmonization of quarantine and seed policies, and access to an increasing array of varieties from the IARCs have provided the preconditions for the formation of an increasing number of domestic seed producers. Most of these have developed their market around hybrid maize and must compete with established international (Pioneer and Monsanto), regional (SeedCo and Pannar) and national (Kenya Seed Company) companies but providing an increasing range of well-adapted hybrid maize varieties is finding increasing markets, increasingly to smallholder farmers. However, the relatively recent introduction of input subsidies across a large number of countries is impacting market development, especially where governments procure through a tendering system (which favours open pollinated varieties and undercuts market competition) and do not allow farmer choice in accessing subsidized seed. The Agricultural Inputs Subsidy Program in Malawi is increasingly being recognized as a model for developing "smart" subsidies that at the same time promote the development of private-sector-based input markets.

Introduction

In no other region in the developing world is plant breeding more difficult, less resourced and more needed than in sub-Saharan Africa. Some indication of the difficulty inherent in successful plant breeding in Africa is that by 2000 only about 22 percent of the food crop area was planted to improved varieties, half of these developed by centres of the Consultative Group on International Agricultural Research (CGIAR) and the other half from national agricultural research system (NARS) programmes and others (Maredia and Raitzer 2006). This is well below other regions in the developing world (Table 1). However, the structure of the economies in Africa are still agrarian, where the agricultural sector employs 65 percent of the labour force and accounts for 32 percent of gross domestic product (GDP) (World Bank 2010). The majority of cultivated land is planted to food crops, and growth in production is still primarily dependent on area expansion, although many countries are now facing limits on the availability of cultivable land. Growth in food production did not match growth in population for much of the 1980s and 1990s. However, agricultural GDP growth in sub-Saharan Africa has accelerated from 2.3 percent per year in the 1980s to 3.8 percent per year from 2000 to 2005 (World Bank 2010), which is still not high enough for sustained economic growth for economies so dependent on agriculture. With yields of African food crops being some of the lowest in the world, increased productivity is one necessary step to increased agricultural growth.

Table 1. Agricultural productivity growth by region and contribution of plant breeding.

	Share of area planted to modern varieties (percent) ^a				Contribution of crop genetic improvement to yield growth ^b	Cereal yield (kg per hectare) ^c	Average annual growth in cereal yield (percent) ^d	Average annual growth in food production per capita (percent) ^e
	1970	1980	1990	1998				
Asia	13	43	63	82	0.88	3.662	2.3	2.30
Latin America	8	23	39	52	0.66	2.09	1.9	0.90
Middle East and North Africa	4	13	29	58	0.69	2.660	1.2	1.00
Sub-Saharan Africa	1	4	13	27	0.28	1.112	0.7	-0.01

Source: FARA (2006).

Plant breeding in an African context

Achieving widespread impact with a few new varieties has a very low probability of success in sub-Saharan Africa, as the context is so very different from that of Asia or Latin America. Agriculture in Africa is almost

completely reliant on rainfed cropping systems – only about 5 percent of arable area is irrigated – more often than not in environments that have relatively high variability in rainfall and where plant nutrients are limiting. This temporal variability together with a plethora of biotic and abiotic constraints is nested within a high degree of spatial variability. Pardey *et al.* (2007) develop a measure of technological distance defined by agro-ecological conditions and agricultural production, namely the set of principal food crops grown. They found not only that Africa is the most dissimilar to agriculture in the developed world among principal developing regions, thus limiting spill-ins from the significant research capacity in the North, but also that within Africa itself there is a very high level of heterogeneity. The combination of multiple breeding targets within a matrix of environments makes plant breeding particularly complex in an African context. This suggests higher costs of plant breeding in Africa compared with other regions of the world, given the need to breed for more-restricted environments and to incorporate a larger number of breeding objectives into breeding programmes.

This more macro context is then complicated further by the structure of African farming systems. Apart from some areas of southern Africa, agricultural production on the continent is dominated by small-scale farming. Because there are high transaction costs in market participation, there is a significant subsistence component, with marked quality preferences for principal staples. Input markets are equally underdeveloped, and fertilizer usage averages less than 10 kg per hectare. Moreover, because of the significant market and production risks associated with smallholder farming, there is a marked diversity in production patterns. There is not only a mix of food staples, but farmers will also usually maintain a portfolio of varieties that individually do not meet all the production and consumption objectives but together ensure subsistence requirements under risky conditions. This diversification reduces the potential returns to the use of improved practices for particular commodities and more generally inhibits farmer interest in increasing agricultural productivity (Sumberg and Blackie 2004).

The history of variety development in Africa by the CGIAR centres started in the 1970s with testing through international variety trials and the search for broadly adapted varieties. This approach, while successful for wheat under Asian conditions, was found to be highly inefficient for maize under African conditions, where the crop was grown in a range of agro-ecologies under limited input use (Kling 2007). The 1980s was a period in which many of the CGIAR centres developed breeding capacity in Africa that produced adapted germplasm. No centre has had success in breeding without developing African populations and moving them into selection in regional networks. However, the issue of how many environments to breed for in Africa still remains to be fully tested by most centres, as does the issue of how many breeding objectives and selection criteria are necessary to effectively compete with local varieties that have been selected over centuries for adaptation to local conditions. A central question is how differentiated do crop-breeding programmes have to be in order to be successful and at what cost? As an example, Kenya organizes its maize breeding around six distinct agro-ecologies, but is their capacity for such an approach sufficient and what is the

potential for importing materials for some of the less important ecologies? The complexity of the breeding problem in Africa has thus led to a combination of national and regional approaches in the development of adapted varieties, in particular developing specific traits in populations through prebreeding and then feeding these into national breeding programmes. This chapter will evaluate past and current investment approaches to breeding within this framework.

The complexity of breeding in Africa is further compounded by the inherent difficulty of developing commercial seed systems for dominant food staples. Many such food staples are grown in Africa and hybrid technology – the primary basis for development of commercial seed companies – has been limited to maize, and then essentially to East and southern Africa, particularly Kenya and Zimbabwe. Hybrid sorghum and pigeon pea varieties are also possible but have not been used in Africa because of the lack of a well-developed seed system. Other food staples in Africa are either clonally propagated (root crops and *Musa*) or are self-pollinating open-pollinated varieties (OPVs). In areas where commercial horticulture has developed, such as the irrigated areas of the Sahel and the highland areas of East and Central Africa, hybrid seed is also used, but it is generally imported. Developing improved varieties for the food economies of Africa is thus further complicated by the lack of incentives for the development of private seed markets and a dependence on publicly funded approaches in delivering seed of improved varieties to farmers.

Donor support to agricultural research

Agricultural research capacity has been built in sub-Saharan Africa through heavy reliance on donor funding. Foreign aid in support of agriculture overall peaked in the mid-1980s (when measured as a percent of overall aid flows) and has steadily declined since then (Figure 1). Only with the recent spike in food prices has aid to agriculture started to increase again. In general this pattern is also reflected in donor support to national agricultural research (Pardey *et al.* 2007). As Eicher (2001) notes, the 1980s were the golden age for support to agricultural research in Africa. The World Bank made its first loan for agricultural research in 1979 (Sudan). The United States Agency for International Development (USAID), building on increasing work in the area since the late 1970s produced in 1985 its Plan for Supporting Agricultural Research and Faculties of Agriculture in Africa. Specifically designed grants and loans for agricultural research focused on institutional building, particularly in the form of semi-autonomous national agricultural research institutes (NARIs). For many countries, such as Malawi, this was the period when a maize-breeding team was trained and the breeding programme structured, which would lead to the release of the first semi-flint maize hybrids in 1990 (Smale and Heisey 1994).

The downturn in funding to agricultural research in Africa in the 1990s reflected a significant shift in overall funding priorities as well as the approach to funding agricultural research. With declining agricultural budgets, the focus on the part of USAID, and supported through other mechanisms by the World

Bank, shifted very much to regional approaches, in terms of support both to regional research networks operated by CGIAR centres and to the creation of subregional agricultural research organizations. Thus, the Conference of African and French Leaders of Agricultural Research Institutes (CORAF) was established in 1987, followed by the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) in 1994, both modelled on the longer established Southern African Centre for Cooperation in Agricultural Research and Training (SACCAR). Moreover, this was the period of structural adjustment and market liberalization, and donors were concerned about the lack of rapid uptake of new technologies from the investment in agricultural research. Although several impact studies carried out at this time provided evidence of significant impact to these investments (Oemke 1992), these results were overshadowed by growing food deficits and a general lack of economic performance. This was also a period of serious political unrest in several countries in the region. Accordingly, several donors shifted priorities to give greater attention to governance, policies and economic enterprises which it was felt would more directly and expeditiously address the region's major problems. Agricultural research was regarded as an investment that would be less likely to produce the quick results that were critical to turning Africa around.

As part of this shift, USAID in particular gave more attention to markets and value chains, which were felt to be key in stimulating and sustaining economic growth. A 1994 review of USAID support to agricultural research (Christensen 1994) found:

The primary conclusion is that the operation of markets plays a critical role in the adoption of technology. This is true at the micro level, where the issue is economic feasibility for a particular farmer. It is also true at the sectoral level. The most successful cases of technological adoption occur when there are viable internal or external markets.

These viable markets were more likely to be found or developed for export crops than for the major staple foods. Although urbanization was contributing to the growth in markets for staple foods, their production tended to be geographically diffused and variable over time. Most farmers did not routinely produce for the market and many rural residents grew to depend on markets for a portion of their food needs. These conditions militate against the development of reliable input supply systems and the efficient provision of information on improved practices to farmers outside of the donor-supported projects. As a consequence of these factors (as well as civil unrest in several countries), effective demand for improved technologies remained weak in most parts of the region.

Despite the shift in donor priorities, NARSs continued to rely on donor funding for a significant part of their expenditures, although this varied significantly across countries. Thus, Pardey *et al.* (2007) observe: "Donor contributions (including World Bank loans) accounted for an average of 35 percent of funding to principal agricultural research agencies in 2000. Pardey and Beintema (2001) estimated that five years earlier, close to half the agricultural

research funding in the region was derived from donor contributions.” Through the middle of this last decade, donor support to national systems has continued to fall, and the World Bank was left as virtually the only donor to national systems, apart from the technical assistance offered by the Institut de recherche pour le développement (IRD), especially in francophone countries. For some countries, such as Malawi, donor funding for agricultural research has virtually stopped completely. In the project appraisal for the Agricultural Development Programme Support Project (World Bank 2008) the focus is on improving productivity under the input subsidy programme but at the same time finds that “agricultural research and extension services currently lack the human resources as well as the physical and operational means to fulfil their roles and mandate at national and local level.” Yet, because of the unsatisfactory appraisal of past loans to agricultural research in Malawi, there is little within the project in support of agricultural research. Selective donor support for agricultural research in Africa is leading to a stratification of research capacity across countries, with the assumption that this lack of capacity will be replaced either by regional programmes or by the private sector.

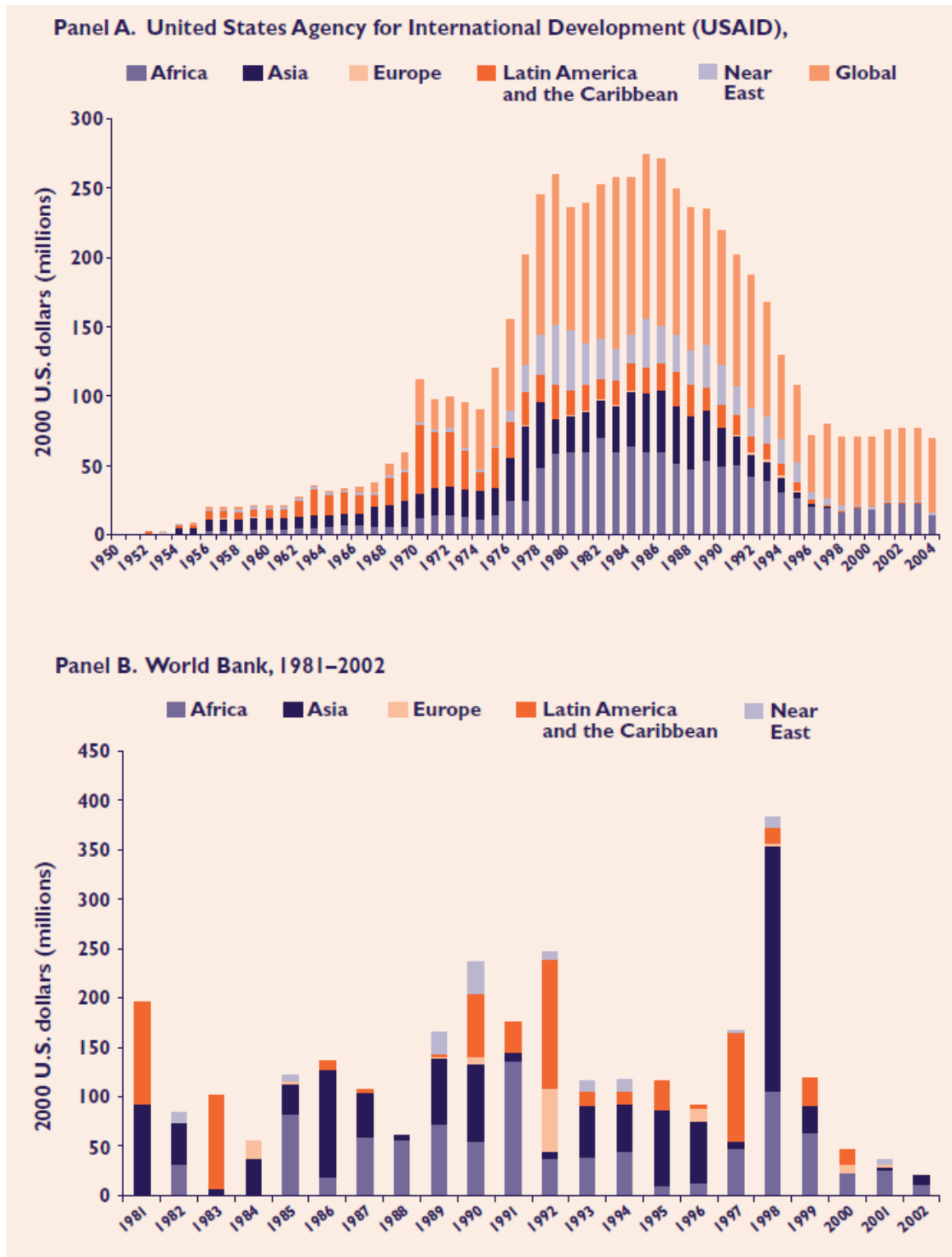


Figure 1. Support from USAID, 1950–2004, and the World Bank, 1981–2002, for agricultural R&D by region, in US\$ millions. Source: Pardey et al. (2007).

Agricultural research capacity has not only been influenced by funding trends but also by significant shifts in approaches to how agricultural research is organized and managed. Projects in the golden age in the 1980s focused on consolidating agricultural research units spread across different ministries and departments into a semi-autonomous parastatal or NARI. Between 1980 and

1995 World Bank lending focused mostly on capacity building. Sixty-one percent of the Bank's commitment to research during the period went to free-standing projects, aimed mostly at strengthening and expanding the capacities of particular agencies. Human resource development projects strongly supported post-graduate training and recruitment (Purcell and Anderson 1997). This emphasis within the World Bank shifted in the 1990s to developing more decentralized, pluralistic systems and delinking funding and research execution, primarily through the creation of umbrella research councils. As the World Bank's Agricultural Investment Sourcebook (World Bank 2006) notes, "In the mid-to-late 1990s, the instability and inefficiency evident in many public research organizations led to an emphasis on developing institutionally pluralistic agricultural knowledge and information systems with greater client participation and financing." For small African countries with embryonic private sectors and limited research capacity in universities, this resulted in the decentralization of the research stations in the NARIs to semi-autonomous institutes, thus undermining any potential economies of scale in areas like plant breeding and creating problems of coordination in areas such as variety testing.

In the last decade the World Bank, USAID and the UK Department for International Development (DFID) went through a major paradigm shift, away from direct support to NARIs towards broader systems that featured a demand-driven approach and greater local control in the provision of agricultural services, including research. This approach is illustrated by the National Agricultural Advisory and Development Services project in Uganda. Again, the diffuse, diverse and generally weak effective demand for improved technologies in Africa greatly limited the articulation of demand back through the research system, putting more emphasis on purely adaptive research and in the end undermining the effectiveness of this approach.

The most recent change to funding of agricultural research in Africa was the creation in 2006 of the Global Development Program within the Bill and Melinda Gates Foundation, with a principal focus on agriculture and with a significant component supporting agricultural research. In turn, the Gates Foundation and the Rockefeller Foundation were instrumental in creating the Alliance for a Green Revolution in Africa (AGRA), which is providing support in the areas of plant breeding and soil health. Large grants given by the Gates Foundation tend to be multicountry in scope but with a relatively narrow subject or thematic focus. Many of the projects in the area of science and technology have a crop-improvement focus, whether by conventional breeding or transgenic approaches. AGRA, on the other hand, has a programme dedicated to crop breeding and seed-system development, the Programme for Africa's Seeds Systems (PASS). This programme primarily funds individual breeding programmes or start-up activities in seed companies.

