Beyond Crop Technology: The challenge for African rural development?[1]

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I. Introduction

Low agricultural productivity and a high percentage of poor and undernourished people – both adults and children, are common features of sub-Saharan Africa. Low infant weight appears predominant in West and Central Africa as well as the Great Lakes Region of Eastern Africa.

The ratio of agricultural land per rural inhabitant of sub-Saharan Africa declined from 3.7 ha in 1970 to 2.2 ha in 1998; and from 2.3 to 1.5 ha in West Africa; i.e., an annual decline of –1.26% for sub-Saharan Africa, and –0.9% for West and Central Africa. In the mid-1990s the decline slowed significantly (-0.50% and –0.1% for sub-Saharan Africa and West and Central Africa, respectively), which shows the effects of rural migration to urban areas, and in some locations the negative effects of pandemics affecting health and life expectancy of rural African people.

I.1. ***Food and Health.*** The annual demand for food keeps growing (3.3%) and may not be matched by the growth in agricultural production (Tables 1 and 2). Not surprisingly, per capita calorie intake remains at low levels in sub-Saharan Africa (Table 3), and below the developing world average. If current trends continue, there will be approximately 300 million of malnourished people or 32% of the total population in 2010, which will convert sub-Saharan Africa (taking over from South Asia), to being the region with the highest number of inhabitants who are chronically malnourished.

I.2. ***Agriculture and African Economy***. Agriculture still accounts for 33% of GDP and 40% of exports for sub-Saharan Africa. It provides jobs to 65% of the labor force (versus 15% in industry and 20% in services), and the forecasts from the African Development Bank suggest that about 60% of the economically active African population will be still employed in agriculture by 2010. In short, agriculture remains as the dominant factor for economic development in most of Africa, and more importantly the rural poor depend on agriculture for their livelihoods (Table 4). Hence, research-for-development interventions aiming to ensure food, reduce poverty and generate income must be high in any agenda in which Science will be pursued for assisting development in Africa.

II. An End-User Driven Research-for-Development Approach to Meet Market- Demand and Opportunity in Rural and Urban Africa

The main role of science in agriculture has been to propel this evolutionary process by generating innovations that allow producing more, with less land, and less effort. Who benefits depends on who controls the technology, who innovates, how selection decisions are made, and how innovations are enacted (Douthwaite and Ortiz 2001). Hence, any strategy for eliminating food shortages and accelerating the evolving rate from household production to more commercial farming entrepreneurs need two interdependent pathways in sub-Saharan Africa: (i) developing commercial "windows" for the less vulnerable farmers through enhancing marketing pathways of agricultural produce with high levels of added-value, and (ii) increasing food security by broadening the reliance on cereals (mostly maize) monoculture into diversified crop-livestock systems, which are more environmentally resilient and nutritionally superior.

Such a strategy follows a "**research-<u>for</u>-development end-user-driven**" approach that replaces the old disconnecting concept of research <u>and</u> development, in which researchers deal with technology generation and developers test this technology with potential end-users. Research-for-development needs society-conscious committed scientists who accept transforming into developers, by bringing a technology focus to their work. The research products ensuing from this work are demand- not supply-driven, by end-users and not by "ivory tower" scientists. Hence, this new approach closes the gap between research and development, and ensures from the start of the research process (i.e., planning) that development goals are driving the agenda. Two metaphors: "from thinking to acting" and from "research to decision" define this new research-for-development approach, in which research institutes, development organizations, the private sector, development investors, and national governments are partners sharing the aim of accelerating agricultural diversification and commercialization for the small-scale agricultural sector.

Four key elements comprise this research-for-development end-user driven approach:

1. trade and marketing to encourage rural economic growth,
2. crop diversification to avert famine and strengthen food security,
3. enhanced governance to build ownership between investors and implementing actors catalyzing development, and
4. partnerships to attain win-win synergies.

II.1. *The Research-for-Development Continuum*. Research-for-development, keeping in mind the end-users, operates within a continuum that uses a "means" (research) for an "end" (development), thereby leading to impact on both people's livelihoods and science. With this new approach, a new working culture evolves in which management rewards internally the top performers following this framework, and externally encourages staff to broaden alliances or partnerships for development in their community of practice. Networking becomes, therefore, a MUST because organizations, which do not always share the same goals, see the advantage of teaming-up for succeeding in their objectives in a target area.

Owing to the complex nature of the agricultural problems in sub-Saharan Africa, solutions cannot be based around a "one fix approach". Research is required to develop decision-making processes that take into account natural resource fragility, community vulnerability, risk profiles, asset resilience, market options, service provision capacity and competitive advantage as the guiding principles, to develop solutions that can be applied to specific client needs, given their own peculiar circumstances. This research-for-development philosophy considers a "small landholder development trajectory" from subsistence to commercial scale (Fig. 1), in which the farmers are not homogeneous and research products should help them to move along the trajectory.

Opportunity and vulnerability factors determine what technology may be the most appropriate in the landholder development trajectory. Farmers with relatively good access to markets, who are educated, and who have financial assets and access to water, prefer interventions which tend towards high income generation; i.e., a high risk strategy that will focus on competitive and comparative advantages and which will build entrepreneurial skills for wealth development, thereby leading to multiplier effects such as job creation. Small landholders with low income, who have poor market access, low education, limited assets, and who may be affected by HIV/AIDS, are reliant on rain-fed farming systems, in marginal or fragile environments with a history of food relief, will tend towards a low risk strategy, which aims to build on livelihood coping mechanisms and which places priority on more resilient long-term mixed cropping systems. Furthermore, agriculture provides the means, and sometimes perhaps the only means, for reconstructing, rehabilitating and resettling people in war-torn and environmentally degraded zones. Rural development that follows peace may need a low risk strategy emphasizing crop technology to re-build livelihood coping mechanisms for resettled inhabitants.