At the turn of the second decade of this century there is a complicated mosaic of donor support for agricultural research in sub-Saharan Africa, on which NARIs still depend to varying degrees. The World Bank, the largest traditional funding agency for national research systems, has tended to move away from

stand-alone projects for agricultural research and towards providing indirect support through other agricultural loans. In some cases, such as the Kenya Agricultural Productivity Programme (KAPP), there is explicit funding for a NARI, in this case the Kenya Agricultural Research Institute (KARI), but this is bundled together with support for extension, farmers' associations and partnerships with the private sector. Other donors, such as the European Union (EU) and USAID, are focusing much more on supporting regional approaches through subregional organizations (SROs) and regional economic communities. However, regional approaches still require some capacity in member national systems while relying on stronger, regional systems to do much of the regionally focused research. Finally, the new funding from foundations is directed to very strategic areas where there is already some capacity on which to build.

Capacity in plant breeding could be developed at both national and regional level and linked to global programmes in the CGIAR. However, to be effective this requires closer coordination both between those implementing these breeding programmes and those funding the programmes than is currently the case, a theme which will run through much of the rest of this chapter.

Capacity in agricultural research systems

Agricultural research in sub-Saharan Africa¹ is done almost completely within the public sector. Pardey *et al.* (2007) estimate that 98 percent of expenditure on agricultural research in Africa is through publicly funded agencies. Public agricultural research is generally organized in semi-autonomous parastatals, otherwise known as NARIs. Capacity in plant breeding is in turn dependent on overall capacity in the NARIs and the relative allocation of funds and personnel to breeding programmes. There is some, limited breeding capacity in universities; where they exist, such programmes are almost universally supported by international public funds.

Plant breeding in sub-Saharan Africa faces particular constraints not found in other regions, and these require quite different approaches to how plant breeding capacity is developed on the continent. The remainder of this chapter includes ideas about what approaches might be appropriate for the region.

Agricultural research in Africa faces what could be called the “small-country problem.” Sub-Saharan Africa consists of 48 countries, the majority of which have agrarian-based economies, have high demands on limited public revenue, and have heterogeneous agro-ecological conditions. No country can afford to be without an agricultural research capacity – although this is not reflected in either donor or national government spending priorities – and this results in relatively small systems that cannot attain the economies of scope and scale that are possible in larger countries such as Brazil, China and India. A comparison of public-sector expenditures on agricultural research between

¹ The discussion in this chapter will be limited to countries in sub-Saharan Africa, excluding South Africa.

sub-Saharan Africa, India and the United States (Table 2) suggests that research systems in Africa are highly decentralized, overstaffed and underfunded in comparison with what might be termed a large-country structure for agricultural research. However, given the significant heterogeneity in African agriculture, a decentralized agricultural research structure may make sense, if those areas of agricultural research where there are scale economies can be provided through other mechanisms and effectively linked to national capacities. As will be argued, this decentralized structure is particularly important in regards to organizing plant breeding capacity on the continent.

Table 2. Comparison of research systems in sub-Saharan Africa, India and the United States around the year 2000.

	Sub-Saharan Africa	India	USA
Arable and permanent crop area (million ha)	147	160	175
Number of public agricultural research agencies	390	120	51
Full-time-equivalent scientists	12 224	8 100	9 368
Scientists with PhD (%)	25	63	100
Annual spending on agricultural R&D (million 1999 international dollars)	1 085	1 860	3 465
Spending per scientist (thousand 1999 international dollars)	89	230	370

Sources: FAO (2006a); Pal and Byerlee (2006); Pardey *et al.* (2007)

The small size of African research institutes in the context of substantial heterogeneity within even individual countries raises the issue of effective priority setting and resource allocation. National agricultural research capacity, as measured by the number of full-time scientists, grew significantly in the post-independence period (Figure 2), especially in the 1980s when there was a significant consolidation of agricultural research units into NARIs and expanded graduate training of scientists. Still, by the year 2000 half the countries employed fewer than 100 full-time researchers. Plant breeding capacity will have to increase significantly if countries are to move from evaluation of imported lines to operating their own crossing and selection programmes. NARIs have to assess which crops give the highest return to such investments in relation to the potential for importing adapted materials that farmers would adopt. Given the diversified nature of food crop production in most African countries and the capacity constraints, this choice is not always straight forward and the decision point is not always apparent at a relevant policy level. Factors influencing this investment choice will be analysed in the course of this chapter.

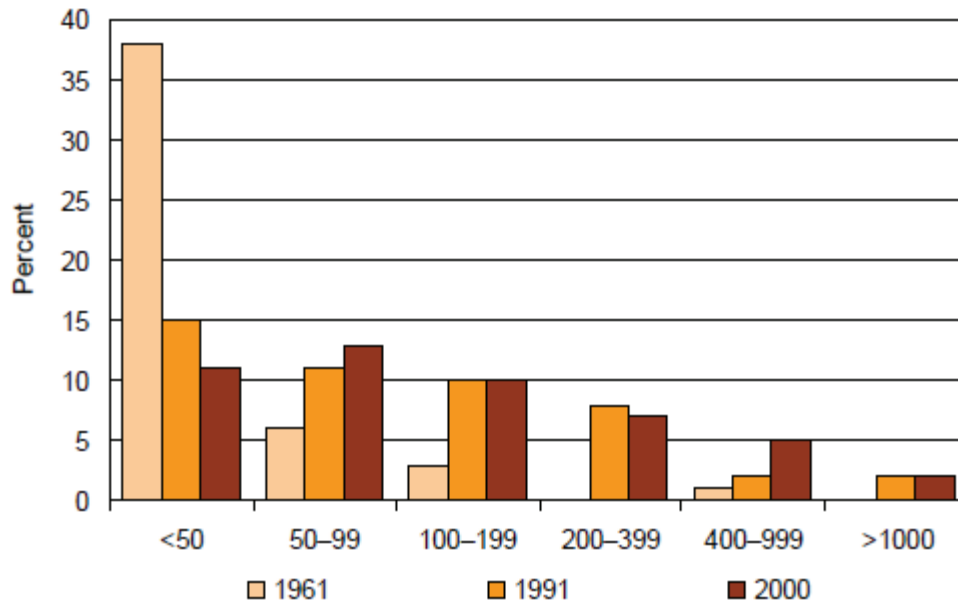


Figure 2. National agricultural research and development capacity in African countries according to number of full-time-equivalent researchers, 1961, 1991, and 2000. Source: Beintema and Stads (2006).

During the period of donor support for institutional development in the 1970s and 1980s, there were large investments in training of agricultural researchers, within both NARIs and faculties of agriculture. The 1970s were associated with an “Africanization” of public-sector staff following independence. In this period, donor programmes focused more on educational programmes, such as the Rockefeller’s University in Development programme, and USAID was instrumental in attempting to reproduce the land grant model in countries such as Nigeria. In the 1980s and early 1990s most of the training was done through grants or loans directly to agricultural research institutes and, in the case of USAID, to faculties of agriculture. However, degree training in NARIs, particularly at PhD level, usually had spillover into universities, with movement of NARI personnel to agricultural faculties in search of better terms of employment. By 2000, 75 percent of all researchers had undergone postgraduate-level training, and about one-quarter held doctorate degrees (Beintema and Stads 2006). The pool of human capital was not insubstantial but scientists often did not have the resources to undertake effective research (see below).

The 1990s was a period of shifting donor priorities, declining support to agriculture and structural adjustment. The last of these put constraints on fiscal budgets and very often resulted in freezes on public-sector hiring, the latter continuing well into the present decade. Any open staff positions had to be filled by advancement of internal staff and this at a time of limited resources for degree training. This was particularly apparent in domestic agricultural education and training (AET) institutions, which became the fallback choice for degree training. Beintema *et al.* (1998), in a study of 34 agricultural science and related faculties located in 10 English-speaking African countries, found that at least 85 percent of all faculty staff with PhD degrees employed in 1991 had undertaken their degrees overseas, and about

two-thirds of them had also obtained their MSc degree overseas. However, with the expansion in universities in the 1990s and into 2000, there was a significant dilution of this critical mass of trained staff. With most of these scientists either retired or on the verge of retiring, there is an emerging critical shortage of trained agricultural researchers in both NARIs and faculties of agriculture. This situation is summarized by a World Bank report on African AETs (World Bank 2007):

The initial institution building achievements of the 1970s and 80s have given way to neglect since the 1990s. Donor assistance to African agriculture has declined sharply and, within that total, support for AET in Africa has largely disappeared. Assistance for formal AET declined to just 0.7 percent of agricultural sector aid between 2000 and 2004. Government funding has tended to follow donor priorities. The ultimate cost of the government and donor pull back from AET has been to distance African professionals from knowledge networks, global information resources, and the cutting edge of technology transfer. This has left a severely depleted human resource pool in African agriculture.

Expansion in staff coupled with less-than-commensurate increases in funding has resulted in a real decline in both operational funding and support staff, the essential components for an effective plant breeding capacity. The number of technicians averaged 1.2 per scientist in 2000, a considerable decline from levels in the early 1990s (Beintema and Stads 2006) and again a reflection of the freeze on public-sector hiring under structural adjustment. Operational funding suffered similar trends (Figure 3), in some cases reaching levels less than 40 percent of what they were in 1971. These data are often based on submitted budgets and the situation is often worse in terms of actual budgetary allocations from Treasury, as these are often reduced and not available on time, reflecting unexpected shifts in immediate government spending requirements.

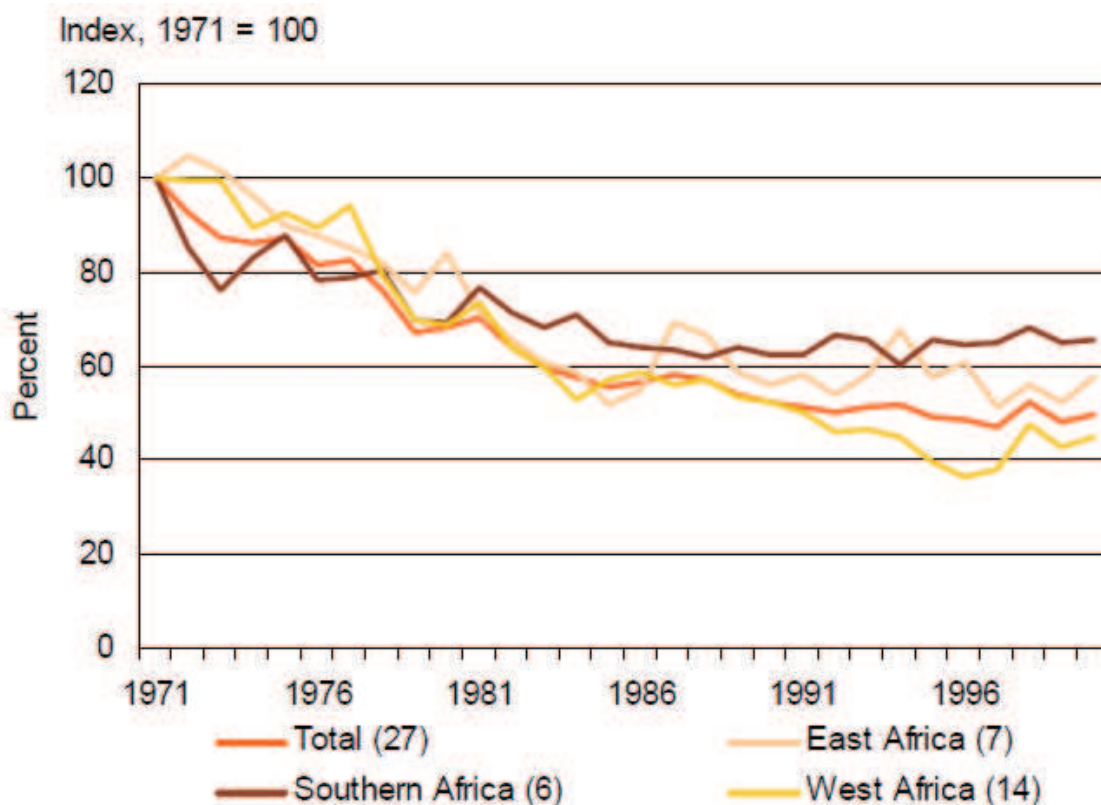


Figure 3. Trends in public agricultural research spending per researcher in Africa, 1971–2000. Source: Beintema and Stads (2006).

Plant breeding is embedded within overall agricultural research budgets and institutions. The capacity context for most NARIs in sub-Saharan Africa is one of an aging scientific staff, severe constraints on operational funding and support staff and continued dependence on donor funding but without a clear framework in how best to align programmes to a highly differentiated donor environment.

Particularly, the World Bank as the traditional funding source of NARS, has shied away from funding weak systems and has tended to collapse research into broader agricultural projects. Support to the stronger NARIs first tended toward institutional decentralization and most recently toward greater integration with an emergent private sector. On the other hand, there is an expanding flow of funds to national breeding programmes through programmes within SROs and CGIAR centres or individual grants from AGRA’s PASS programme.

Effective plant breeding is a hierarchical and highly coordinated activity, as is very apparent in the large global breeding programmes of the multinational corporations. In Africa that is currently not the case due to the highly uncoordinated nature of how plant breeding capacity and operations are funded. However, to understand this, it is first necessary to review the emergence of the SROs and then to review plant breeding within the SROs and the CGIAR centres.

Subregional agricultural research organizations

The development of SROs in sub-Saharan Africa changed the direction of donor funding of agricultural research on the continent and continues to affect how agricultural research is organized in the region. This process began in the mid-1980s with the creation of SACCAR in 1984 as a coordinating unit for agricultural research within the Southern African Development Community (SADC). This was followed by an agreement among principal donors to create the Special Programme for African Agricultural Research (SPAAR) in 1985, one of the objectives of which was to develop strategies for regional research programmes. These two events were quickly followed by the creation of the Conference of African and French Leaders of Agricultural Research Institutes (CORAF) in 1987, which subsequently became the West and Central African Council for Agricultural Research and Development (CORAF/WECARD). The creation of the three SROs was completed in 1994 with the formation of the ASARECA, led principally by the World Bank and USAID. SACCAR and CORAF/WECARD built their programmes on a previous organizational history, while ASARECA developed its from scratch and with a much simpler governance structure formed solely by the directors of the participating NARIs.

ASARECA's programme developed around the rationalization of the plethora of regional research networks, most of which had been created by the CGIAR centres. These had expanded in the 1980s and were supported by a wide range of bilateral donors, who saw these as a strategic, if not sustainable, means of supporting agricultural research on the continent. In the early 1990s the demands that these put on retrenching NARIs was viewed on all sides as an increasing management problem. In West Africa in this period there were four networks working on maize, operated by the African Union's Semi-Arid Food Grains Research and Development project (SAFGRAD), CORAF/WECARD, the International Institute of Tropical Agriculture (IITA) and the International Maize and Wheat Improvement Center (CIMMYT). By the beginning of this decade, ASARECA was a coordinating platform for 17 networks, which were viewed as a mechanism for achieving ASARECA's overall objectives to "1) make spillovers happen across national boundaries, 2) achieve economies of scale and scope in research, 3) produce regional public goods, 4) provide a mechanism to share benefits and costs of collective action, and 5) find research solutions to transboundary problems" (Oruko 2008). Seven of these networks were crop-focused and supported a regional breeding programme. Synergies were sought with networks on plant genetic resources, policy analysis, biotechnology and biosafety, soil and water management, post-harvest issues and agricultural information. These interacting networks provided a range of support in terms of training, operational funds and access to research of the international agricultural research centres (IARCs) during a period in which NARIs were going through "an era of stagnation" (Beintema and Stads 2006). CORAF followed ASARECA in the development of its programme structure around network coordination, although it lagged somewhat due to the incorporation of the former French agronomic research network and some aspects of overlap in operational mandates with IITA.

ASARECA was generally recognized to be the most advanced SRO (InterAcademy Council 2003). SACCAR was terminated with the restructuring of SADC in 2001, and there has been a coordinating vacuum in southern Africa until the prospective formation of the Centre for Agricultural Research and Development for Southern Africa (CARDESA) in 2010.

The Forum for Agricultural Research in Africa (FARA) was established in 2002 as an apex body representing the interests of its constituent SRO members. At the same time SPAAR was abolished. This set in motion a series of interlinked processes. Firstly, FARA was given the responsibility to implement the Comprehensive Africa Agriculture Development Programme's (CAADP) Pillar 4 on agricultural research, technology dissemination and adoption, which has recently come under the auspices of the African Union. Secondly, FARA developed the Framework for African Agricultural Productivity (FAAP) as a guide for the implementation of CAADP's Pillar 4 and as a link to the World Bank's loan mechanism for the Multi-Country Agricultural Productivity Program (MAPP), which was developed about the same time in 2003.

This intersecting set of regional and subregional organizations, frameworks and funding arrangements was built on effective participation by NARIs, which in turn rested primarily on increased government expenditure on agriculture, and especially agricultural research. Under CAADP African governments agreed to increase their spending on agriculture to 10 percent of overall government expenditures. However, by 2009 only Mali, Madagascar, Malawi, Namibia, Niger, Chad and Ethiopia had met the target, and for many of these countries, such as Malawi, much of the spending was directed to subsidizing fertilizer rather than to agricultural research.

In 2007 ASARECA restructured its governance by expanding representation beyond just NARI directors and completely recast its programme structure. It devolved the networks and developed a programme structure around seven themes, which would primarily run competitive grant programmes. USAID, DFID and the EU supported this restructuring process and in turn shifted all of their funding from the networks to the competitive grant programmes. This severed close partnership arrangements between ASARECA and the CGIAR centres and, as described below, effectively curtailed a significant number of regional breeding programmes. The MAPP for East Africa, the East Africa Agricultural Productivity Program (EAAPP), was signed between the World Bank and the four participating countries (Ethiopia, Kenya, Tanzania and Uganda) in 2009. Under this agreement regional centres of excellence (RCoE) would be supported within highly selected NARI programmes. Thus, Tanzania would become the RCoE for rice, Ethiopia the RCoE for wheat, Kenya the RCoE for dairy and Uganda the RCoE for cassava. Each country would receive a loan of US\$30 million for five years to improve research capacity in these commodities and to develop a framework to ensure regional spillovers, part of this through ASARECA's leadership in developing a regional seed sector.

A similar programme restructuring is underway in CORAF/WECARD. The West African Agricultural Productivity Program (WAAPP) was initiated in 2007, with Ghana taking regional responsibility for root and tuber research, Mali for irrigated rice and Senegal for drought-resistant cereals. In southern Africa, CARDESA is near to being formed, and will take the lead in the development of the MAPP for SADC.

From the narrower perspective of capacity in plant breeding programmes, the recent restructuring in SROs either creates a disjunction in the effective coordination and flow of germplasm from international to regional to national programmes or it isolates SROs as players in such programmes. Running research programmes on the basis of competitive grants, usually of a three-year duration, offers little potential for coherent support for crop breeding programmes. Moreover, the MAPPs as currently constructed do not address the development of scale economies in plant breeding, nor the need for effective trial infrastructure to manage spill-ins from such centralized breeding programmes. At the same time, the shifts in donor funds at the level of the World Bank and bilateral donors to a focus on regional programmes ends up weakening capacity at the two other ends of the plant breeding spectrum, namely national programmes and the regional breeding efforts of the CGIAR centres. The following section will review some of these impacts.

Regional breeding networks

Regional breeding networks can exploit the scale economies often found in plant breeding but at the same time support the development of locally adapted varieties. Such networks are almost universally supported by international public funds. In a very few cases national public-sector breeding programmes collectively support research that could benefit all programmes but that no single programme would have the capacity to support. An example of this is the Latin American Fund for Irrigated Rice (FLAR) network for rice breeding in Latin America. To a limited extent the latter forms the justification for EAAPP and WAAPP, although these are based on centres of excellence rather than nodes in the systematic movement of breeding populations.

These regional breeding programmes are almost universally coordinated by CGIAR centres. Collaborative Research Support Programs (CRSPs) have had breeding programmes but usually supported by breeding activities at a US university. The French Centre for International Cooperation in Agricultural Research for Development (CIRAD) has supported national-level breeding programmes with regional links. Such regional breeding programmes can improve efficiency in national breeding programmes through a range of activities, particularly prebreeding and population development, division of labour across national programmes especially in trait development, regional testing, and provision of centralized services such as disease or drought screening techniques.

The organization of breeding programmes in CGIAR centres in general consists of a three-stage process: 1) a centralized breeding platform linked closely to a world germplasm collection; 2) a set of regional breeding

programmes drawing on support from the central unit; and 3) differentiated support by regional networks to national breeding programmes depending on their capacity. During the 1990s many of the regional breeding programmes were on an equal footing with the breeding programme at headquarters, but the introduction over the last ten years of molecular characterization of the germplasm bank, use of molecular markers in breeding, integrated information systems linking genetic, genotype and phenotype information, and transgenic platforms have all led to a significant increase in services provided by the centralized breeding platforms to the regional networks. These programmes generally also support an international variety testing network, which is often integrated with testing networks in the various regions. However, there is a lot of variation across the CGIAR system in how such breeding programmes are organized, for example by commodity or by region. National breeding programmes can access different germplasm products from IARCs depending on the capacity of their breeding programme. If the whole system functions properly, farmers across the developing world should have access to an increasing array of locally adapted varieties, which would lead to increasing farm-level benefits over time. However, the system remains far from optimal.

The IARCs' regional breeding programmes for maize, cassava, rice, beans and vegetables are presented in Table 3. Several broad trends are apparent in the table. Firstly, regional breeding programmes have been much more common in sub-Saharan Africa than in other regions, reflecting in part the number of small countries and in part the more limited capacity in African national programmes. Second, as might be expected, centres in general usually do not have networks in the region in which the headquarters are based (IITA and the Africa Rice Center [AfricaRice] are exceptions). Finally, many regional breeding programmes have had to close over the last decade or so due to the inability to source funding. In Africa most of the closures were due to the shift in funding by USAID and the EU from support to commodity networks to competitive grant programmes within the SROs.

Table 3. Regional crop breeding networks operated by CGIAR centres.

Commodity	IARC	LAC	Asia	Africa
Maize	CIMMYT	None	Terminated	ECAMAW
	IITA	None	None	Terminated West Africa
Cassava	CIAT	None	Terminated	None
	IITA	None	None	Terminated East, West & S. Africa
Beans	CIAT	None	None	ECABREN SABRN
Rice	IRRI	None	None	ECARRN
	CIAT	FLAR	None	None
	AfricaRice	None	None	ECARRN ROCARIZ
Vegetables	AVRDC	None	None	vBSS hubs

IARCs: AVRDC – The World Vegetable Center; CIAT – International Center for Tropical Agriculture; CIMMYT – International Maize and Wheat Improvement Center; IITA – International Institute of Tropical Agriculture; IRRI – International Rice Research Institute.

Networks: ECABREN – East and Central Africa Bean Research Network; ECAMAW – Eastern and Central Africa Maize and Wheat Research Network; ECARRN – Eastern and Central African Rice Research Network; FLAR – Latin American Fund for Irrigated Rice; ROCARIZ – West and Central Africa Rice Research and Development Network; SABRN – Southern Africa Bean Research Network; vBSS – Vegetable Breeding and Seed Systems.

Regional breeding networks all have some form of centralized breeding capacity run by the IARC. In general it has taken some time to develop breeding populations adapted to the constraints prevailing in the region and the quality characteristics demanded in the market. This was true for CIAT's bean breeding programme in East Africa, AfricaRice's rice programme in coastal West Africa and CIMMYT's maize breeding in East and southern Africa. Virtually all IARCs with crop-breeding mandates have had to develop regional programmes in sub-Saharan Africa given the range of constraints on crop productivity in essentially rainfed systems as well as the limited input use by smallholder farmers. There has been virtually no adoption of varieties bred outside of Africa except for vegetables, and these are grown under higher input use and better crop management.

There is a basic assumption in the organization of these networks that prebreeding and other services that support a distributed set of national and subnational crossing and selection programmes will produce a flow of adapted varieties superior to those that could be bred from a large, centralized breeding programme with regional or international testing, on the one hand, or an uncoordinated, decentralized set of national breeding programmes on the other. The greater efficiency of a large centralized

breeding programme has been argued for in the case of wheat breeding (Maredia and Byerlee 2000; Byerlee and Traxler 2001). Such a centralized system also characterizes the organization of maize breeding in Monsanto and Pioneer in Africa, where each has one crossing and selection site on the continent, although they each have three or four sites in Asia. Size of crossing blocks and the attendant genetic variability, widespread testing and data integration, and movement of germplasm between selection sites is projected to lead to the development of regional markets for varieties, a strategy that has been less successful so far in Africa than it has in either Asia or Latin America.

On the other hand, there are strong arguments in favour of regional breeding programmes, especially for sub-Saharan Africa (DeVries and Toenniessen 2001; Kling 2007). As Kling (2007) notes:

“Broad” adaptation is used in some instances to refer to adaptation across wide geographic areas within a defined agroecology, and in other instances to refer to adaptation across multiple agroecologies. In the latter sense, where GXE exists, selection for broad adaptation is similar to selection for multiple traits. Simultaneous selection for multiple environments may decrease the rate of progress that could be achieved through selection for specific adaptation to a single environment.

Kling (2007) discusses regionalization of breeding programmes but does not make a distinction between: 1) a coordinated network of national breeding activities supported by prebreeding capacity; 2) large centralized breeding programmes such as CIMMYT’s wheat programme; and 3) a set of uncoordinated, decentralized national breeding programmes. This paper argues that this distinction is at the core of investment strategies for plant breeding, especially in sub-Saharan Africa.

Most regional breeding programmes, and even many national programmes, stratify their breeding programme by agro-ecologies and work within acceptable levels of genotype-by-environment (G×E) interaction. Such stratification then produces the potential for division of labour between breeding programmes within the network.

A comparison of regional breeding programmes can be done on the basis of the functions or activities of such networks, including:

- the proportion of prebreeding vs fixed line development done in the centralized programme within the region;
- the division of labour across NARI programmes in terms of either agro-ecologies or market types;
- a regional testing network with integrated data management;
- training in breeding methods;
- participatory variety selection, possibly leading to community based seed systems; and

- pass-through funding of NARI operational expenditures where lack of such funding constrains the performance of the overall network.

Again, because such networks depend on international public funds, funding arrangements are also a key factor in the organization and sustainability of the network. The following sections briefly review regional breeding networks for each of the five commodities.

Rice

Sustaining increases in rice productivity is one of the larger challenges within the plant breeding community into the near-term future, given pressures on water resources in Asia, rapidly increasing demand in Africa and competition for irrigated land, particularly from increasing horticultural production.

Rice is grown across a continuum of water management, usually divided into irrigated, rainfed lowland and upland categories. Within the rainfed lowland category there is great diversity in production niches and constraints, which can run from submergence to drought in the same production year. At the same time, there are significant differences in preferences for quality characteristics, and these are critical determinants of both price and acceptability. Breeding programmes are stratified into these broad ecologies within the three IARCs that work on rice and are further stratified within national breeding programmes.

IRRI primarily focuses on rice breeding in Asia but has more recent activities in East and southern Africa. Given the diversity of systems and stratification of breeding programmes in each of the Asian countries, IRRI does not operate regional breeding programmes but rather services national programmes with a range of different breeding lines and germplasm from its headquarters. It also may, with special-project funding, develop country programmes where a breeder may be stationed. Consortia of national programmes and other stakeholders are organized around the major rice breeding ecologies and one of the principal activities is implementation of the International Network for Germplasm Evaluation in Rice (INGER), where national programmes can send varieties for international testing and possible inclusion in national variety testing systems.

AfricaRice supports rice breeding in sub-Saharan Africa, although activities in East and southern Africa have been relatively recent. Rice breeding in AfricaRice is organized around the three ecologies. Because of the more limited capacities in national programmes and the scarcity of operational funding, AfricaRice has a relatively unique partnership modality with national programmes. Centralized crossing blocks are operated by AfricaRice breeders and F₂ lines are distributed to national breeders for further selection and evaluation. The dependence on national capacity – and the support to develop that capacity – is a particular feature of AfricaRice's breeding. Its viability depends on pass-through funding from AfricaRice donors. A system of participatory variety selection is organized in participating countries to further integrate farmer selection criteria and farmer production conditions.

Elite material is tested within the African component of INGER, but that has had difficulty in maintaining sustainable funding. In West Africa these activities are coordinated through a network, ROCARIZ, whose funding was terminated in 2006. In East and southern Africa a rice research network, ECARRN, was formed within ASARECA, but with the change in programme structure this network has been devolved to AfricaRice. As yet, it is a coordinating network with no centralized breeding activities.

Maize

The widespread adoption of improved maize varieties significantly lagged behind the experience in wheat and rice. This was due partly to the fact that maize is not grown under irrigated conditions and partly to the fact that the initial organization of CIMMYT maize breeding could not be patterned on that of wheat. As Kling (2007) notes:

In the 1970's when the CGIAR centers were established, breeding for "broad adaptation" was a commonly accepted paradigm. CIMMYT, for example, would prepare sets of 250 full-sib progeny from a number of maize populations, which were distributed on request to breeding programs in the developing world. Data from collaborators were combined and used to make selections at CIMMYT headquarters to advance each population for another round of recurrent selection. This system was inefficient for a number of reasons. First, the material from CIMMYT lacked specific features needed for local adaptation, so collaborators were essentially starting over again every selection cycle. Secondly, the range in testing environments was so great that there was considerable variation in relative performance of progeny across locations (genotype-by-environment interaction or GXE). Selection for average performance would have little impact on performance at each location.

CIMMYT regionalized its breeding programme in the 1980s and IITA also developed a maize breeding programme in West Africa. The breeding work in the 1980s and 1990s focused primarily on the development of OPVs. Over the last decade there has been an almost-complete shift to hybrid breeding. Most of these regional breeding programmes were located within a maize research network. For IITA in West and Central Africa this was the West and Central Africa Maize Network (WECAMAN), which was started in 1987. Virtually all of the population development was done at IITA. USAID supported the network through 2005, and funds were provided to national breeding programmes in Burkina Faso, Cameroon, Côte d'Ivoire and Ghana. Sites in these countries screened for tolerance of drought, striga and low nitrogen, and advanced lines were selected in these sites. Advanced lines from both IITA and national programmes were tested in regional uniform variety trials. However, funding for this network has lapsed, as a result of both changing priorities of the principal donor and restructuring of regional research networks within CORAF/WECARD.

CIMMYT had similar maize research networks in Asia (the Asian Regional Maize Network), East and Central Africa, and southern Africa. The breeding activities in these networks were quite differently organized. In the Asian

network the activities centred around a regional variety testing network and a focus on drought-tolerant germplasm and drought screening methods. The breeding activities in southern Africa had a similar focus on drought tolerance and were built around the regional breeding programme in Zimbabwe. National programmes screened and evaluated CIMMYT germplasm to develop elite lines, which were then tested in both mother–daughter trials and regional uniform yield trials. Elite varieties were then entered into national performance and variety release procedures. ECAMAW came under the umbrella of ASARECA, was funded by USAID, and provided a network vehicle for CIMMYT’s activities in East and Central Africa. Breeding activities were not as highly structured as in southern Africa, partly reflecting the greater heterogeneity in production ecologies, and germplasm was more tailored to specific national programme requirements. Over time, breeding activities shifted from Zimbabwe to Kenya, in part in response to changes in funding.

The reorganization of ASARECA in 2007 led to the disbanding of ECAMAW. The southern Africa network was then absorbed into the Drought Tolerant Maize in Africa (DTMA) initiative, funded by the Gates Foundation. Long-term funding of maize research networks essentially came to an end by 2005 and regional maize breeding and testing shifted very much to more focused areas, especially drought tolerance. This reflected the loss of long-term donors to maize breeding, particularly USAID, and a shift to new donors with more focused priorities, particularly the Gates Foundation. At one point there may have been said to be a division of labour between AGRA and their funding of national plant breeding programmes and the Gates Foundation and its tendency to fund more regional programmes, often through the IARCs. That division of labour has become less clear in the last year or so.

Beans

Bean breeding is complicated not by the complexity of the breeding methodology but rather by the number of traits that are required and because the particular combination of traits is relatively specific to a country or agro-ecology. CIAT operates regional breeding programmes within a network structure only in Africa. These are long-standing research networks of 20 years or more and have been brought together under an umbrella organization, the Pan-Africa Bean Research Alliance (PABRA), which includes CIAT and two subregional networks, SABRN and ECABREN. A West African network is under consideration. Breeding is essentially done within the two networks, which are organized by distributing breeding targets across breeding programmes in NARIs.

In ECABREN breeding for beans is organized around nine market types – essentially grain colour, size and shape but also including snap beans – and a similar number of key constraints – classic diseases, new emerging diseases and abiotic factors, with nitrogen fixation capacity and micronutrient content being recent additions. Of the nine countries in ECABREN, Burundi and Sudan do not have crossing programmes. NARI breeders usually have responsibilities for at least one other legume, e.g. cowpea, groundnut, broad

bean, etc. Thus, national programmes divide up responsibilities based essentially on market type, within which there are key production constraints. The results then are pooled into a regional nursery for distribution to all countries. There is a range of production systems and agro-ecologies within each of the subregions, but these are encompassed within the breeding populations for particular market types and distributed across the various countries. This ensures a continuous flow of new germplasm, while building the regional programme on the expanding capacity of national programmes in the region. There is significant support for operational expenditures incurred by the national bean breeding programmes and one breeder is supported full time by the network to coordinate regional trials, access prebreeding populations from CIAT and undertake breeding activities not handled by the national programmes.

SABRN is organized in very much the same way but operates in a region with significantly less capacity for bean breeding. Of ten countries in the network, only five (Malawi, South Africa, Southern Tanzania, Zambia, Zimbabwe) have active breeding programmes. The gap is filled by the regional breeder employed by the network. All ten countries have access to varieties coming out of the programme for evaluation under local conditions, most often within a participatory variety selection framework.