Researchers therefore need to offer a broad array of products because low input environments require a yield stabilizing technology, whereas matching technology to achieve high yield potential should be developed for high input environments. Such a moving target needs to be addressed by a heterogeneous, but dynamic moving strategy, which often changes at a given point of time. Researchers along this trajectory must use all available research tools for development. In this way farmers in sub-Saharan Africa may move from marginal agriculture to an improved system. Hence, farming should be a business rather than a job of last resort in Africa. Viable farming enterprises require crop post-harvest management –including primary processing, product development and marketing. By stimulating consumer demand for crops and their products and satisfying farmers immediate domestic needs, farmers will be assured of outlets for their produce, and the associated cash earning opportunity.

Increasing productivity per unit area leads to more food, extra produce for sale, and other crops may be included due to enhanced productivity on the land. Likewise, the higher and more stable yield potential and profitability permits poor farmers to invest in inputs for producing more food and income, whereas high yield may lead to reduced food prices for the urban and rural poor, which leads to monetarization of rural areas, whose inhabitants may prefer “money in the pocket” (income generation) rather than only “a meal on the table” (food security). Furthermore, high yielding crops may provide employment for poor people throughout the trade chain (from harvest to processing). The outputs from research-for-development must be linked to a well-resourced capacity-building program such that farmers will be equipped with plant and animal genetic resources and sustainable plant/animal protection and soil/water conservation options to cope with changing environments and the entrepreneurial skills to asses and take advantage of any agricultural market opportunity.

II.2. ***The new paradigm in Crop and Natural Resource Management for Sustaining Agro-Biodiversity and Impacting on Livelihoods.*** Agricultural sciences provide a means for closing the gap between actual and potential yield in stressed environments through genetic manipulation, crop protection and resource management. Crop technology or cultivars within each cropping systems are replaced with others showing better fitness along an environmental gradient arising from the physical or naturally limiting uncontrolled factor(s). Therefore, farmers and scientists search for new technology along these gradients to address specific stresses. For example, plant breeders know well that cultivars with a high yield potential are not able to out-yield stress resistant cultivars (i.e. a crossover interaction) in the respective stressful environment. These high yielding cultivars may even perform poorly in stressful environments.

Researchers, farmers and policy markers should also keep in mind the following new paradigm that economic phenotype performances (P) are influenced by many factors and their interactions as indicated in the equation below:

P = Genotype x Environment x Crop Management x Policy (affecting both people and markets) x Institutional Arrangements x Social Demographics

II.3. ***Decentralized and Participatory Undertakings for Building Local and Regional Capacity.*** Decentralized (through networking) and end-user participatory research with local partners may provide a means for working in marginal, low input, stressful environments. This decentralization requires refining target areas, targeting local research partners for crop and resource management and shifting responsibility from a central research station to local undertakings (which may not only include technology testing but also new material generation through specific research for further selection and testing). In this way, individual- research programs (irrespective of their size) will deliberately maintain diversity across locations.

Such an approach should be driven by the needs of the rural poor to ensure such work impacts positively on their livelihoods. Agricultural research, to become cost-effective and efficient in Africa, must follow an agro-eco-zone approach with farmers participating with professional researchers in developing locally adapted technology, which will need to rely on responsive local systems for its dissemination to the farming community. This technology needs to assemble a set of characteristics that reduce yield loss and confer greater yield stability in the target areas (IITA 2001, DeVries & Toenninssen 2001). Input and output traits are included in a market-driven research agenda. Input traits such as resistance to insect pests, diseases (bacteria, fungi, viruses), and weeds such as *Striga*, or acceptable performance in stress-prone environments (e.g. owing to drought, heat or salinity) lead to yield stability, while output traits affecting quality and end-uses provide new options for generating or improving people's incomes.

Decentralized country-level research programs are mandatory because these teams can only operate efficiently when close to the various targeted agro-eco-zones for each crop (DeVries & Toenninssen 2001). The centers of the Consultative Group on International Agricultural Research (CGIAR) should play a facilitating role to allow these country-level programs to succeed.

III. The Global Research System and An Engagement Protocol for the FARA-led Challenge Program for sub-Saharan Africa: Working FOR, IN and FROM Africa

Development principles and decades of both positive and negative developmental experiences, dictate certain desirable approaches. One obvious approach is that target audiences be encouraged to do what they can to the fullest extent possible. The International Institute of Tropical Agriculture (IITA) embraces this strategy. It is a cost-effective development pathway which simultaneously also addresses directly the issue of sustainability that all are concerned about. This strategy suggests different tactics at different points in the research-for-development continuum (R4D). It strongly suggests, for example, that organizations closer to the target beneficiary can work along the full R4D scale, whereas those further away need to concentrate more on upstream research; i.e., on the R side of the R4D scale. The justification - in terms of costs and sustainability - is not there for an entity or organization coming from afar to research on the downstream; i.e., on the D of the R4D.

However, given the high returns to research, the involvement of organizations, no matter where located, toward the R end of the R-D spectrum, is generally defensible. This is because; returns to research are in the two-digit category. This is not the case when organizations far removed from the target beneficiary try to work on a low-end developmental activity such as managing networks, doing basic field-testing, marketing or processing, i.e., working on the D of the R4D scale. This end of the scale is best done by local and regional entities closer to the target beneficiary. Fortunately, in Africa there is no shortage of local and regional professional skills and organizations that can do such work.

III.1. ***IITA Engagement Protocol.*** In the light of these factors, IITA has adopted since 2002 the global research system (Fig. 2) and converted it into an engagement protocol. To bring R4D partners into its agenda. IITA, through this partnership approach is taking the position that Africa's needs dictate the partner and IITA will look for the best to address the problem according to this engagement protocol. This means IITA partnerships are now tailor-made to meet a particular challenge and not on any other basis.

III.2. ***Capacity Building to the Power of Two***. An important activity of this approach will be to continue enhancing the national and regional professional capacity. IITA expects to continue with traditional training, for example, it has trained 9000 professionals of which 750 colleagues (up to the late 1990s) obtained their MSc or PhD degree through partnership research-for-development at IITA, and today its alumni are in virtually all African agricultural research institutes, quite often in leadership positions. However under the new engagement protocol described above, capacity building is taken to a higher level. IITA engagement protocol means that local, national and regional capacity will be greatly enhanced also by their direct involvement and participation in IITA delivery mechanisms. Where it is necessary for organizations in the 'international' category (the third ring in Fig. 2) to be engaged in capacity building, they will be called in with the primary purpose of imparting, through training or demonstration, the skills needed to undertake the necessary activity.