Both networks have been supported by a range of donors, but particularly the Swiss Agency for Development and Cooperation (SDC) and the Canadian International Development Agency (CIDA). Because of these donors, the restructuring at ASARECA had little effect on the activities of ECABREN, as it was brought back under the PABRA administrative umbrella. Moreover, PABRA provides a framework to integrate more specialized breeding work coming from more focused projects, such as GL-II for drought tolerance, HarvestPlus for micronutrients and a recent project on biological nitrogen fixation, all supported by the Gates Foundation.

Cassava

Cassava is a clonal crop, highly heterozygous and has a long growth cycle. Except for a few areas the crop is usually grown without inputs and often in more marginal agricultural conditions. There is often a very high G×E interaction for principal traits. Both CIAT and IITA have breeding programmes for cassava, the former focusing on Latin America and Asia and the latter on sub-Saharan Africa. Given the characteristics of the crop and the fact that international variety testing trials were difficult and costly to organize (due to quarantine issues or costs in managing tissue culture), regional breeding networks were a feature of both IARCs' programmes through the 1980s and 1990s.

IITA, with USAID funding, established cassava research networks with a central breeding programme in both southern Africa (Southern Africa Root Crops Research Network – SARRNET) and East and Central Africa (Eastern Africa Root Crops Research Network – EARRNET), the latter with ASARECA. In West Africa, cassava research was organized within the Central and

Western African Root Crops Network. However, cassava breeding essentially relied on IITA's programme in Nigeria, which provided primarily clones to national programmes in the region for evaluation and multi-site testing. Breeding in East and southern Africa has had to focus by necessity on pests and diseases, as the crop has been hammered by successive pandemics, including cassava mealybug, a virulent form of cassava mosaic virus and, currently, an outbreak of cassava brown streak virus. These pandemics, especially the diseases, put immediate priority on identifying clones with resistance. However, regional breeding terminated in SARRNET in Malawi in 2003 and in EARRNET in Uganda in 2005, just as the brown streak pandemic was becoming apparent.

Given the importance of the crop and the need for a more distributed breeding system, there is an underinvestment in international breeding capacity in the crop, particularly over the last decade. This comes at a time when cassava's role as a basic food staple is compromised by disease pandemics in Africa. This underinvestment is especially pronounced where breeding is highly centralized in both national and international programmes; multilocational trials are costly and in many cases do not represent the diversity in growing conditions. Moreover, cassava is a crop where farmer participatory breeding at early stages in selecting from significant genetic variability might prove more efficient than current systems in addressing the particular characteristics of the crop. The development of more strategic approaches to investment in cassava breeding requires a movement away from the project basis on which current activities are funded.

Vegetables

Vegetables are a very dynamic sector in most developing countries, especially in Asia which consumes the bulk of the world's production. There is a premium put on product quality, part of which depends on the variety that is used and part on crop management, especially disease and pest control. The seed of improved varieties is a relatively modest cost in production systems and most farmers utilize improved varieties for exotic species, even in sub-Saharan Africa (Ellis-Jones *et.al*, 2008).

The entry of the private sector into the vegetable seed market has been particularly rapid in Asia. Companies have moved quickly into breeding F₁ hybrids for most of their vegetables. Seed production of hybrids is based mainly on hand pollination (as opposed to gene-controlled male sterility) and this in turn depends on appropriate production conditions (usually cool tropical conditions), skilled but relatively cheap labour and good seed-quality laboratories. These companies are relatively small by comparison to the large companies breeding field crops and have distributed breeding and seed-production capacity, often across several countries. There are many new entrants into the industry, often from India and China. Few countries have public-sector vegetable breeding programmes; those that do are mostly in South Asia. However, there are few private companies in Sub-Saharan Africa that have vegetable breeding programmes; most of those that do are in

Kenya. Seed of exotic vegetables is primarily imported and indigenous vegetables are grown from farmer-saved seed.

AVRDC's breeding programmes have tended to be concentrated at the centre's headquarters in Taiwan, have increasingly focused on identifying sources of resistance, key traits demanded by the seed industry and molecular breeding techniques. Vegetables are grown throughout the tropics and subtropics across a range of different agro-ecological conditions but the breeding programmes do not have extensive variety testing networks; AVRDC is still discussing whether to develop either a regional or international variety testing system. However, the centre is developing regional centres where there may be regional breeding programmes. This is certainly the case with the vBSS breeding programmes in sub-Saharan Africa funded by the Gates Foundation in 2007.

vBSS consists of four hubs where regional breeding units will be developed. These hubs are located in Cameroon, Madagascar, Mali and Tanzania. From these hubs the regional breeding unit will provide varieties for testing in neighbouring, "spoke" countries. As noted in the baseline study (Ellis-Jones *et al.* 2008): "Vegetable breeding in three of the four hub countries (Cameroon, Mali and Madagascar) and its spoke countries is practically non-existent with capacity in the public sector having been severely reduced through lack of funding and privatization." This initiative is based on the assumption that adapted varieties developed under African conditions will outperform varieties bred elsewhere and currently imported. The seed for these varieties will be produced by private seed companies, with the expectation that they will evolve their own breeding programme. This would imply that the programme will primarily do hybrid breeding. The four hubs will then be supported by a significant increase in capacity at AVRDC's Regional Center for Africa in Tanzania, which will provide nurseries, screening methods and potentially even marker-assisted selection (MAS) capability for the four hubs.²

Overview

This review of regional breeding programmes, essentially involving IARCs, is intended to provide a missing piece in most discussions of plant breeding capacity in Africa. The central argument in this section is that international and regional breeding capacity is not a substitute for but rather a very strong complement to plant breeding capacity at the national level, even in small and medium-sized countries. This runs counter to the assumption that underlies the significant literature on technological spill-ins, in which scale economies in breeding allow more cost-effective variety development in either larger countries or within either the public or private international system. Certainly, this assumption underlies the increasing investments by multinational seed companies in strategic regional plant breeding capacity that will serve a range of markets in smaller and medium-sized countries. However, the literature on

² At the end of 2009 Rijk Zwaan of the Netherlands and East West Seed of Thailand announced a joint venture called Afrisem which would undertake hybrid breeding for four vegetables in Arusha, Tanzania.

this subject is based essentially on the case of wheat (Maredia and Byerlee 2000; Byerlee and Traxler, 2001; Byerlee and Dubin, 2008) and the argument here is that wheat is something of a special case given the temperature limits on where it is grown (i.e. outside the lowland tropics), the predominant production systems (i.e. irrigated) and the principal constraints (i.e. disease). Traxler and Pingali (1999) undertook an initial demonstration of this, comparing wheat and rice, and concluded:

The rice and wheat systems differ greatly in the prominence of IARC crosses as a source of varietal releases. In wheat, more than half of all releases in 1985-89 are the result of NARS's screening CIMMYT crosses, and the share of releases in this category has increased over time. In fact, there are no countries in which screened CIMMYT varieties are not an important source of farm level technology. The number of wheat releases each year from NARSs crossing programs has increased slightly over time, but their share of total releases has declined significantly. On the other hand, IRRI is no longer an important source of finished rice varieties. Screened IRRI crosses accounted for just nine percent of rice releases in 1985-89, while NARSs crosses accounted for 85 percent of releases worldwide. IRRI scientific resources have been freed to move upstream to engage in work on new plant types.

The intent is not to test this hypothesis at this point, but rather to set up the principal arguments that would underlie such a test. Particularly, it will be argued that several factors influence how a breeding programme might be organized at different hierarchical levels, particularly relating to the characteristics of the crop and the range of agro-ecologies in which it is grown, the range of production systems and the potential for more intensive crop management, and the characteristics of the seed system and the potential to develop hybrids.

The organization of plant breeding in the IARCs in the 1970s and 1980s was very much patterned on the success of rice and wheat. As Byerlee and Dubin (2008) note: "All of these [IARC breeding] programs conformed to a classic definition of open-source collaboration, including (i) free distribution and redistribution of the original materials, (ii) free redistribution of materials derived from the originals, (iii) full sharing of information, including pedigrees and yield and other information relating to the materials, (iv) non-discrimination in participation in the networks, and (v) intellectual property rights on final materials that, if used, did not prevent their further use in research." However, as Traxler and Pingali (1999) note above, the organization of the breeding programmes and their interaction with national programmes were very different, with CIMMYT to a significant extent substituting for national plant breeding capacity and IRRI moving toward a more interactive division of labour with NARIs.

Bean breeding at CIAT, cassava breeding at CIAT and IITA and maize breeding at CIMMYT and IITA followed very much the trend of rice breeding at IRRI, but for somewhat different reasons. The 1970s and 1980s were characterized by large centralized breeding programmes with a principal focus on cultivar development feeding into an international variety testing network.

However, these programmes had to breed for crops grown primarily under rainfed conditions and across a wide range of production ecologies. As noted above for maize in CIMMYT, breeding progress to meet the needs of farmers across these agro-ecologies was limited and it was difficult to demonstrate adoption and impact. This was especially true in sub-Saharan Africa, where per capita food production was declining. This situation led to a regionalization of the IARCs' breeding programmes during the latter part of the 1980s and into the 1990s, with a particular focus on sub-Saharan Africa. This regionalization occurred just as molecular approaches in plant breeding were being developed in advanced labs and were being linked to capacity in the developing world, particularly through the Rockefeller Foundation's Rice Biotechnology Program. These two trends, in turn, started to create more of a division of labour between headquarters and the regional programmes, with headquarters focusing increasingly on trait development, molecular markers, transgenic approaches and highly focused prebreeding. The recent, abrupt termination of financing for regional programmes now creates a critical gap in IARC support for and interaction with national programmes.

The review above suggests significant variation in how IARC regional programmes organize themselves and interact with NARI and private sector breeding programmes. Traxler and Pingali (1999) identify two modes of interaction between the IARC and national programmes:

Our discussion focuses on the IARCs decision to allocate resources between prebreeding and cultivar development research. These activities produce the two main types of IARC research output and correspond to distinct models of the IARC/NARSs interaction. Prebreeding research produces elite lines that can be used by NARSs breeders as parents to produce varieties precisely adapted to their home environments. IARC cultivar development research generates finished cultivars that can be tested and released directly by NARSs without further crossing or selection.

However, this typology does not take into account modes of interaction through regional breeding programmes and research networks.

The experience to date suggests four alternative organizational models for IARC–NARI plant breeding interaction at a regional level. These alternatives depend on breeding methods employed in the crop itself, agro-ecological and market variation, the capacity of the national programmes and the investment resources available. These organizational models are described as follows:

1. Centralized cultivar development: This model is that of Traxler and Pingali (1999), but moved to a regional level. The IARC programme develops fixed lines and these are either tested in a regional variety trial or integrated into the national performance trials of individual countries. For countries with a crossing programme, varieties may enter as a parent, but that is relatively inefficient compared with the provision of nurseries and populations.
2. Centralized crossing and dispersed selection: This model is particularly used in rice and is especially useful when priority traits are common to a region but

their combination will vary across markets or production systems. Thus, AfricaRice can feed into its crossing block traits from wide crosses and work with a significant range of genetic variability, but then the early generations undergo selection across a wide range of conditions in national programmes.

3. A division of labour across multiple breeding projects: This derives primarily from the CIAT bean-breeding model. Traits such as colour and grain size, where preferences vary by country, must be segregated into different breeding populations and these in turn combined with disease and pest resistances specific to principal agro-ecologies. Each national programme can thus concentrate on the market type most demanded in their country but draw on varieties for more minor market types or agro-ecologies.
4. Centralized population breeding supporting national crossing and selection programmes: This is Traxler and Pingali's (1999) other model, but developed at a regional level. Such a model appears to be particularly applicable to sub-Saharan Africa, at least in terms of the combinations of traits that need to be assembled for particular agro-ecologies. Such prebreeding within broad agro-ecologies could feed directly into national crossing and selection programmes or into the other three models, depending on capacity at the national level.

Were resources to be unconstrained, the optimum configuration for sub-Saharan Africa would be the fourth model, given that all countries are small to medium-sized, rainfed agriculture predominates, there is a broad range of agro-ecologies but significant heterogeneity within even small countries, and scope for intensification of crop management practices is still limited.

Evaluation of national plant breeding capacity

The analysis above provides an institutional context for the analysis of national plant breeding programmes in the three African case study countries – Ghana, Kenya and Malawi – and the potential for adjusting investment in plant breeding at the national level to the changing and multifarious capacity to draw on regional and international programmes. This section reviews the situation for maize in Ghana, Kenya and Malawi; cassava in Ghana and Malawi; and beans in Malawi.

Maize breeding and seed system in sub-Saharan Africa

Maize is a basic food staple of many countries in East and southern Africa, including Kenya and Malawi. In these two countries maize is both a rural and urban staple. It is a smallholder crop and a large percentage of arable land is planted to it. Both Kenya and Malawi have relatively high rural population densities in their agricultural areas and over the last decade or so both have moved to a net import position, although not every year. A large percentage of rural households are net buyers of maize: 62 percent in Kenya (Jayne *et al.* 2006) and even higher a percentage in Malawi. On the other hand, over 50 percent of commercial supplies originate from about 2 percent of rural households (Jayne *et al.* 2006). The market is organized around large-scale millers producing high-quality flour for the urban market and small-scale hammer mills in villages that produce flour for local consumption. With high

rates of urban population growth, both countries find that maintaining both prices and supplies of maize has major political ramifications in a context of insecure supplies of the principal food staple. With high pressure on land, inability to meet household subsistence needs and continuing growth in urban demand, increasing productivity or increasing imports are the principal means of meeting increasing demand for maize in these two countries, and yet progress in sustainably increasing maize yields has been limited. Kenya significantly increased yields in the 1970s but since the early 1980s yields have plateaued then declined before increasing again recently.

In Ghana, maize is a secondary staple, widely consumed but in far smaller amounts than the root crops that tend to be the primary staple. Maize is grown throughout the country, but the major expansion has been in the transition zone between the forest and the savannah. The large majority of the crop goes to meet subsistence needs or is traded at local level. About 14 percent of the crop, or 170 000 tonnes, goes into large-scale food processing which makes a range of products for urban consumption and another 13 percent is absorbed by the growing animal feed and poultry sector (WABS Consulting Ltd 2008). Yellow maize is sometimes imported, especially by animal feed producers, who prefer bulk imports to assembly of supplies on the local market. This is due to the high marketing margins for maize and the ready access to imports from the USA. As with many countries in sub-Saharan Africa, there is an emerging formal market for maize in Ghana but with constraints on efficient marketing of maize grain and with insufficient incentives for farmers to improve productivity.

Ghana maize breeding and seed systems

The history of maize breeding in Ghana is one of progress under donor programmes and then regression, as capacity has been lost. As in most sub-Saharan countries, there insufficient organization and dynamic growth in maize grain markets to provide the incentives for the production of a steady flow of new varieties, a seed system that will distribute them to farmers and remunerative prices and market access for farmers to adopt both seed and fertilizer in the search for higher yields and incomes. Each one of these is necessary for the overall system to move to a process of market-led growth in productivity, utilization and demand. To put in place any one without the other leads to stagnation in that component. The history of maize breeding in Ghana is thus one of promising starts followed by lack of sustainability in core capacity.

Progress in maize breeding in Ghana began with the Ghana Grains Development Project (GGDP), which was launched in 1979 and supported maize breeding for 18 years until 1997. GGDP was supported by CIDA and was implemented by CIMMYT, in essence as a country project. The programme relied on spill-ins from CIMMYT's international variety testing network, where experimental lines were sent from Mexico and evaluated on station at the Crops Research Institute (CRI) and then in farmers fields. This is normally the first stage in the development of any breeding programme, namely assembling a wide range of genetic diversity and determining which is adapted to local conditions and has the traits that are needed in the country.

As Morris *et al.* (1999) note: “GGDP scientists identified truly outstanding materials, which were then taken back to CRI for several additional cycles of selection and improvement.” The programme thus introduced a wide range of genetic variability but within relatively advanced breeding populations. The final finishing provided the basis for the establishment of a concerted crossing and selection programme, which was able by 1996 to produce some of the first quality protein maize (QPM) hybrids.

The GGDP released 12 varieties in its duration, starting in 1984 with a medium-maturity, white dent OPV and finishing with three QPM hybrids in 1996. At the same time three breeders were trained at the PhD level, establishing a basis for ongoing development of maize breeding in Ghana. There were no further releases of maize varieties until 2007, when a yellow OPV primarily designed for the poultry market was released. With the termination of the GGDP, the breeding programme was not able to move to the next stage in its development, the three breeders resigned, some accepting positions with international centres, and the programme retrenched, until the recent return of donor funding in support of crop breeding in Ghana.

It is useful to ask why the programme could not be sustained. The most obvious answer is the resignation of the senior maize breeders, partly as a result of the significant decline in operational funding following the withdrawal of donor funding. A testing network, particularly one that involves farmer testing, requires considerable operational funds, and in many ways this is the key component in a variety development programme. At the same time, a breeding programme often gets locked into the sources of the first successful variety, which in this case was ‘Obatanpa’, a white, QPM OPV. This was the early days of QPM breeding and was a particular CIMMYT objective (although CIMMYT’s QPM breeding programme closed temporarily in the early 1990s). Two principal populations were used to develop these four varieties, population 62 and 63. At the same time yield potential was about 4 to 6 tonnes per hectare with three-way-cross hybrids, well below what was initially achieved in Bangladesh and Thailand.

The Ghana programme was the first to develop acceptable QPM varieties in sub-Saharan Africa, and ‘Obatanpa’ was distributed to several other countries through the Saskawa Global 2000 programme (Krivanek *et al.* 2007). The QPM hybrid ‘Mamaba’ continues to perform well against more recent hybrids developed within the DTMA programme in West Africa (Badu-Apraku *et al.* 2009). Breeding for QPM has to manage three distinct genetic components at the same time and as such requires a significant number of breeding cycles to develop the trait. At the same time the programme was breeding for other characteristics that would establish it as a commercial variety. Much of QPM breeding focuses on converting established elite cultivars to QPM (Krivanek *et al.* 2007), an increasing breeding approach with novel traits or even transgenic approaches. At issue then was how much further progress could be made with recurrent selection with these populations. The breeding programme was at a juncture in breeding strategy when donor support ended.

Ghana received a World Bank loan, the Agricultural Services Subsector Investment Project, in 2000, but support to agricultural research was primarily channelled through competitive grants, which did not support the longer-term capacity needed in maize breeding. IITA's WECAMAN network provided some minimal operational funding for maize breeding, but mostly focused on testing of IITA maize lines, even providing breeder seed for multiplication by national programmes. However, no new maize varieties were released in this period, much less adopted by farmers (Figure 4). Only about 2 000 tonnes of maize seed is produced in Ghana (Alhassan and Bissi 2006), virtually all OPVs, enough to meet less than 10 percent of potential seed demand in the country. Seed production is variable and linked to the supply of foundation seed produced by the Grains and Legume Development Board, a parastatal charged with the production of foundation seed for sale to certified seed producers. This amounts to about 400 tonnes per year, but production is based on expression of demand by seed companies and often requests are limited. Development of seed companies and agrodealer networks are still nascent in Ghana, which limits the potential for effective distribution of new varieties.

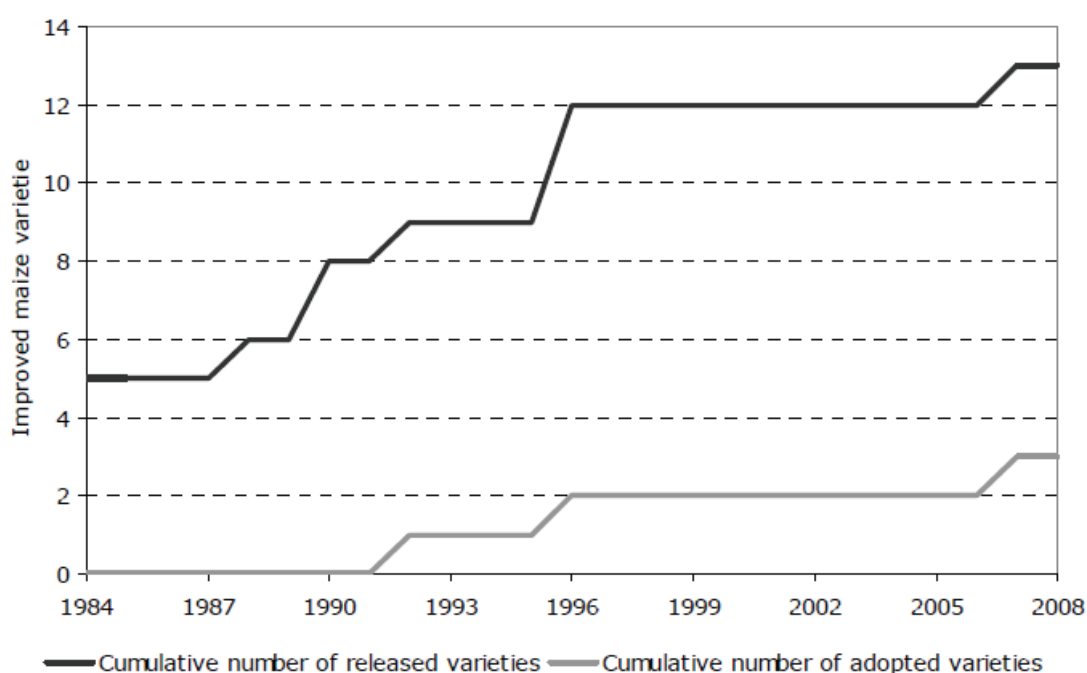


Figure 4. Release of maize varieties and uptake by farmers in Ghana, 1984–2008. Source: Derwisch (2008).

The current phase of rebuilding maize breeding, which started in 2007, again relies on donor support, provided through two principal channels.

The first channel is the DTMA initiative, which is a joint project by CIMMYT in East and southern Africa and IITA in West Africa and funded by the Gates Foundation. DTMA's stated aim is "to develop and disseminate drought tolerant, high yielding, locally-adapted maize varieties and to reach 30–40 million people in sub-Saharan Africa with these varieties in 10 years." The

programme provides pass-through funding to support national maize breeding and multilocational trials on farmers' fields. In the 2008 trials the great majority of the varieties came from the IITA maize breeding programme, although CRI and Premier Seed Co in Ghana each contributed two hybrids. What is striking from these trials is that in the Sudan Savannah ecology of the upper northeast of the country, the farmers' variety outperformed the drought-tolerant hybrids and OPVs (Badu-Apraku *et al.* 2009). In the trial of late and medium maturity OPVs at five sites in Ghana, the farmers' variety averaged 3.2 tonnes per hectare against a trial average for 16 varieties of 3.6 tonnes and maximum yield of 4.2 tonnes (Badu-Apraku *et al.* 2009). This suggests good cultural practices, especially adequate soil fertility, gives the largest yield advantage and the potential yield gain from new varieties, even with drought tolerance, is at best of the order of 20–30 percent.

The second channel is through AGRA and provides direct support to the maize breeding programmes in both the Savannah Agriculture Research Institute (SARI) for the Sudan Savannah zone and CRI for the transition zone. These are normally three-year grants and support an existing crossing and selection programme. At the same time start-up grants are provided for domestic seed companies. However, the central constraint remains a lack of demonstrated effective demand by farmers for improved seed, especially where the principal constraint on yields is soil nutrient management. In 2008 the government instituted a fertilizer subsidy programme based on vouchers that allowed farmers to purchase fertilizer at half the market price. However, only half the vouchers were redeemed in the 2008 season, reflecting in part both the late issue of the vouchers in relation to the planting season and the underdevelopment of the agrodealer network (Banful 2009). The subsidy programme has continued into the 2009 and 2010 season, and is not unlike similar schemes in a number of countries in Africa. It is not clear whether the increased use of fertilizer has had any spillover into increased sales of improved maize varieties, although some coordination between the two would be potentially beneficial. Ghana still is searching for a trigger that will motivate the development of a maize seed sector in the country, supplied by a stream of new varieties.

Malawi maize breeding and seed systems

The history of maize breeding in Malawi developed through a series of stages not unlike other African programmes, namely initial reliance on expatriate breeders, hybrid development for commercial farmers, development of indigenous capacity focused on smallholder needs and, most recently, increasing reliance on private-sector varieties. Development of breeding capacity in the public sector began in the late 1970s, particularly with the initiation of a hybrid maize breeding programme in 1977, stimulated by the high cost of procuring SR-52 from Zimbabwe given the trade sanctions during that period (Smale and Heisey 1994). USAID supported agricultural research in Malawi in between 1979 and 1984. The three maize breeders were all sent out for PhD training in 1981, although after producing three dent hybrids (MH14–16) for commercial producers. A breeding programme to produce flint hybrids was initiated in 1987 after the return of the maize breeding team. Flint

varieties were preferred by smallholders because of their higher yield and greater efficiency in producing the fine maize flour preferred in the country. By this time the World Bank had funded the National Agricultural Research Project (1985–93), which provided support to the breeding effort. By 1990 the team had released the first semi-flint hybrids, MH17 and MH18, developed using the top-cross method (Smale and Heisey 1994). This involved taking one parental line from the dent hybrid breeding programme and crossing it with a line from Population 32, a flint population developed by CIMMYT. Adoption of hybrids by smallholders increased from 10 percent of maize area in 1989/90 to 24 percent in 1992/93 (Smale and Heisey 1994).³

Maize breeding focused on two ecologies, mid-altitude and lowland (primarily lake shore). The mid-altitude zone is the principal maize-growing area, and the programme bred for medium- to late-maturing types, flint to semi-flint and a range of disease constraints in both OPVs and hybrids. For the lowland area the focus was on early maturity, drought tolerance and disease resistance, with a principal focus on OPVs. However, capacity in the maize breeding programme was difficult to maintain through the rest of the 1990s. World Bank support to agricultural research ended in 1999, although there was some operational support from the Rockefeller Foundation. This was also a period of significant turnover in personnel in the maize research programme, in part due to the impact of HIV/AIDS and in part due to staff leaving because of very low remuneration. A review of salaries for breeders in 1996 found that Malawi and Tanzania offered by far the lowest salaries in East and southern Africa (Hassan *et al.* 2001). No further varieties were released during the 1990s, even though this was a period of significant change in provision of seed and fertilizer in the country.

The production and distribution of seed in the 1980s and early part of the 1990s was essentially through state-owned parastatals. The National Seed Company of Malawi (NSCM) was formed in 1978 to produce seed, which was then distributed through the Agricultural Development and Marketing Corporation, often at subsidized prices. In 1993, with the change in government, there was a process of market liberalization. Both input and output markets were liberalized and a national seed policy was adopted. This allowed the entry of private seed companies and turned NSCM into a private, profit-making company. However, functioning markets do not develop overnight, and the seed market in Malawi was especially limited by the relative dearth of commercial varieties and the lack of an agrodealer or stockist network through which to efficiently distribute these varieties. At the same time, under Malawian conditions the return to purchase of hybrid seed is also determined by the price and availability of fertilizer. The removal of the fertilizer subsidy in 1996 caused use of both fertilizer and hybrid seed to drop dramatically. Maize shortages in the 1996/97 season and the associated food

³ Hassan *et al.* (2001) estimate 14 percent of the maize area was planted to hybrids in 1997, while Setimela *et al.* (2009) estimate hybrid adoption at 22 percent in 2006/07. Minot and Smale (2007) present data showing significant variability in hybrid use after 1994, varying from as low as 10 percent to as high as over 50 percent, primarily due to changes in government policy and subsidy programmes.

crisis resulted in the development of the Starter Pack Program in the 1998/99 season, which evolved into the Targeted Inputs Program (TIP) in 2000/01. Under these programmes a package of seed and fertilizer was distributed to farmers in a particular income or resource bracket. In 2002/03 rather than distributing packs of seed and fertilizer, the programme moved to a voucher system, which evolved into the Agricultural Inputs Subsidy Program (AISP) in 2004/05. Development of the maize seed market essentially depended on the evolution of these programmes.

Government policy from the late 1990s to the present have focused on immediate solutions to raising maize productivity and production through ensuring access to fertilizer and seed. These distribution and subsidy programmes evolved in order to allow effective development of input markets, becoming so-called smart subsidies. The more difficult market was that for fertilizer, but seed had its own special characteristics as well.

About 3 000 tonnes of maize seed are sold each year in Malawi, mostly to commercial farmers (Figure 5).

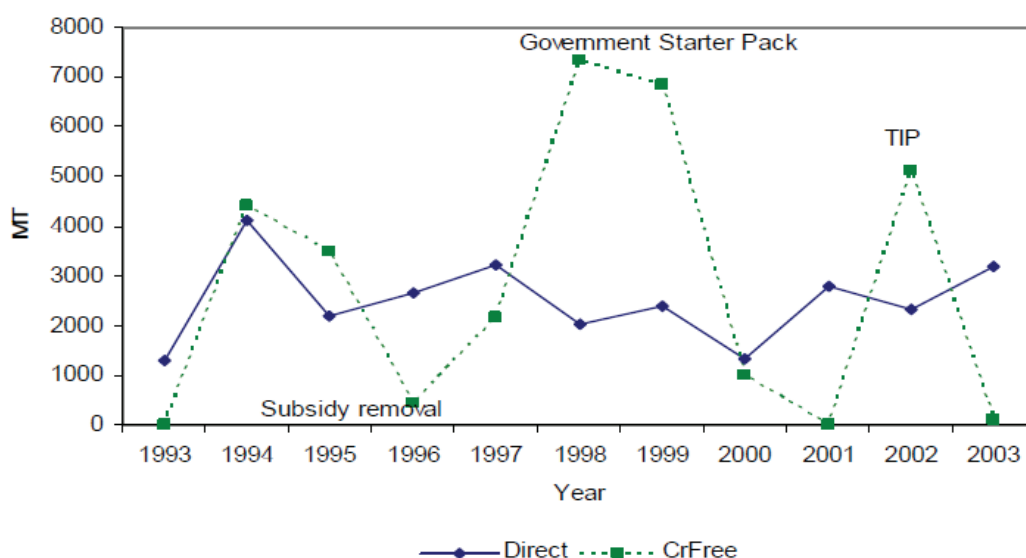


Figure 5. Maize seed sales by seed companies and distribution under government programmes in Malawi, 1993–2003. Source: Langyintuo (2004).

A “smart subsidy” programme is difficult to design, particularly in the early stages of seed-market development. The early success with hybrids was replaced by a government programme focus on OPVs. An increasing number of companies were entering the market at this stage. The first was Monsanto, which purchased a controlling share in NSCM in 1998. This was followed by entry of Pioneer, SeedCo and Pannar. This biased seed production toward those companies producing OPVs, particularly SeedCo and Pannar. Moreover, the distribution of free packs of seed, while potentially having a demonstration effect, essentially undermined the development of a commercial market. This was also at a time when the non-profit organization

CNFA had programmes to develop agrodealer networks and capacity in the country. There was a rapid increase in production and distribution of OPVs between 1997 and 2000 (Figure 6), essentially because of procurement policies of government programmes.

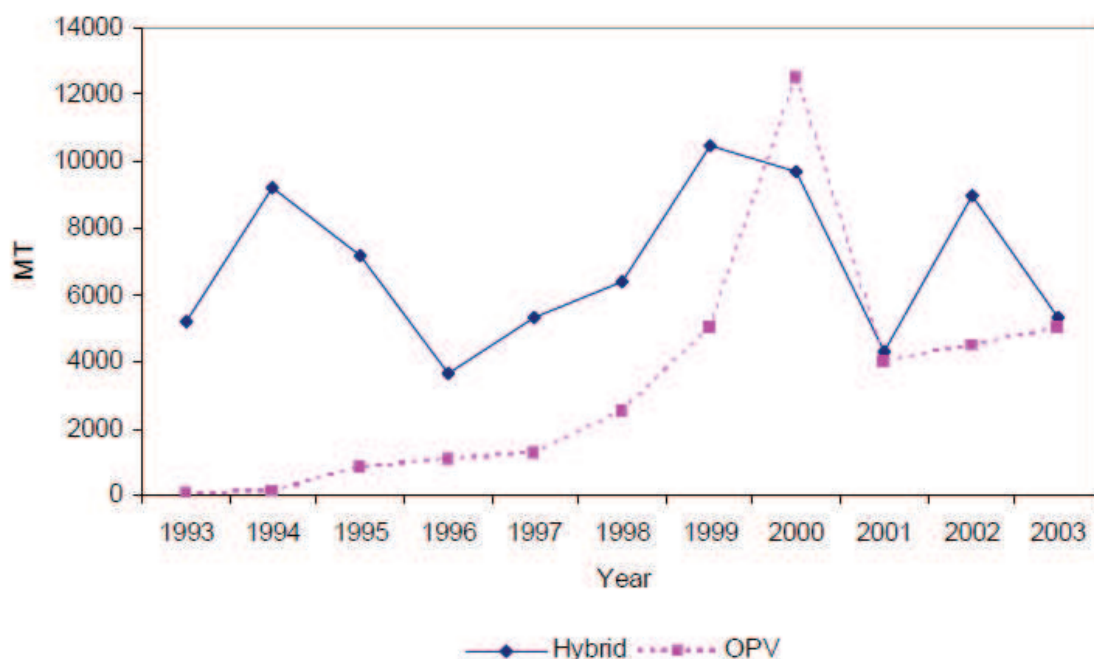


Figure 6. Hybrid and OPV seed supply in Malawi, 1993–2003.
Source: Langyintuo (2004).

Two changes had to be made in developing a commercial seed market under the subsidy programmes. The first was to distribute inputs on the basis of vouchers that farmers could redeem for inputs at agrodealers or other distribution points. These were instituted in the latter part of the TIP programme, but were central to the design of the AISP which started in 2005/06. However, these could be exchanged only for the seed provided through the programme. In 2006/07 flexible vouchers were introduced which gave farmers the choice of whatever maize seed packages were available. This opened the market for all companies and both OPVs and hybrids. The second and related component is that programme supplies would not be provided through a tender system. This is a standard system for government procurement, but biases against hybrids, because OPVs can be produced so much more cheaply. In the shops farmers would have to pay a supplement with the vouchers for hybrids, but it gave farmers a clear choice in terms of product. In the last two seasons of AISP purchases of hybrids have gone back up.