IV. Good News from Africa

A recent survey by the International Food Policy Research Institute (IFPRI) reveals key successes emerging in African agriculture particularly breakthroughs in maize breeding across Africa, sustained gains in cassava breeding and successful combat of its disease and pests, control of the rinderpest livestock disease, booming horticultural and flower exports in East and Southern Africa and increased cotton production and exports in West Africa (Gabre-Madhin & Haggblade 2003). Available data from FAO (Table 5 and 6) clearly endorses this assessment whereas other impact assessment reports in agriculture question the phrase: "*Africa: a hopeless continent*"[4] (Adesina & Coulibaly 1999, CGIAR/TAC 2001, Herren & Neuenschwander 1991, Inaizumi *et al.* 2000, Jaffee 1995, Manyong *et al.* 2000a,b, Noorgard 1988, Nweke & Spencer 1995, Ortiz 1998, Ortiz et al. 1997, Pretty 2000, Rohrbach *et al.* 1999, Sanginga *et al.* 1999, Teft 2000, WARDA 2001).

Furthermore, a thorough understanding of the successes in African agriculture, support the proposal for the engagement protocol in the FARA-led Challenge Program for sub-Saharan Africa: e.g. the local capacity building through the National Cereal Research and Extension Project (an IRAD-IITA partnership through USAID investment in Cameroon) of the 1980s and early 1990s, which still significantly impact on maize yield and total output (Table 5). Likewise, the Pan-African partnerships throughout the cassava commodity chain (Nweke *et al.* 2001), which impact crop output in the world (Table 6) because of the significant gains in the fields grown by African farmers (Table 7) that are not only contributing significantly to the African diet but also propelling entrepreneur development through agro-processing of this crop; i.e., moving cassava from a food security to a trade crop across the continent.

[4] The Economist 15 May 2000

IV.1. ***Improving Maize for, in, and from Sub-Saharan Africa***. Maize production in sub-Saharan Africa today would be 25% less (Table 5), if new cultivars were not grown by African farmers. Breeding for resistance to maize streak virus, the parasitic weed *Striga*, insects, downy mildew and other pests was among the major targets of partnerships set up by IITA in West and Central Africa, and Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) in Eastern and Southern Africa. The CGIAR acknowledged the successes on the genetic enhancement of African maize by giving the 1986 King Baudouin Award to IITA for its work to overcome maize streak virus, a major endemic disease affecting maize throughout Africa.

In the mid-1990s East and Southern African farmers planted about 50% of maize area with bred-hybrids that showed yield gains of about 40% over local cultivars (Byerlee 1994). From the 1970s onwards, IITA and research-for-development partners recorded 267 releases of maize cultivars in 11 West and Central African nations, of which 81 were released by the private sector, including hybrids. IITA and CIMMYT provided 49% and 11% of genetic materials, respectively to the new cultivars, which were grown in about 37% of the total maize area in this sub-region. The mean on-farm yield gains with improved germplasm appears to be about 45%, which explains why over nine million West and Central African farmers grow improved open-pollinating cultivars on about 20% of the total maize area, thereby boosting total sub-regional maize output by 2.5 million t year^{-1}.

The African R4D partnerships setup along the genetic enhancement of maize played a catalyzing role in the process of providing improved seeds to farmers. For example, in response to the request made by the Nigerian Federal Government, IITA with active participation of Nigerian partners developed and released the first generation of inbred lines and hybrids in 1983. The spillover effect of this release was the formation of a small seed industry to market hybrid maize in Nigeria. In 1993, each of the three seed companies operating in Nigeria (Premier, UTC and UAC) officially announced IITA open pollinated and hybrid maize cultivars in their seed catalogues. Furthermore, IITA promoted community-based seed production schemes in West and Central Africa with many regional partners in order to make improved seeds available to farmers.

IV.2. ***Cassava: the Best Kept-Secret of Africa***. Nweke *et al*. (2001) revealed for the first time, that cassava can be transformed from being a poor man's crop to an urban food, from being a subsistent crop to industrial cash crop. Their book describes how long-term research by IITA and African partners led to the development of improved, high-yielding Tropical *Manihot* Selection (TMS) cultivars that increased cassava yields by 40% without the use of fertilizer (Table 7). About 206 releases of cassava cultivars from IITA germplasm are recorded in 20 African nations. In the 1990s African programs incorporated IITA bred-materials in 80% of their cassava bred-germplasm, which led to 50% gains in cassava yields on average. The improved cultivars raised per capita output by 10% continent-wide, benefiting 14 million farmers.

The national research capacity available in Africa and backstopping from IITA provide a means to deal with new threats affecting this crop in the continent. For example, the total benefits from the cassava multiplication R4D partnership project between NARO

(Uganda) and IITA to combat the cassava mosaic disease pandemic in six districts was approximately US $ 36 million over 4 years (1998-2001) for an initial investment of US $ 0.8 million. Partnerships between National Agricultural Research Systems and IITA are key for this and other successes in the genetic enhancement of cassava in Africa. In this regard, the first ever CGIAR Outstanding Partnership Award was given in 1996 to the Institute of Agricultural Research (Sierra Leone) and IITA for cassava improvement.

Because of the successes in cassava research-for-development by IITA and partners (Enete et al. 1995, Manyong *et al.* 2000, Nweke & Spencer 1995), the Integrated Action Program for Cassava Starch Production and Export was launched by the President of the Republic of Ghana for developing the cassava starch industry in this country as a major vehicle for job creation and poverty reduction in rural areas. Similarly, the Government of Nigeria took positive steps to promote cassava production in the country, and inaugurated in 2002 a cassava production committee of all stakeholders: research directors, farmers and extension agents, food processors, and marketers to encourage cassava export. While addressing the committee in Abuja recently, President Obasanjo stated that cassava export could be capable of generating an income of US$ 1.5 billion within two years.

IV.3. ***Cowpea: the African Legume for the Dry Savannas***. In the last 40 years, Africa recorded significant improvement in the production trend for cowpea owing to both increases in area and yield - the largest among legumes (Table 1) At about US $ 500 per t, the increased production represents an annual value of some US $ 650 million in Nigeria alone. In the early 1990s, IITA –in collaboration with the International Livestock Research Institute (ILRI), initiated a breeding program to develop improved cowpea cultivars that provide both grain for human consumption and fodder for livestock in the dry season. Impact assessment shows that farmers obtain substantial benefits by adopting dry-season dual-purpose cowpea (Inaizumi *et al.* 2000). These include food security during a critical period of the year, cash income, fodder, and *in situ* grazing after harvesting, in periods when the prices of cowpea grain peak, and when good quality fodder is scarce. Dry season dual-purpose cowpea is thus a profitable technology that will find economic and ecological niches in the mixed crop/livestock farming systems of the semi-arid zones of Africa.

IV.4. ***Soybean: the Potential for "a Legume Revolution" from Africa***. Adoption of IITA high yielding and pod shattering resistant soybean cultivars over the last decade increased average farmers' yields in Nigeria from 310 kg ha^{-1} in 1991 to 730 kg ha^{-1} in 2001, which led to a nearly 3 times increase in production –from 145,000 t to 429,000 t, within the same period, though soybean area grown increased by only 26% (Sanginga *et al.* 1999). Children who consume soybeans are showing a significantly better nutritional status than those that do not. Not surprisingly, several health centers and hospitals in Nigeria are using soybean products to treat malnourished children. Government policy and farm-level technology influenced the success of soybean in Nigeria (Smith *et al.* 1995). This crop also contributed to the economic independence of women and generation of more income allowing acquisition of new household items and payment of medical bills and school fees.

IV. 5. *Improving Chickpea, Faba Bean, and Lentil for Sub-Sahara Africa*[5]. Chickpea, faba bean, lentil and grass pea are other food legume crops grown in Sub-Sahara Africa. The International Center for Agricultural Research in the Dry Areas (ICARDA, Aleppo, Syria), has a world mandate for improvement of lentil and faba bean, and collaborates with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT, Patancheru, India) on chickpea improvement. Partnership research with African NARS are bringing impact on chickpea, lentil, faba bean and grass pea yields.

Chickpea. The area and production of chickpea increased from 0.196 m ha to 0.330 m ha and production from 128,000 t to 218,000 t during the last four decades but the overall yield remained almost at the same level (Table 1). Cultivar Mariye is now widely grown in Gondar (Ethiopia), and the cultivars Arerti and Shasho –recent kabuli types with resistance to wilt, are anticipated to impact in the near future in the mid-altitudes and highlands of Ethiopia.

Faba bean. The area and production of faba bean increased from 240,000 ha to 420,000 ha and production from 220,000 t to 460,000 t during the last four decades, while the overall productivity increased from 918 kg ha^{-1} to 1078 kg ha^{-1} in same period (Table 1). The use of genetic resources resistant to chocolate spot disease resulted in increased productivity in Ethiopia. In Sudan, a series of cultivars with yield advantages over local lines of up to 20% are now widely used with an improved production practice: early sowing, frequent irrigation, insect pest control, and proper weed control.

Lentil. Lentil is an important component in the food and crop production systems in East and North Africa. It provides a cheap source of high-quality protein to the African poor people. Although area of lentil in sub-Saharan Africa reduced in the last four decades, its yield increased from 461 kg ha^{-1} to 649 kg ha^{-1}. This yield gain was mainly due to the improved cultivars Rubatab-1, Aribo 1 and Nedi in Sudan; and Ada'a, Gudo, Alemaya (resistant to rust disease and their attractive seed quality) in Shoa (Ethiopia). The area losses ensued mainly from the withdrawal of government support to cultivation –particularly in Sudan.

Grass pea. Grass pea is an important food legume in dry areas of highland Ethiopia. During the dry seasons the crop is the only surviving legume. Furthermore grass pea is a key source of high-quality protein (seed often exceeds 30% content). However high dietary intake can cause lower limb paralysis and farmers growing grass pea are potential victims of this disease particularly during dry years when they totally depend on the crop for their survival. EARO (Ethiopia) and ICARDA researchers bred cultivars with low neurotoxin levels (less than 0.2% B-ODAP), improved management for safe consumption, and through crop husbandry enhanced yield. As a result, lines with low B-ODAP and high yield potential are now grown by pilot farmers in Shoa and Gondar (Ethiopia).

[5] Information provided by Dr. W. Erskine et al. (ICARDA)

IV.6. ***Impact-led Participatory Millet Research-for-Development in Namibia*.** Farmers change agrobiodiversity by introducing new forms of the crop (i.e., migration) or other plants species, or by selecting mutants arising *de novo* or hybrid genotypes derived from natural outcrossing. Farmers have also accumulated for many generations, native or traditional knowledge for crop management, which includes selecting promising materials or introducing pest control in their specific geographical areas.

Okashana-1 is an early-maturing, high-yielding pearl millet cultivar developed by ICRISAT researchers and partners through the Sorghum and Millet Improvement Program (SMIP). The parent material for this cultivar originated in Togo and was collected jointly by ICRISAT and national partners. ICRISAT breeders in India crossed this raw material with several lines of African origin. Teams in Zimbabwe and Namibia improved it further through selection and regional adaptation trials. A non-government organization initiative in Namibia involved smallholder farmers in participatory cultivar selection. Farmers expressed a strong preference for Okashana-1 (or ICTP 8203), insisting on a "fast-track" release. Therefore, Okashana-1 was released in 1989, and is now grown on 49% of Namibia's pearl millet area.