AISP has to a significant extent met the objective of providing national food security by increasing maize productivity, although this comes at some cost. The subsidy programme takes up about 60 percent of the total agricultural budget. The agricultural budget has risen from 8 to 14 percent of the overall

government budget. This significantly limits potential investments in longer-term research capacity, and this is reflected in adjustments in maize-breeding capacity within the national programme. Since 2000 there has been a major increase in the number of new varieties released. Most of these have come from Monsanto, Pannar, SeedCo and, to a lesser extent, Pioneer. The national maize breeding programme has drawn on CIMMYT to either release finished hybrids or cross elite lines with adapted Malawian lines. In 2002 three hybrids were released, CZR 3, 4 and 8. This was followed by the release of MH26 in 2005, MH27 in 2007 and MH28 in 2008. Six OPVs were also released, some developed in association with Afgri Seed Company of South Africa.

In 2007 the national maize programme moved to licensing its varieties to private seed companies, although without exclusive rights. AISP has provided the market space for the participation of four domestic seed companies, Seed Tech, Fungwe, Demeter and ASSMAG, the latter being an association of community-based seed producers. Thus, Seed Tech produces MH26 and MH27 and ASSMAG produces MH26. Fungwe and Demeter serve an important market niche in producing only OPVs, although Pannar and SeedCo also produce some OPVs. The Seed Trade Association of Malawi (STAM), set up in 2004 primarily to lobby for the removal of tendering in AISP, has since been developing plans on how best to support the development of small, domestic companies in such areas as production of foundation seed, jointly owned processing facilities and setting industry standards for certified seed. STAM started with 32 members and is now down to a membership of 13, reflecting the consolidation in the market.

The only maize breeding done in Malawi is by the national maize research programme. At a point in time when there is increased capacity in the private sector for maize seed production, the capacity for maize breeding continues to decline. The senior maize breeder is also the director of the station, and only has two young scientists with MScs to whom to delegate activities for both ecologies. The head of the Seed Services Unit is also a maize breeder and receives funds from AGRA. However, there is increasing pressure exerted by STAM for certification services in the production of hybrids, a particularly difficult task in the Malawian context because of increasing dependence on smallholder seed producers (Langyintuo 2004). Government funds cover only about 20 percent of operational requirements, and this at significantly reduced operational levels. Pedigree breeding has stopped in the main programme, although the AGRA support allows the one maize breeder to continue to work with CIMMYT materials. A principal source of funding for the programme and the focus of much of the operational activities is the trials network. Because the four multinational companies breed outside of Malawi, they require multilocational testing facilities within the country. This is to a certain extent provided by the East and southern Africa regional trial network coordinated by CIMMYT under the DTMA project. The national programme runs a set of 12 trials across five sites funded through the project (Magorokosho *et al.* 2008). The programme also runs a set of regional trials especially designed for SeedCo and Pannar. The breeding programme runs the national performance trials that support varietal release; and these are

done in five sites and participants pay for the testing of varieties. CIMMYT provides occasional support for mother-baby trials through the DTMA drought-breeding work.

Should Malawi rely in the future on the maize varieties coming out of regional breeding programmes, particularly given the lack of funding from either government or donors to support such a capacity? That breeding capacity is based either in South Africa or Zimbabwe. In part this is a question that could be addressed by empirical data but those data are largely proprietary. The results of the DTMA regional trials at Chitedze are possibly indicative. There is a large yield sacrifice for early maturity, and quite reasonable yields for intermediate and late-maturity OPVs (5.6 tonnes/ha) and hybrids (6.4 tonnes/ha). What is potentially most interesting is the very low yield under nitrogen stress: 0.6 tonnes/ha compared with 2.4 tonnes/ha with fertilization (Magorokosho *et al.* 2008). Soil fertility management is a large component of the yield gap between farmers' and on-station yields, which is the principal rationale for the subsidy on fertilizer and for an increasing focus on sustainable land management. However, the best-performing variety in the trial also gives the highest return to farmers' application of nutrients. Flint quality and poundability is incorporated in most varieties released by the private sector, and there are no particular biotic constraints in Malawi that are not found in the rest of southern Africa. So the question remains of whether the national programme should only focus on maintaining its trials network, supporting both international seed companies and CIMMYT in the evaluation of material but also giving Malawi's farmers access to the best-adapted lines.

Private sector investment is primarily tied to expected growth prospects in the Malawi seed market. The size of the current market for maize seed is about 8 000 to 9 000 tonnes, and a majority of that is OPVs. Farmers in Malawi still purchase more OPVs than farmers in any other country in East and southern Africa (Setimela *et al.* 2009), which gives an advantage to the smaller seed companies. Hybrids have not yet shown their clear superiority in the Malawian context (Pixley and Banzinger 2004) and a continued breeding capacity in this area is needed on the part of CIMMYT. Eventually a plan needs to be developed for how to gradually shift the cost of inputs back to the farmer, potentially based on more-efficient use of fertilizer combined with other soil management practices together with varieties with greater efficiency in nitrogen use. The size of the maize seed market is estimated at 38 000 tonnes (Setimela *et al.* 2009), significantly larger than, for example, the maize seed market in Thailand. However, growth in this market will not be so rapid and competition will for the foreseeable future be for market share rather than a rapidly increasing market. In the short term there is no incentive on the part of government to reinvest in the national maize breeding programme. However, this leaves CIMMYT with one vexing issue: whether to continue to release its varieties through the national programme or, as in Asia, to work with private seed companies in the development of their own varieties based on CIMMYT material, which the company would then put into the national performance trials and have exclusive rights to market.

Kenya maize breeding and seed systems

The history of maize breeding in Kenya can be encapsulated in two stages. The first stage built on the reinvigoration of the colonial research service in the 1950s and a Rockefeller Foundation programme which introduced germplasm from South America in the 1960s. The release of the new hybrids from this effort in the early 1970s led to very rapid adoption, particularly the long-season 600-series hybrids in the highland areas of Kenya. This rapid uptake was facilitated by the development of the Kenya Seed Company (KSC), a parastatal company that produced seed and distributed it through another parastatal (the Kenya Farmers' Association), and the purchase of maize grain at controlled prices by the National Cereals and Produce Board. The 500-series hybrids for the mid-altitude areas and the Katumani composites for the semi-arid areas also had quite good uptake by farmers. Agricultural research in Kenya then went through a major reorganization with the creation of KARI in 1987 and its absorption of some of the programmes from the collapse of the East African Agriculture and Forestry Research Organisation in 1977. Kenya has had a continuous cycle of World Bank loans supporting agricultural research since the creation of KARI.

During the 1980s and 1990s there was significant support from USAID in training and development of maize research programmes. Virtually all of the work revolved around recurrent selection from the populations that had been so successful in the 1970s. Varieties from the 500 and 600 series continued to be released but uptake was limited compared with the standard H614 and H512 varieties that dominated the market. At the same time breeding did not deal with some key constraints, particularly maize streak virus and the introduction of grey leaf spot. Maize yields in Kenya tracked these developments, increasing from the 1960s through to the mid-1980s, stagnating over the next decade and declining during the latter part of the 1990s. The declines in the 1990s were partly a result of market liberalization and the lag in private-sector investment in fertilizer distribution. Over the last decade productivity has again trended upwards, primarily due to increased fertilizer use with hybrid varieties.

Structural adjustment and the market liberalization process of the 1990s created the conditions for liberalization of the seed market in Kenya, which occurred in 1996. Since then domestic private seed companies have started and multinational seed companies have attempted to establish market share in competition with KSC, which was partially privatized at the time. Currently there are over 72 registered private seed companies operating in Kenya, including Monsanto, Pioneer, Pannar and SeedCo. Sales of maize seed in Kenya run between 25 000 and 30 000 tonnes, suggesting an adoption rate by farmers of around 75 percent. In the region only Zimbabwe has similar volumes and adoption rates. In 2003, when sales were at 27 600 tonnes, KSC had 85 percent of the market, with Western Seed at 660 tonnes and Pannar at 430 tonnes being the closest competitors. Competition for market share focuses on the mid-altitude areas and the three multinational companies, Monsanto, Pioneer and Pannar have increased the number of varieties that they put into the national performance trials. Between 1998 and 2008 166 maize varieties were released in Kenya, 42 in 2008 alone, of which about two-

thirds were from the public sector. However, all of the varieties of the three multinational companies come out of breeding programmes in southern Africa (South Africa or Zimbabwe) and even the seed is produced in South Africa and imported by local seed companies for distribution and sales. Of the domestic seed companies only KSC and Western Seed have breeding programmes and these appear to rely on supplies of near-finished material from CIMMYT.

Maize is the basic staple food in Kenya and the country has over the last couple decades become a net importer, although this is highly variable and closely linked to rainfall in the country. In 2009 Kenya imported over 800 000 tonnes of maize or almost a third of its requirements, largely because of poor rainfall in the country. These shortfalls led to short-term policy measures such as the distribution of free maize seed and fertilizer. Maize prices are politically sensitive but government policy has tended to focus on short-term interventions in the market rather than the longer-term development of the maize sector, particularly many of the microeconomic constraints on increasing farm productivity.

Maize breeding in Kenya is located essentially in KARI. KARI is the third largest research system in sub-Saharan Africa and this is reflected in the breadth of the maize breeding activity. Maize breeding is organized around six agro-ecologies: the coastal zone in Mtwapa; the dryland mid-altitude zone in Katumani; the dry transitional zone in lower Embu; the transitional zone in upper Embu; the wet transitional zone in Kakamega; and the highlands in Kitale. Each of these stations has at least two breeders; Mtwapa and Kitale have three. Six of these breeders have PhDs. Initially KARI was organized around national commodity programmes and regional research centres in something of a matrix system. Under the World Bank's loan to KAPP, KARI moved to a more decentralized system of regional research centres. This reduced the coordination across maize breeding, as funds went through the centres and not the national programme, although there is still a national maize breeding coordinator. Kenya is in some senses a test of local adaptation as reflected in KARI breeding versus broad adaptability as reflected in the multinational companies' breeding programme, although with significantly different financial resources.

The key constraint, as with most of breeding programmes, especially in sub-Saharan Africa, is operational funds and these tend to be from outside funding sources. Of the six breeding programmes, only three are fully operational: Katumani with AGRA and DTMA funding and Kitale and Kakamega with USAID funding. KAPP distributes its funds primarily on the basis of competitive grants and breeding programmes have not been successful in securing these. Virtually all maize breeding currently focuses on hybrids, even for the coastal and marginal zones, even though it is not clear that hybrids have a particular yield advantage in these zones. Rather, it is a strategy for getting seed companies to produce and distribute the new varieties.

The breeder at Katumani has a PhD from Cornell. He works with about 600 inbred lines, evaluates 6 000–9 000 rows per season (with two growing

seasons each year), tests 400–600 hybrids in the preliminary yield evaluations and then 30–50 in advanced yield trials in 10 sites, four in the coastal region and six in the dry transitional zone. This work is staffed by four technicians (two KARI staff and two on project funds). All the labour is temporary and hired with project funds. AGRA provides about US\$50 000 a year for the crossing and testing work. The breeder last received operational funds from KARI in 2007, from World Bank support. He submitted a budget request for 2.5 million shillings (US\$33 000) and received 600 000 shillings (US\$8 000).

In KARI the annual budgeting is done at headquarters and then divided among the centres. However, quarterly allocations from Treasury vary depending on other government spending priorities, and these funds are allocated directly to centres, who then decide how the funds are spent. In the end there is very little consistent flow of funds to maize breeding in Kenya. Within the regional centre structure, the incentive is for each centre to have a maize breeding capacity, rather than assessing the need for that capacity at the national level.

The relationship between KARI and the increasing number of private seed companies is still developing. There is no centralized unit that manages licensing of varieties. The breeders themselves have to take the initiative and establish a relationship with a company or companies. Once the demand for a variety by a company is identified, a license based on royalties is signed between KARI and the company. The royalty is supposed to be divided between KARI, the breeding programme and the breeder, although it is not apparent that there is yet a flow of such funds. It is the hybrids that are licensed and these are provided on a non-exclusive basis, which most companies resist. Most of the hybrids are double-crosses or three-way crosses. A recent CIMMYT review of the seed sector in East and southern Africa notes that “Many breeders in the public sector as well as regulatory bodies do not pay attention to the seed production aspect when developing and releasing varieties. At the end of the day, seed companies end up with very high yielding varieties which are very expensive to produce and hence attract high seed costs” (Langyintuo *et al.* 2008). This is often a constraint for start-up seed companies to compete in a highly competitive market such as in Kenya.

Market liberalization, the development of an expanding network of seed and fertilizer agrodealers, and the second generation of maize breeding has over the last decade reversed the downward trend in maize yields. Average maize yields, based on periodic farm surveys, have increased from 1.47 tonnes/ha to 2.07 tonnes/ha. What is more impressive is that this yield increase has been consistent across the maize ecologies. However, much of this increase is primarily attributable to increased fertilizer usage, as adoption rate of improved maize varieties has remained constant at about 70 percent of farmers, while fertilizer adoption has gone from 57 percent to 71 percent and application rates have also increased slightly to 145 kg/ha (Tegemeo, 2008). At the same time the number of varieties planted by farmers has increased significantly.

Kenya has in large part put in place the conditions for a sustainable increase in maize productivity, with the potential of doubling maize yields and reducing yield variability. Kenya has a vibrant and expanding seed sector supplied with new varieties coming from both KARI and the regional breeding programme of CIMMYT, which is based in Kenya. Although KSC remains dominant in the market, farmers are experimenting increasingly with new varieties and the newer seed companies have made inroads, particularly into the mid-altitude areas. The size of the Kenyan seed market has made it attractive to multinational seed companies but their varieties from regional breeding programmes in southern Africa have faced stiff competition. CIMMYT has led efforts to breed for particular traits, including drought tolerance, resistance to striga and stemborer, and increased nitrogen-use efficiency. How these traits will be deployed through varieties produced by the seed companies is still a relatively open issue. CIMMYT has developed two tracks for their varieties. KARI itself will put some of these into the national performance trials, ostensibly as KARI varieties. However, companies are still somewhat reluctant to pick up these varieties because they would have non-exclusive rights. Those that utilize CIMMYT material that is close to being released as a fixed line, such as Western Seed and KSC, do a little selection and then release it as their own variety with exclusive rights. KARI does not provide exclusive rights to its varieties. The result, nevertheless, is an increasing supply of new varieties, primarily hybrids, moving into the market. This, however, must be matched by continuing work on fertilizer use efficiency, given the high price of the commodity, and this may be done through better targeted blends, combinations with organic nutrient sources, higher adoption rates for conservation agriculture and genetic approaches.

Cassava breeding and seed system in sub-Saharan Africa

Cassava competes with maize as being the most widely grown crop in sub-Saharan Africa. It is the major food staple in large parts of the continent, and is the principal staple food in the Congo basin and the root crop belt of West Africa, including Ghana. It is also widely grown in the more semi-arid areas of southern Africa where it is important in providing stability in food supplies. Its high yielding ability, particularly on poorer soils, has also led to significant growth in production in countries with a high population density such as Malawi. The roots are processed into a wide range of foods. A roasted flour, *gari*, has developed as an inexpensive, convenience food in urban markets in West Africa, especially in Nigeria. Most cassava research programmes currently link research on production technologies with market development, as for example with the Regional Processing and Marketing Initiative on Cassava, funded by the International Fund for Agricultural Development (IFAD), which has supported integrated production and marketing programmes in West Africa, including Ghana, since 1996.

Cassava research has a relatively long history in Africa (Nweke 2004), with breeding for resistance to cassava mosaic virus (CMV) in the 1930s at the Amani research station in Tanzania. The crop, which was domesticated in Latin America, has faced a range of biotic challenges over the last several

decades. The early work on CMV resistance had to employ an interspecific cross with *Manihot glaziovii* to develop a resistance source, which became the basis for the start of the IITA cassava breeding programme in 1971. The breeding programme focused on incorporating resistance sources to CMV and cassava bacterial blight. This was followed by the cassava mealybug pandemic in the 1980s, the outbreak of the virulent CMV variant in East Africa in the 1990s, and the more recent pandemic of cassava brown streak virus in East and southern Africa. Cassava research, and particularly the breeding strategy, has had to respond to these destructive pest and disease outbreaks. At the same time cassava exhibits a significant G×E interaction (Vargas *et al.* 1999), which makes the number of breeding ecologies and the choice of selection sites very important in designing a cassava breeding programme. Yet, in many respects, breeding for cassava has been one of the more centralized crop breeding programmes on the continent, highly dependent on the breeding efforts at IITA in Nigeria and the unsustainable regional breeding programmes of IITA in Malawi and Uganda.

Ghana cassava breeding and seed systems

Nweke (1994) argues that Ghanaian government policy focused on grains up to the mid-1980s, often to the detriment of cassava. However, a major drought in the early 1980s highlighted the role of cassava in stabilizing food supplies – as also was evident with the recent spike in world food prices – and government policy shifted to greater investment in cassava research and development.