The benefits generated have a net present value (in 1998) of US$ 11 million (Rohrbach et al., 1999). This widespread adoption was essentially due to partnerships. National research and extension staff worked with farmers to promote the new cultivar and distribute seed. The national program developed a farmer-based seed production system with technical support from SMIP, funding from development investors, and advisory assistance from national policy makers and other development agents. This system has now grown into a financially self-sustaining farmers' cooperative that produces over 200 t of certified pearl millet seed each year. The success of Okashana-1 in Namibia results from the introduction of genetic material improved by ICRISAT breeders, early involvement of farmers in participatory selection, rapid cultivar release responding to farmers' preferences, and the commitment of the national government for high-quality seed multiplication and dissemination (Bidinger 1998). The success of the pearl millet improvement program for Namibia has increased the confidence of the public research and extension services in their capacities to promote technological change. In 1996, ICRISAT received from the CGIAR the King Baudouin Award for its successful work on pearl millet improvement, which includes the breeding of Okashana-1.

IV.7. ***NERICA: the New Rice for Africa***. African rice (*Oriza glaberrima*) and Asian rice (*Oriza sativa*) evolved independently in the two continents over millennia. The African species falls over when grain heads fill, and shatters easily, thereby losing grain yields. Many African farmers, therefore replaced African rice with the high-yielding cultivars of the Asian species –particularly the semi-dwarf genotypes that drove the "Green Revolution". However, in West Africa drylands farmers are unable to grow the Asian rice cultivars because of their inability to withstand weeds or poor yield in drought-prone environments.

In the early 1990s, the Africa Rice Center (WARDA), started cross-breeding with the aid of embryo rescue for producing hybrids between the two rice species (Jones 1999). By the mid-1990s, following participatory plant breeding, African farmers, national and WARDA researchers were testing together the new rice for Africa ensuing from this cross between African and Asian rice. The NERICA cultivars inherited wide, droopy leaves from their African parent, which smother weeds in early growth –a very important trait because weeding –mostly by women and children, accounts for 30 to 40% of all labor. NERICA cultivars also allow farmers to work the same land longer, rather than having constantly to clear new land. Likewise, the NERICA cultivars inherited, from their Asian parent, longer panicles with 'forked' branches, and hold up to 400 grains tightly, thereby avoiding shattering, which often occurs in African rice. It seems that NERICA cultivars, which mature 30 to 50 days earlier than available rice cultivars in Africa, outyield others with no inputs and with small fertilizer amounts: 2.5. t ha^{-1} under low inputs and at least 5 t ha^{-1} with little fertilizer amounts, i.e., 25% to 250% yield gains (WARDA 2001). Because NERICA cultivars are taller than other rice grown by African farmers, women prefer them at harvest and they also provide 2% more protein than the Asian cultivars. The NERICA cultivars are also resisting better than Asian rice the African pests affecting the crop (particularly African rice gall midge, rice yellow mottle virus and blast) and grow well in acid soils, which account for 70% of the upland rice area in West Africa.

By 2000, over 20,000 farmers were growing NERICA varieties in Guinea alone, and there will a return of an extra US$ 8 million $year^{-1}$ to farmers with just about 10%adoption by more farmers in Guinea, Côte d'Ivoire and Sierra Leone, whereas a 25% adoption will return US $ 20 million $year^{-1}$. In 2000, the CGIAR selected WARDA for the King Baudouin Award owing to success of NERICA -a major scientific breakthrough because of high-quality science; impact; and partnerships.

IV.8. ***Cooking Bananas and Plantain Hybrids for African Farmers and Markets***. West African plantains in the lowlands and East African highland bananas (for both cooking and beer) are examples of African farmer ingenuity, tenacity, organizational and inventive capacity in adapting this imported *Musa* crop species from Asia to respective environments. Although their asexual propagation may limit crop evolution, today both sub-regions are acknowledged as secondary centers of variation for plantains and bananas, because farmers selected sports (mutants) arising in their fields, which today account for most of the caloric intake from fruit crops in the African diet.

In 1987, African governments encouraged IITA to launch an urgent research program to help combat black sigatoka disease. This fungal leaf spot disease causes significant yield loss in plantains, an important food and cash crop to more than 70 million people in sub-Saharan Africa. An interim measure adopted by IITA in the late 1980s, was the introduction from Asia of black sigatoka-resistant cooking bananas (Ferris *et al.* 1998), while the long-term strategy was to develop black sigatoka resistant plantains. After their introduction to Nigeria, cooking banana plantlets were produced in two tissue culture laboratories located at IITA High Rainfall Station (Onne, near Port Harcourt) and the Agricultural Development Programme at Owerri (Imo State). With the collaboration of

24 institutions[6], vegetatively propagated planting materials (suckers) were distributed to 29,585 farmers in 710 villages. An impact assessment study examined the adoption and diffusion of cooking banana in Nigeria (IITA 2000). Cooking banana gained a high level of acceptance and spread among the people, and thus established itself within the farming system in the region. The crop has been adopted by 55% of farmers, occupying about 26% of total fields, while its cultivation has increased by more than 930% since the introduction, with a multiplication rate of 600% across farmers. Bearing in mind that cooking banana was neither a traditional crop nor an improved cultivar from an existing one, the level and rate of adoption and diffusion are quite high and encouraging. At the end of the 1990s, about 80% of farmers, who adopted this new crop, were selling 10 to 90% of their total cooking banana production, while the other 20% produced entirely for household consumption. About 58% farmers sold at least 50% of their cooking banana. At the end of the 1990s, the average selling price of cooking bananas was N6.5 per kg compared to N13.3 per kg for plantains (about US $ 1 = N 111). However, the cooking bananas may have an increased overall value because of their significantly higher bunch weight than plantains. The introduction of cooking bananas and their subsequent adoption and diffusion made a positive impact in the region: on farmers' farm enterprises, farm resource use and allocation, income and food base of the people as well as employment generation. Therefore, the potential of cooking banana in contributing to bridging the hunger gap, and uplifting the income level of farmers in the region is quite high. As such, it is no longer appropriate to regard cooking banana as a stopgap measure, rather a suitable supplement (or even substitute) to plantain for some farmers and consumers in Nigeria.

IITA researchers were able in early 1990s to rapidly (about 5 years) develop improved plantain-banana hybrid germplasm using a range of conventional and innovative approaches: interspecific hybridization, ploidy manipulation, embryo culture, rapid in vitro multiplication, field testing, and selection. This result is a noteworthy achievement, considering that programs elsewhere required decades of breeding before *Musa* hybrids became available. The potential impact of using black sigatoka-resistant plantains shows a cost-benefit impact of 10:1 over fungicides during periods of adequate production in rural southeastern Nigeria; while this advantage may reduce to 5.5:1 during periods of scarcity in plantain production – which dramatically influences the prices of plantain fruit (Ortiz *et al.* 1997). Owing to its pioneering research-for-development on breeding hybrid plantains resistant to black sigatoka and for advances made in the genetics of *Musa* –not an easy task for a triploid species, IITA received the King Baudouin Award in 1994. The successful professional career -solely in Africa, of the leader of this IITA team, the late Dirk R. Vuylsteke, was acknowledged by dedicating one of the recent volumes of the annual series *Plant Breeding Reviews* (Ortiz 2001), perhaps the only ever given to a plant breeder of the CGIAR. PITA 14 (or TMPx 7152-2) appears to be one of the most promising IITA plantain hybrids because of its early fruiting, high bunch weight and big fruits (Ortiz a& Vuylsteke 1998). While detailed analysis of the acceptability of PITA 14

[6] State Ministry of Agriculture, Agricultural Development Programmes, Agricultural departments of Local Government Areas, and non-public organisations such as Shell Petroleum, Nigerian Agip Oil Company and the Anglican Diocese of Awka.

in southeastern Nigeria is underway, it is noteworthy that several farmers have established sucker multiplication plots and are selling suckers to other farmers (IITA 2000). Owing to this early success, IITA started in 2002 large-scale introduction (on-farm) of hybrids with black sigatoka resistance to the farming community in 11 Nigerian States of the plantain-belt.

IV.9. *Participatory Breeding and Crop Husbandry of Yams*[7]. IITA and national or local partners generated several new cultivars of yams (*Dioscorea rotundata* and *D. alata*) with high and stable yield of tubers (50 to 100% superior to popular local cultivars) as well as good storability and food quality attributes through breeding and selection. High levels of host plant resistance bred into the cultivars against the two most important diseases of the crop, yam anthracnose disease (YAD) and yam mosaic virus (YMV), contribute significantly to the high level and stability of field performance. With the aim of limiting production cost, the improved yam cultivars were selected for good performance in the absence of external input of fertiliser or staking (in the moist savanna zone) and emphasis was placed on tuber shapes that facilitate harvesting. Many of these new cultivars were assessed at multiple sites in the yam producing locations of West Africa for suitability to local farming and food systems in comparison with popular indigenous cultivars and with active participation of potential farmers. Three IITA-bred cultivars of *D. rotundata* (white yam) were formally released by Nigeria in 2001. Several others are in the pipeline in the other major producing countries in the sub-region.

Water yam (*D. alata*), a species introduced to Africa from Asia, deserves special mention. It is generally superior to the indigenous white yam (*D. rotundata*) in yield potential (especially under low to average soil fertility), ease of propagation (production of bulbils and reliability of sprouting), early vigour for weed suppression, and storability of tubers. Indeed it has superior characteristics for sustainable production. Its major limitation in the field is the susceptibility of most cultivars to anthracnose disease caused by *Colletotrichum gloeosporioides* that exerts a devastating impact on productivity. The tuber culinary quality of most cultivars of the species is inferior to that of white yam in the preparation of West African dishes. New water yam cultivars with much improved food quality, resistance to anthracnose and high tuber yield have been developed and are under multi-site testing with partners in Nigeria and Côte d'Ivoire. Already one of the key parental sources, earlier introduced from Puerto Rico, has gained very wide acceptance in West Africa. Introduction to farmers through an NGO in Ebonyi State of Nigeria has led to a rapid spread in that State and neighbouring ones.

The parasitic nematodes *Meloidogyne incognita* and *Scutellonema bradys* cause direct damage to yam tubers and interact with fungi and bacteria to cause tuber losses (through rots) that can exceed 60% by three months in storage. Research by IITA in Nigeria showed that, in areas under high infestation of these nematodes, treating seed yams with hot water before planting generates more than twice the net profit (about US \$ 1,477 ha^{-1}) compared to planting them without the treatment. Effective cultural control of these nematodes in the field has also been demonstrated through the introduction into the cropping system of leguminous cover crops such as *Aeschynomene histrix, Tagetes*

[7] Information provided by Dr. R. Asiedu (IITA)

erecta, and *Mucuna pruriens*. Such cover crops (especially *Mucuna pruriens*) also help in maintaining soil fertility and restrict encroachment of pernicious weeds like *Imperata cylindrica* whose piercing rhizomes inflict wounds on yam tubers in the ground. In addition, information is available on the suitability of crops for planting in the same field with yams based on their levels of host efficiency for those two major parasitic nematodes.

Limited availability and cost of seed tubers (about 50% of total production cost) are major considerations in the productivity of yam cultivation. Methods for rapid production of large quantities of healthy seed tubers were developed and disseminated by IITA and partners elsewhere. These methods include the use of minisetts from field-grown tubers, major advances in pathogen (especially virus) diagnostics, in vitro micropropagation, and seed disinfestation. For instance over a period of 15 months (1998-1999) more than 6,000 farmers (including 4,298 women) from 10 districts of Uganda received training in rapid propagation techniques and a total of 525,000 setts of new white yam cultivars as stocks for multiplication. Methods that would be even more rapid and profitable are being tested at the moment.

A technological package has been developed for the production of fried yam chips suitable for use in the fast food industry to meet the demands of an increasingly urban population. This package includes suitable yam cultivars (with defined physical and chemical characteristics) partial frying of the chips followed by freezing and final frying to get the finished product. Processing parameters were established at the bench scale and these will soon be adapted to commercial scale.