The first introductions from IITA began in 1988 with the import of stem cuttings for evaluation under the Central and West African Root Crop Network. This resulted in the release in 1993 of three varieties that originated from the IITA breeding programme in Nigeria, followed by one variety in 1997 derived from mutation breeding. There was a progressive shift from pure evaluation to the beginnings of a crossing and selection programme, primarily based at CRI, with the IFAD-funded Root and Tuber Improvement Programme (RTIP), which started in 1998 and ran to 2004. There was a significant shift to a focus on marketing in the second phase, which was renamed the Root and Tuber Improvement and Marketing Programme (RTIMP). Five varieties were released under the RTIP programme, mostly from evaluation of fixed lines by CRI, SARI and even the universities. Two of these varieties were selections from local landraces. The other three were early-maturing varieties directed to the drier areas in the north of the country.

In 2003–2005 DFID's Research Into Use (RIU) programme funded a participatory breeding programme implemented between the Natural Resources Institute and CRI (Gibson 2005). This programme sourced 1350 seeds from an IITA crossing block in Nigeria involving 16 half-sib families. Both farmers and breeders evaluated and selected clones through various selection cycles, resulting in 29 superior accessions that were ready to go into multilocational testing for potential release.

The last source of support to cassava breeding is through the World Bank's WAAPP, aimed at "strengthening the alignment of national priorities with

regional priorities within participant countries' national agricultural research systems" (World Bank 2007) and supplying new cassava varieties to the Economic Community of West African States (ECOWAS) region. CRI's root and tuber programme became a national centre of specialization under WAAPP.

This highly summarized review of cassava breeding in Ghana makes the point that both capacity and operational funds have depended on a succession of uncoordinated donor programmes. The initial introduction of varieties was both limited and relatively ad hoc, and yet these became the base for the development of a sustainable "seed" multiplication and distribution system under RTIP. One of these four varieties went into early multiplication but was rejected by farmers because of its low dry-matter content (IFAD 2005). The three remaining varieties were multiplied and distributed in 50 districts across the different agro-ecologies of Ghana, reaching close to 100 000 farmers. While adoption data is not available, there is a question of whether farmer acceptance was based on the availability of clean planting material free of virus or on the inherent traits provided by the new varieties. Further support to the development of a larger portfolio of varieties was built on a very weak breeding capacity, essentially relying on evaluation of existing varieties. The participatory breeding effort was very short lived and relied on an IITA polycross block for germplasm, and movement to multilocational trials was cut short by the ending of the project. All of this provides a very weak base indeed on which to structure a regional cassava breeding programme under WAAPP at the CRI station. To a certain extent a fully functioning breeding programme would have to start with the collection and evaluation of potential parents across agro-ecological zones. Because of difficulties with flowering, the crossing block would probably be best located in the transitional zone. However, early generational evaluation should be done in a number of sites, if possible with evaluation by farmers, building on the expertise created under the RIU project, but even that does not provide the basis for transferring and testing these varieties in the ECOWAS region.

Ghana's experience in developing a seed system for cassava is, however, worth noting. The RTIP multiplication and distribution system was based on a three-stage process. The country was divided into six agro-ecological zones. Varieties were multiplied in each zone at a primary site operated by either the Grains and Legumes Development Board or the Ministry of Food and Agriculture. Optimal agronomic practices were applied and plots were monitored by plant material inspection teams that rogued diseased plants. Material from the primary sites sufficient to plant two hectares was then distributed to a broader network of secondary sites managed by certified farmers. The costs of certified seed production were covered by the project. The seed material was then distributed by the project to an even larger network of tertiary sites located within 20 km of the secondary site, usually organized around farmer groups that met a set of criteria ensuring equitable access. Tertiary groups changed each year, and these groups could also sell stems of the new varieties to other farmers in the community. However, the sustainability of such a system depends on a continuous flow of new varieties and each stage in the process being able to cover its costs through sales of

the stems. The seed system never evolved to this point, partly because of lack of new varieties and partly because of the inability to test a pricing system for cassava stems.

Malawi cassava breeding and seed system

Cassava production in Malawi has expanded rapidly since the 1991/92 drought in the country (Haggblade and Zulu 2003). As part of the drought relief measures applied in the two years after the drought, four local landraces that had been released were multiplied and distributed. This was also the time of the market liberalization process and the removal of fertilizer subsidies. Increasing problems with soil nutrient depletion and succeeding droughts further motivated a shift to cassava cultivation. Increasing supplies of cassava found their way to urban markets, resulting in a significant increase in demand for fresh cassava roots.

These events to a certain extent track the development of cassava breeding in Malawi. A crossing and selection programme for cassava started in 1989–90 with the placement of an FAO expert in Chitedze with funding from the United Nations Development Programme. This programme lasted about four years, which dovetailed with the start of the first phase of SARRNET, implemented by IITA in 1994. The FAO expert moved over to IITA, and within the SARRNET structure Malawi was given responsibility for breeding research. The breeding was jointly managed as a “country-led regional activity” until the end of phase 1 in 1998. Phase 2 put emphasis on marketing and processing; there was no further support for plant breeding and the programme just ticked over. In 2000 three varieties were released, all IITA varieties originating in the Nigerian breeding programme and all bitter varieties. One further variety coming out of the SARRNET programme was released in 2002, also a bitter variety.

The MSc breeder was sent for PhD training at this stage, returning in 2003, which coincided with the termination of USAID support to SARRNET. The programme became fully a Malawian breeding programme, subject to the resource constraints faced by other breeding programmes in the country. The breeder adjusts breeding activities to the funds available from the government and from grants. Thus, in some years no crossing will be done and the work focuses only on moving material through selection stages. Since 2007 AGRA has provided a grant and the programme has expanded, although it is still small by comparison, for example, to the Thai programme (Table 4).

Table 4. Cassava breeding capacity parameters, Thailand and Malawi.

	Thailand	Malawi
Operational budget (US\$)	120 000	15 000 + US\$40 000 (AGRA)
Personnel		
Breeder	1	0.5 (Sweet potato)
Support scientists	5	1
Technicians	3	2
Germplasm bank	879	40
Parents in crossing block	70	20
F ₁ seedlings	8 000–12 000	5 000–6 000
Single-row trials	600–1 000	250
Regional trials	8–12 clones, 8–10 sites	12–14 clones, 8 sites
On-farm trials	35–40 for 3 years	none

However, the breeding programme is behind in meeting the demand for new cassava varieties. Most of the released varieties are only suitable for the lower altitude areas along the lake shore in the north, where consumers are used to processing bitter cassava. However, the growth is coming in the mid-altitude areas in the central part of Malawi, closer to urban areas. These regions consume fresh cassava and require sweet varieties, which to date are supplied by local landraces. The programme must produce its own foundation seed and also operates a six-hectare multiplication plot to supply NGO and government programmes. These are all sweet varieties. Yet, two varieties were released in 2008, both of which derived from past breeding efforts and were bitter. Reconfiguring the breeding programme and shifting breeding targets is not easy but is necessary if the programme is to support the increasing area being planted to cassava in Malawi.

Bean breeding and seed systems in sub-Saharan Africa

Beans are the most widely grown grain legume in sub-Saharan Africa and are especially important in providing a complementary protein source in the maize-based diets of East and southern Africa. Beans are a short-season crop and fit well within intercropping systems with maize. They can be grown even in semi-arid environments at the beginning of the rains. However, because beans are adapted to relatively low temperatures they are most often grown in higher-altitude areas, particularly the highlands of East and Central Africa, which are very densely populated.

Beans come in a range of sizes and colours and there are very strong consumer preferences attached to these quality characteristics, which in turn influences their acceptability in markets and their price. Moreover, such preferences vary significantly across countries and even between regions within a country, complicating both breeding and seed-system development.

Bean breeding requires significant stratification in the crossing and selection programme on the basis of market types and the pest and disease constraints where those types are grown. Moreover, capacity in national programmes is limited in comparison with staple-crop programmes, as breeders usually have more than one grain legume in their set of responsibilities. These characteristics argue for a network approach to bean breeding, which CIAT has led through the two regional networks, ECABREN and SABRN, which come together under the PABRA umbrella. This is a very decentralized breeding network that builds on national programme capacity but is supplemented by core capacity in prebreeding at CIAT headquarters and a regional breeding capacity in both East and southern Africa. The regional capacity can take on breeding targets not covered in the national programmes and can coordinate the regional trials network. Donors have been investing in bean breeding and research in sub-Saharan Africa for more than 20 years and the national programmes function effectively due to the pass-through of operational funding. National capacity, varietal output and impact of national bean-breeding programmes are integrally tied to the regional breeding network.

Malawi bean breeding and seed system

Bean research in Malawi was initiated with the start of the Bean/Cowpea CRSP collaboration with Bunda College in 1981 and the establishment of the Malawian National Bean Program at Bunda. This programme ran until the redesign of the CRSP in 2008. Breeding effectively started in 1988, followed closely by the initiation of SABRN in Malawi. Three varieties were released in 1993: a widely adapted CIAT variety, a Malawian landrace and a cross between two Malawian landraces. In 1994 DFID funded the establishment of the Bean Improvement Programme at the Department of Agricultural Research Services (DARS) research station in Chitedze, creating two competing breeding programmes but with some ability through SABRN to allocate breeding priorities between the two. In 1995 six varieties were released from the Bean Improvement Programme, all derived from CIAT lines; four were large-seeded Andean types and two were small-seeded Mesoamerican types. In 2002 two climbing bean types were released, both from CIAT lines, one of which was bred in Uganda. Before the close of the CRSP project Bunda College released three varieties, one high-yielding small-seeded type and two medium-seeded cranberry types. A 2005 impact evaluation found that “93% of rural households had accessed and adopted new varieties, however the proportion of farmers that adopted improved crop management practices was lower (64%). In terms of the share of seed planted in 2005, improved varieties accounted for 68% of total seed” (Kalyebara *et al.* 2007). The study noted the effectiveness of the seed dissemination strategy but that on-farm yields were still constrained by lack of effective crop management practices.

Malawi’s inability to provide adequate levels of funding for agricultural research is reflected in staffing within the bean programme and in overall trends in the number of plant breeders (Figure 7). There has been a consistent decline in the number of breeders since the end of the National

Agricultural Research Project. Currently the Bean Improvement Programme has three scientific positions: pathologist, breeder and agronomist. In 2002 the breeder left to join SABRN as the regional bean breeder. A plant breeder who was supported for training to PhD level died before taking up the position. A breeder who just finished his PhD on bruchid resistance in beans at the African Centre for Crop Improvement in KwaZulu-Natal was immediately moved up to be put in charge of the grain legumes, oilseeds and fibres programme, as well as soybean and groundnut breeding – with a small grant from AGRA to keep his bruchid material moving forward. A staff member with a BSc is now studying for her MSc in plant breeding in Penn State University under a USAID scholarship. The plant pathologist does all the breeding work in the bean improvement programme. There are supposed to be three technicians in the programme but there is currently only one and he is out for training to get his diploma.

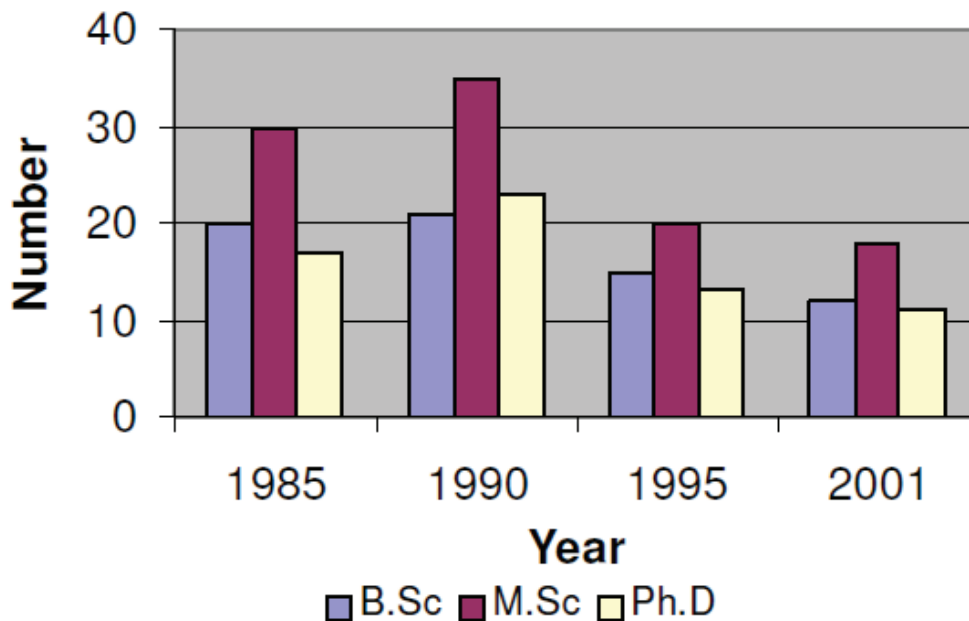


Figure 7. Number and educational level of plant breeders in DARS, Malawi, 1985–2001. Source: Ambali *et al.* (2004)

The programme has one vehicle which is old, not running and will cost more to fix than there is budget. The programme submits annual workplans and budget averaging a little less than US\$10 000 for the whole programme, and on average receives about US\$280 a month.

The bean improvement programme continues to function essentially as a partner in SABRN, where the “breeding” programme, because of the current lack of a plant breeder, focuses on evaluating nurseries and moving lines forward and on producing sufficient foundation seed for dissemination, all supported by funding coming through the network. The programme remains effective and can maintain continuity because of SABRN. Other funding

sources such as AGRA and the GL II project on drought funded by the Gates Foundation are only supplementary and do not address in a coordinated manner the capacity constraints at the level of the Bean Improvement Programme, much less at the level of the Grain Legumes, Oilseeds and Fibres group. Building breeding capacity for secondary food staple crops in an African context, such as in Malawi, relies on the type of long-term effort provided by the regional breeding networks, at least until there is again a joint government and donor effort at developing fully functional NARIs.

The impact study (Kalyebara *et al.* 2007) suggests a pluralistic set of dissemination pathways of new varieties that eventually are consolidated in informal seed markets through purchases either in markets or from other farmers. The most widely planted variety in 2005 (33 percent of farmers) was a 2002 release, followed by two varieties released in 1995. All of these were medium-sized, red or cranberry types, and the 2002 release was an indeterminate type that could climb. The high point of adoption was in the 2003/04 season, which also coincided with distribution of bean seed through TIP, as well as through NGOs. However, one season's multiplication at farm level was sufficient to supply a large number of farmers in the next season through informal seed markets. This has put emphasis on developing multiple channels for initial evaluation and potential adoption of new varieties, including participatory plant breeding, distribution of small packs of seed (a strategy promoted under the Bean Improvement Programme), and the occasional government or NGO seed distribution programme. Highly preferred types will then find their way into the markets for even broader distribution. Early farmer evaluation, a more continuous flow of new varieties and a capacity to produce foundation seed are characteristics of a bean seed system that has been very successful in Malawi.

Conclusions: Building a functional plant breeding capacity in Africa

The post-independence history of plant breeding capacity and impact in sub-Saharan Africa has been intimately coupled to the significant shifts in funding for agricultural research and with the very rapid changes in "paradigms" relating to the most effective organizational modalities for research systems on the continent (Sumberg 2005). Sometimes these shifting paradigms have been congruent with the needs of a functional plant breeding system, but more often they have been destabilizing. At the same time, plant breeding has its own particular organizational architecture, which relies heavily on predictable recurring support, continuity and longevity. This architecture is inherently hierarchical and in an African context must balance centralized and decentralized functions, which in turn often link at supranational level. Furthermore, because plant breeding in sub-Saharan Africa is essentially a public-sector enterprise, the source and flow of funds have an integral impact on the overall integrity of the plant breeding system and the relative strengths and weaknesses of its component parts. Recently, specific funding for plant breeding has been given increased emphasis through its perceived role in generating a Green Revolution in Africa (Blaustein 2008).

While there is some potential for compensatory adjustment at different levels of the system, overall it still inherently depends on some degree of functional capacity within national plant breeding programmes, which has often been the weakest and most unstable component in the system. This concluding section will summarize these overall trends, with a view to suggesting options of how a more functional, productive plant breeding system might be developed on the continent.

An emerging architecture for plant breeding in Africa?

Plant breeding in sub-Saharan Africa over the last four decades has been driven by the multiple challenges of coexisting with locally adapted varieties within the context of significant spatial heterogeneity and temporal variability, underdeveloped input and output markets and a resultant inability of farmers to manage principal biotic and abiotic constraints effectively, especially within the context of intensification of farming systems. Moreover, when quality characteristics were sacrificed for yielding ability, as with maize and cassava in Malawi, adoption rates were low among subsistence-oriented farmers. This has led to a complex calculus of trade-offs between meeting needs for multiple improvements amidst highly constrained financial and human resources at both national and regional levels. This calculus is particularly difficult at the national level where breeding programmes may be asked to breed for a number of agro-ecologies and improve many significantly important traits, all while the size of the crossing and selection programme is limited by insufficient personnel, physical facilities, technology, budget and access to sufficiently well characterized germplasm. This has created the potential for some division of labour at a subregional level and sharing of germplasm among countries. However, that potential also has rarely been achieved, in part due to lack of effective institutional arrangements and a very weak empirical base on which to select the best sites for germplasm evaluation.