IV. 10. ***Measuring Impact of Crop Improvement for, and in Marginal African Lands***. A recent report (Brader 2002) shows that high adoption rates of early-maturing cultivars does not translate into large yield gains because they are targeting new land thought to be marginal for agriculture. Hence, yield *per se* was not the main aim of breeding early-maturing cultivars in crops such as maize and cowpea but to enable the crop to be grown in new areas –perhaps by replacing other crops; e.g. maize displacing sorghum in drylands. As pointed out by Adesina *et al.* (1997) early maturing maize cultivars allowed the crop to be grown in the semi-arid tropics of Burkina Faso, Guinea, Mali, Niger and Senegal. Likewise, crop breeding for pests or abiotic stresses was a cornerstone in stabilizing yields and reducing risks in pest-prone, low-input, rainfed environments (where drought may often occur), rather than resulting in potential yield gains by small landholders who are not having an easy access to credits for inputs or to output markets.

IV.11. ***Biological Control of Pests: a Pan-African Program*****.** The spectacular control of the cassava mealybug by an introduced parasitoid (a predator wasp) was the first of many successes in the history of the Biological Control Center for Africa set up by IITA in the 1980s. It yielded economic returns of 200:1, with minimum benefits of US $ 2.2 billion from a total expenditure of US $ 14.8 million (Noorgard 1988, Zeddies *et al*. 2001), and led to the 1995 World Food Prize to Hans Herren, which followed the 1990 CGIAR King Baudouin Award to the IITA team for the Africa-wide cassava mealybug control. One could easily surmise that without biological control, mealybug would have destroyed most of the cassava grown across Africa. This project was unique in its geographic scale, organization and level of documentation, and has become a classic textbook example (Herren & Neuenschwander, 1991).

Biological control of cassava green mite, larger grain borer, mango mealybug, spiraling whitefly and water hyacinth are already making a significant impact (Boavida *et al*. 1995, Bokonon-Ganta *et al*. 1995, 2003, Borgemeister *et al*. 1997, d'Almeida *et al.* 1998, de Groote *et al.* 2003, Neuenschwander *et al.* 1994, Yaninek & Hanna, 2003).Water hyacinth made many lakes and waterways in sub-Saharan Africa impassable and adversely affects the local economy and biodiversity. However, control of this weed was first achieved in Northern Australia, and IITA introduced weevils as biocontrol agents to Africa, where good control appears clearly in locations as far as Benin and East Africa – the latter a cooperative effort with the National Biological Control Unit of Uganda.

IV.12. ***Biopesticides through Public-Private Partnerships***[8]. Locusts are among the most important pests affecting farmers living around the world deserts. Millions of liters of environmentally damaging pesticides are sprayed over vast areas of land to control them and the grasshoppers –another insect pest of crops. The *Lutte Biologique contre les Locustes et Sauteriaux* (LUBILOSA) project was set up in 1989 by IITA and R4D partners for the development of a biological pesticide that kills locusts and grasshoppers without harming the environment. The LUBILOSA project ensued from knowledge about mixing oil rather than water with fungal spores (aerial conidia), which not only remain potent longer in dry environments that are therefore much more infective. Suitable isolates were found following an arduous search for infected grasshoppers across all of northern Africa and the Arabian peninsula. A biopesticide that is based on the conidia (spores) of *Metarhizium*, an entomopathogenic fungus was developed and its pathogenicity and mammalian safety were tested according to international legal requirements. The species *M. anisopliae* var. *acridum* was selected owing to its appearance throughout Sahelian Africa, which facilitated licensing and phytosanitary requirements because the biopesticide was not introducing an exotic fungus into sensitive ecosystems. Furthermore, *M. anisopliae* var. *acridum* coevolved with grasshoppers and locusts in Africa, making the strains very host specific and minimizing risk of infecting non-target insects in the farming systems. The design of a small mass production unit was an adaptation of a *Metarhizium* mass production unit from Brazil to materials available in West Africa. This factory uses a two-stage sterile process to produce the conidia which can be stored over one year at 30°C. The product is now registered in South Africa, the West African CILSS countries, and Sudan, under the name "Green Muscle". Based on experience gained at the IITA mass production unit, an industrial plant run by a South African commercial company started large-scale production in 2001. At an application rate of 50g conidia in 0.5l oil formulation per hectare the product costs lie between US $ 5 to 15 ha^{-1}; i.e., within the range of modern synthetic insecticides. Aerial spraying demonstrated that Green Muscle provided greater long term control of grasshoppers than synthetic insecticides commonly used for grasshopper and locust control (Langewald *et al.* 1999, Lomer *et al.* 2001).

[8] Information provided by Drs. P. Neuenschwander and J. Langewald (IITA)

Two crucial components for success were the long-term commitment (10 years) from the development investors of this project to turn basic research into a useful product and the broad range of stakeholders, which led to the creation of a "constituency of support" around Green Muscle®, the byproduct of this public-private partnership, which was licensed to the South African company for manufacturing (Douthwaite *et al*. 2001). The eventual impact and return on investment of the LUBILOSA project will depend on correcting a market failure that does not account for the human and environmental health costs of spraying chemical pesticides, which are not charged to the purchaser. Policy changes are, therefore, required to overcome this market weakness for this and other biopesticides. Perhaps the constituency's power will be able to bring about this policy change. As a first step in this direction, FAO has listed Green Muscle® on the top of two lists of insecticides, for lack of impact on the environment and human health. Farmers, NGOs and donor agencies involved in grasshopper control have started purchasing large amounts of Green Muscle, replacing synthetic insecticides

IV.13. ***Alley Cropping in West and Central Africa***. IITA researchers developed alley farming as an improved fallow technology to substitute slash-and-burn systems in African agriculture (Kang 1993). However, the lack of widespread adoption by farmers led to skepticism about its relevance and adoptability. It appears that the decision to adopt alley cropping technology depends on (1) socioeconomic characteristics of farmers, (2) land tenure rights held by the farmers where alley cropping systems are used, and (3) village-specific characteristics (Adesina *et al.* 1999). Impact assessment show that maize production under agroforestry-based systems may be socially profitable and financially competitive when compared to maize production relying only on chemical fertilizer, especially after recent policy shifts (Adesina and Coulibaly, 1997). At unsubsidized fertilizer prices, an agroforestry-based technology like alley-cropping that depends on internal nutrient cycling would be viewed different, and the interest from both farmers and policymakers in such a natural resource management technology could be expected to increase. For example, farmers are adopting alley cropping in villages characterized by high land-use pressure, soil fertility decline, erosion problems, and fuel wood and fodder scarcity. Indeed, farmers are willing to adopt resource management technology that contributes to both soil fertility and income generation.