Plant breeding is an information-intensive activity that can benefit greatly from applying modern information systems to integrate spatial analysis through GIS with phenotypic data from multilocation trials and, increasingly, genotypic data from molecular characterization. Spatial data bases for Africa are now increasingly available and can be used to select the optimum number and location of trial sites in relation to agro-ecological variance. Modern breeding relies heavily on gathering, understanding and applying multiple sources of information about the genetic make-up of the plants connected to their performance in multiple environments. An efficient trial network is a first essential component of any national or regional breeding programme, allowing effective testing of introduced varieties from other breeding programmes, characterization of potential parents and evaluation of advanced breeding lines. However, trial sites are generally chosen on a relatively ad hoc basis with only limited understanding of the extent to which they represent the “population” of target environments for production. Given the spatial heterogeneity problem that challenges plant breeding in Africa, greater investment in testing and trial capacity is needed both within countries and on a regional basis, where the various regional breeding programmes of the

CGIAR centres can be utilized. To date the costly and beneficial data generated in those trials are not systematically analysed and fed back into national and regional breeding programmes. For national programmes that choose to or must rely on spill-ins of fixed lines and cultivars developed in other programmes, comprehensive and informative accompanying data can provide the basis for a very efficient mechanism for organizing and optimizing spill-ins with considerable potential value.

Implementing and managing a crossing, selection and evaluation programme requires another level of investment from national programmes. In general, countries will invest in these for their principal staple food crops and primary export crops. Developing capacity for improving secondary food crops and specialty crops requires more justification, especially in smaller countries. Effective strategies with sufficient capacities, such as for maize breeding in East and southern Africa, might be provided by a set of decentralized breeding programmes distributed across the region with structure, guidance and support for a functional division of labour on the basis of agro-ecology, traits, consumer preference types or just selection across a wider range of conditions.

The CGIAR centres have responded to this potential in very different ways. AfricaRice does prebreeding, crossing and very early selection centrally but provides a wide range of genetically diverse populations for selection and generational advancement through national programmes, often involving some level of farmer participatory selection. CIAT has organized its bean breeding activities on the basis of a division of labour between market types and traits, doing selection where the appropriate combination applies and also incorporating farmer participatory selection at a relatively early stage. CIMMYT has a more centralized breeding effort for maize organized around three to five agro-ecologies and three maturity classes and provides advanced materials to national programmes for either evaluation or incorporation as parents into crossing blocks. Finally, IITA has a more centralized breeding programme for cassava, primarily providing finished varieties to national programmes for evaluation. These differences arise due to the nature of the crops, ability to fund operational expenses of the national programmes and the breeding histories of the centres. Whatever the overall strategy, in general the ability to select from a wide range of genetic diversity across a range of agro-ecological conditions representative of target production areas and employing selection criteria critical to farmer adoption would seem to offer the best potential for developing locally adapted and appropriate varieties.

The building blocks then are the type and functionality of capacity at a national programme level, the relative centralization, division of labour and networking in crossing and selection at a subregional level, and finally the prebreeding and more advanced breeding methods that feed genetically-enhanced, trait-targeted germplasm into the lower levels of the system. The higher-end activities have a specific base of donor support and are often seen as the scientific frontier for generating breakthroughs in the search for crop productivity increases in Africa. While undeniably important, quantifiable

impacts often are delayed. Because donors expect to see impact from these investments, this has generated a push toward building capacity for some of the cutting-edge knowledge and technology within national programmes. At the same time, this is desired by national governments who want to demonstrate that their national science and technology capacity can take advantage of rapidly changing techniques in molecular biology and other evolving fields. However, given the unconsolidated state of the basic breeding system for most commodities, how best to interface these upstream capacities with an evolving architecture for plant breeding on the continent remains an open question, with the potential for misdirecting basic investment decisions.

Coordination and integration: Linking CGIAR and national programmes

With unstable capacity in national breeding programmes and lack of long-term funding for CGIAR regional breeding programmes, evolving a coherent partnership arrangement between the two sectors has been difficult. In particular, restructuring of the SROs and development of MAPPs are institutional changes that run counter to the organization of well-integrated subregional varietal development programmes. National centres of excellence within a subregional context have not worked well as a model in the past, having been attempted earlier in SACCAR, and not just in the case of crop improvement.

Nonetheless, these institutional reforms have very significantly shifted the locus of donor funding for agricultural research in sub-Saharan Africa. CIAT has maintained its traditional funding sources and has been able to return to the pre-SRO model of operating independent commodity research networks. The ASARECA rice network was terminated but AfricaRice is currently integrating both subregional networks (ECARRN and ROCARIZ) in a pan-African network. CIMMYT and IITA have been able to maintain their subregional maize breeding efforts with grants from the Gates Foundation. The focus, however, is on breeding for drought tolerance and is shifting from conventional MAS approaches under DTMA to transgenic approaches under the Water Efficient Maize for Africa project. The movement to more upstream approaches involving specific traits assumes the availability of elite varieties to be improved in each of the countries, but at best such varieties are in various stages of development in African countries. Cassava breeding has retrenched to the IITA programme in Nigeria, with some breeding being done in Tanzania to cope with the recent cassava brown streak pandemic. The implication is that effective design of a crop-breeding system in sub-Saharan Africa that truly integrates the capabilities of both national programmes and CGIAR centres is subjugated to the changing flow of donor funds that support agricultural research on the continent. Some systems have gone through a sustained period of evolution and development, such as the bean-breeding networks, while others have gone through periods of expansion and severe contraction, such as with cassava-breeding networks.

It is too early in the CGIAR reform process to know whether development of sustained core funding for centre programmes will allow improved coherence and further consolidation of a comprehensive plant breeding system for sub-Saharan Africa. The inclination has been to pull the centres and breeding programmes into more of a global posture, with increased work on new breeding methods and biotechnology. Nevertheless, plant breeding in an African context remains a clear challenge for all of the centres, but one for which there is no clearly articulated strategy. Moreover, there is an increasing separation in the evolution of the CGIAR, on the one hand, and the sub-Saharan African platforms on agricultural research, namely CAADP, FARA and the three SROs, on the other. One alternative architecture to bridge these organizations is the recent Coalition for African Rice Development (CARD), a joint initiative of the Japan International Cooperation Agency and AGRA. This initiative takes a subsector approach and funds national rice development strategies, developed within the CAADP/FARA/FAAP framework. Rice research is only one component of these strategies. At the moment both AfricaRice and IRRI are on the steering committee, which includes representatives of principal donors, FARA and the New Partnership for Africa's Development. Whether funding for regional rice-breeding networks will be part of this initiative remains to be seen. Lamentably, improved rationalization and sustainable funding of plant breeding on the continent does not have enough visibility to enter into most strategic planning processes taking place at the regional level. As a result it appears that plant breeding efforts are likely to suffer further fragmentation rather than more integration.

Breeding capacity at the national level

Plant breeding is a long-term venture that is particularly dependent on a sustained level of operational funds, especially when a crossing and selection programme has been established. The funding process in many NARIs and systems is not conducive to consistent, sustainable support for breeding programmes, given that allocation decisions are made at higher management levels and respond to a plethora of short-term needs. Functional plant breeding capacity, where it exists in sub-Saharan Africa, has depended on recurring outside sources of funding, and there is nothing on the immediate horizon suggesting this will change. In the late 1980s and early 1990s, national plant breeding capacity was in many respects at its strongest, due to donor programmes supporting development of the overall agricultural research system. This, in turn, provided a base for creation of the CGIAR centres' regional networks. However, building national plant breeding capacity within the context of increased investment in NARIs is possible only in a few countries, with Ethiopia and Kenya being current examples.

If plant breeding is to contribute to increasing agricultural productivity, more direct means are needed for funding the programmes. Several alternatives are emerging. AGRA's Programme for Africa's Seeds Systems (PASS) focuses on this objective, particularly the programme element called Fund for the Improvement and Adoption of African Crops (FIAAC). FIAAC provides funds primarily for crop breeding programmes in national research institutes. The funding, however, tends to focus on individual breeders rather than the

national crop breeding programme itself. Moreover, this support strategy does not necessarily ensure effective linkages to breeding programmes of the CGIAR centres, but rather encourages breeding networks within its own programme structure.

The alternative is to enhance national crop breeding capacity through the subregional crop research networks, or at least those that remain. . To achieve this, the lead centre must recognize national programmes as central to its breeding strategy in Africa. Choosing which elements or functions of the breeding programme to centralized is critical. The three most widely applicable approaches are: 1) for national programmes to select and evaluate early, segregating material from a centralized crossing programme (the AfricaRice model); 2) to subdivide the breeding populations or crossing blocks across national programmes (the CIAT approach); or 3) for the centre to provide lines or nurseries with particular traits that would enter into national programme breeding programmes as parents. AGRA's rice breeders' network has suggested that AfricaRice and IRRI organize regional nurseries at a particular site for evaluation by national breeders in the region. Each of these alternatives involves different degrees of coordination and ownership of the emerging varieties and has implications for overall cost for the "system". It would be useful to conduct a comparative evaluation of these three alternatives to guide investment decisions of donors.

Applying new breeding approaches in Africa

Molecular breeding approaches, from MAS to integration of transgenes in line development, may be useful in breeding programmes. There was something of an early rush to argue that these techniques have particular applicability in the sub-Saharan African context, where there is urgent need for improved crop productivity. Molecular labs were developed under several programme initiatives supported primarily by bilateral donors, including the Netherlands Directorate-General for International Cooperation (DGIS), the Swedish International Development Cooperation Agency (SIDA), USAID and the Rockefeller Foundation, that focused largely on building human capacity linked to specific research applications, often within a university context. The development of molecular labs within NARIs has been more sporadic and usually linked to particular research programmes, either through the CGIAR centres and Generation Challenge Programme or through foundations such as the Kirkhouse Trust, McKnight Foundation and the Rockefeller Foundation. The World Bank loan to Ghana for the root and tuber component of the WAAPP includes funds for the development of a large molecular laboratory. There are, however, few if any instances of investment by national governments in agricultural biotechnology outside of South Africa. Moreover, in this review there was no instance of MAS being used in national crop breeding programmes. This leads to questions of where are the expected efficiency gains in the use of MAS in plant breeding programmes in Africa, where will the operational funds come from to support those applications, and are there greater efficiency gains to be had just in the area of conventional breeding programmes?

Molecular breeding approaches facilitate more efficient manipulation of traits. MAS, for example, is an effective mechanism for ensuring incorporation of target traits into populations for different agro-ecologies. It can also be used for pyramiding genes into elite cultivars, so called meta-varieties, where commercial varieties have an increasing number of other desired traits. In Africa this approach is occasionally turned on its head in incorporating resistance traits into principal landraces already widely grown by farmers; this has been particularly applied in grain legumes. CIAT has used markers in their prebreeding of beans for the incorporation of traits from wild relatives into breeding populations for commercial grain types (Acosta-Gallegos *et al.* 2007). Most of the CGIAR centres now employ MAS in at least part of their prebreeding work for sub-Saharan Africa. Finally, in more centralized crossing blocks, such as are used by AfricaRice, markers can reduce early progeny numbers and thereby increase the number of environments for early selection and evaluation, a particularly critical application in an African context.

Most of these applications argue for the use of MAS in more centralized breeding programmes, either in the prebreeding stage or the early generational stage, ensuring deployment of target traits within the frame of decentralized selection and evaluation from sufficient genetic variability. However, marker-assisted backcrossing is quite effective for introgressing simply inherited traits, e.g., disease resistance, to provide incremental improvement of already adapted cultivars. If marker analyses were done at a centralized facility, breeding capacity at the local level would require only an effective multisite selection and evaluation capacity for advanced generations together with an efficient trials network. Breeding efficiencies are potentially improved at each stage of the breeding process, but it requires a significant level of coordination between subregional breeding capacity and national programme capacity, potentially linked to a high throughput marker lab that would serve all crop breeding programmes in the region. The argument here then is that the gains from molecular breeding at this stage in sub-Saharan Africa rest on resolving issues around funding and institutional arrangements discussed above.

Linking plant breeding and seed systems

Seed system development in sub-Saharan Africa is quite different from other regions, primarily because of the large number of food staples grown in African farming systems, the underdevelopment of input markets and relatively deep-rooted reliance of farmers on well-functioning informal seed systems. These combine to limit extensive demand by farmers for improved varieties which in turn limits incentives for private-sector investment. However, market liberalization during the late 1980s and 1990s provided some preconditions for development of a formal seed market, particularly based on private-sector investment and increasingly on development of subregional seed markets. What seems to be increasingly clear is that development of formal seed markets is closely linked to development of fertilizer markets. As with maize in Kenya (De Groote *et al.* 2005), adoption and yield impact of improved varieties are integrally linked to farmers' access to fertilizer, and because of the disadvantageous value-to-weight ratio of fertilizer, the market-

liberalization process has particularly constrained development of fertilizer markets, with a recent return to subsidies to encourage increased farmer use.

The critical point arising from findings in the case-study countries is that improved cultivars are not a silver bullet for increasing farmer yields. Concurrent improvements in soil and crop management are essential to getting yield improvement from new varieties. For crops such as beans and especially cassava varieties resistant to the principal diseases have encouraged farmer adoption, particularly in the face of pandemics, and have contributed to yield stabilization. Seed systems developed under such circumstances have been effective but are not sustainable. A putative conclusion from these studies shows that seed-system development requires pluralistic approaches, effective linkage between formal and informal systems and private-sector participation where market conditions warrant. Development of the formal seed sector based on steady supply of improved varieties will continue to rely on effective linkages between primary multiplication in the public sector, secondary multiplication through some combination of NGOs, community seed producers and individual entrepreneurs, and tertiary distribution through informal systems based on markets and farmer-to-farmer distribution.

These case studies also highlight the lack of capacity for producing foundation seed. Neither breeding programmes nor seed units in NARIs have sufficient operational funds to mount effective foundation-seed activities and the private sector has not yet found it sufficiently profitable to fill the gap. The one attempt to develop foundation-seed capacity in a NARI was KARI's seed unit. However, because it must cover its own operational costs it has evolved more into a private seed producer, especially of OPVs, rather than providing a link between KARI's plant breeding programmes and the evolving private sector. In several programmes CGIAR centres have had to produce foundation seed, although on an apparently temporary basis. Provision of foundation seed is central to any seed system, in essence connecting initial seed multiplication with estimated or anticipated demand from farmers. Where seed markets are not well developed, mechanisms for articulating such demand have been difficult to develop, except where there are programmes expressly supporting downstream seed multiplication and distribution. The continuing lack of commercial seed markets will necessitate more ad hoc solutions, depending on push from the plant breeding side, pull from programmes distributing seed and farmer-driven demand. In some cases there have been large investments in seed multiplication and distribution systems without having a sufficient range of improved varieties on which to develop the programme, with cassava being a particular case in point.

Funding from donors such as AGRA and USAID for seed-system development has tended to focus on private-sector development, building around companies producing hybrid maize. Without a doubt, hybrid maize has encouraged development of private seed companies in East and southern Africa, to the extent that most public-sector breeding programmes in the subregion also focus just on hybrid development, rather than alternative cultivar types that may be applicable. To some extent development of the

maize seed market is also driven by fertilizer subsidy programmes. At the same time, seed certification capacity, seed company associations and plant variety protection laws are also supported. However, the question is what triggers private-sector diversification into the production of OPVs and other hybrids, such as high-value vegetables. Diversification is happening in Kenya, partly on the basis of the large horticulture industry but also due to an emerging market for grain legumes and the potential for oilseeds. Outside of South Africa, Kenya leads in the expansion and diversification of its seed industry. It has closed the circle in developing farmer demand, producing an increasing number of improved varieties, having in place an effective seed certification and varietal protection capacity, increasing the network of stockists and agrodealers and developing a highly competitive market for seeds. Closing that circle in other countries will take time and an appropriate sequencing of interventions. Until then capacity will have to continue to be maintained to produce and distribute OPVs.

Endnote

Plant breeding capacity in sub-Saharan Africa is something of a bellwether for expansion and contraction in agricultural research, for various fads of donor support for agriculture, for market liberalization and expanding input markets, and for application of advancing science in an African context. It is easy to say that national governments should invest more in plant breeding, but plant breeding being a long term investment requiring recurring commitment does not have as much policy visibility or impact as interventions such as a fertilizer subsidy programme. Nor, given current budgeting and financial resource allocation systems, will it be easy to increase spending on plant breeding. These underlying factors often cause plant breeding capacity building to be viewed as a low priority during critical decision-making. Processes such as the current reform of the CGIAR, restructuring of SROs and alignment with the CAADP process, and continuing vacillating changes in donor support to agriculture in Africa become important factors conditioning the ability to develop an efficient and integrated plant breeding system for the continent. Many important organizational components are already in place, but still there is the absence of a compelling vision for how the particular domain of plant breeding can be effectively integrated, coordinated and managed to produce an increasing flow of improved varieties to African farmers.

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