IV.14. ***Cover Crops in the African Lowlands.*** Population pressure forces farmers to shorten or abandon bush fallow systems. *Mucuna* fallows may be an option for soil fertility management in intensive agriculture (Tarawali *et al.* 1999, Versteeg *et al.* 1998). The most important factors influencing farmers' adoption of this cover crop technology were weed infestation, land tenure rights, and contact with extension services (Manyong *et al.* 1999). Impact assessment shows that farming systems with *Mucuna* provides a higher benefit:cost ratio than those without this cover crop technology, which provides yield gains, reduces labor and restores soil fertility. Technology for transforming *Mucuna* grains into food and feed will enhance the adoption of this species and may lead to great impacts among small-scale farmers.

IV.15. ***Integrating Crop Genetic Enhancement and Natural Resource Management in the Savannas***. Improvement of the cropping systems in the dry savanna seems to be driven by the adoption of crop technology within integrated natural resource management addressing productivity enhancement, e.g., promiscuously nodulating soybean and dual-purpose cowpea cultivars in Nigeria. Adoption appears to be very high, even in the absence of an efficient seed distribution system. The number of farmers cultivating the improved cultivars increased by 228% during the last 3 years. Increased production of promiscuous soybean has been stimulated by increased demand from the industry and home utilization. Increases in legume areas of 10% in Nigeria (about 30,000 ha in the northern Guinea savanna,) and increases of 20% in yield have translated into additional fixed nitrogen valued annually at US $ 44 million. This reflects at the same time an equivalent increase in land-use productivity and with further spread of the improved crops there are excellent prospects for additional economic and environmental benefits from a very large recommendation domain across West Africa.

In recent years IITA and R4D partners developed and implemented sustainable: (i) maize– promiscuous soybean rotations that combine high nitrogen fixation and the ability to kill large numbers of *Striga hermonthica* seeds in the soil, and (ii) sorghum and dual-purpose cowpea that greatly enhance the productivity and sustainability of integrated livestock systems. The two systems are effectively used for the replenishment of soil nutrients and organic matter. In addition, the legume cultivars possess the traits that are most appreciated by farmers, such as high yields of grain and fodder that provide them with income. Economic analysis of these systems shows already an increase (50–70%) in gross incomes of adopting farmers compared to those still following the current practices, mainly continuous maize cultivation.

It seems to be generally accepted that it would be impossible in Africa to grow crops continuously without soil degradation or without the use of impractical or uneconomical quantity of inputs, and it was therefore, considered that at all levels of farming there would still be a need for fallows. However, at this stage it may be feasible to recommend continuous cropping with cereal – grain legume rotations that can make agriculture much more attractive for the farmers in the dry savannas of Africa. Indeed, such a system offers excellent opportunities for the sustainable management of natural resources, while at the same time providing better incomes. Research-for-development by IITA and partners (including farmers) on this best-bet technology in the benchmark areas clearly show the environmental and economic benefits from these new cropping systems.

IV.16. ***Benchmark Approach: a Truly Global Public Tool in Research-for-Development***. Integrated natural resources management (INRM) may improve adaptive capacity by using new approaches and crucial tools for implementing a R4D agenda, which ensues from key principles affecting planning and output delivery (Sayer & Campbell 2001). This new INRM approach brings changes in culture and organization of R4D; i.e., learning together for change keeping in mind the underlying principle of going to scale but remaining practical to confront complexity in the field and to address productivity enhancement. The learning process at the early stages needs the blend of “hard” and “soft” science to allow local technology to lead for regional impact because there are multiple stakeholders with distinct views and approaches (Douthwaite *et al.* 2001).

To put INRM into practice –particularly in heterogeneous areas, R4D needs a characterized benchmark area that considers farming system dynamics and diversity that represents a wider agro-eco-zone to develop best-bet innovations and processes (Fig. 3). The benchmark areas represent major features of the eco-region, and enable the knowledge networks among key stakeholders that are necessary to scale –up and –out (Douthwaite *et al.* in press). Characterization approaches that take into account not only biophysical data from geo-information systems (GIS) but also known cultural and social factors influencing likelihood of adoption and extrapolation of results. Hence, the benchmark area approach should be regarded as a truly global public R4D tool, which facilitates the exchange of best-best innovations from farmer-to-farmer, or community-to-community within the same stakeholder group; i.e., scaling-out; and at the same time ensure an institutional expansion of best practices from grass root organizations to policy makers, development investors, and other stakeholders to keep building an enabling environment for change; i.e., scaling-out (Fig. 4).

Integrating the benchmark approach (BMA) with a sustainable livelihood (SL) framework, will enhance our understanding of poverty and food insecurity by analyzing the relationships between relevant factors at the household, community, and regional levels; i.e., dissecting the complex in which people live. Likewise, by integrating BMA and SL, researchers can identify recommendation domains that are similar, and therefore target appropriate technology in pilot sites, which are outside the benchmark area but within the same agro-eco-zone. Pilot sites serve for testing and adapting technology ensuing from R4D in the benchmark areas.

V. An Agro-Eco-Zone Crop Research-for-Development Agenda for sub-Saharan Africa

Integrated gene management and integrated natural resources management (INRM) are two important pillars in international agricultural research, which together with plant health management and socio-economics and policy analysis constitute the focus of the core of an international research agenda for agriculture in sub-Saharan Africa. By working in these domains, African national agricultural research systems, international centers of the CGIAR, advanced research institutes, civil society, and other stakeholders will be able to apply Science to improve agriculture –particularly in areas of the world where "marginal crops are grown on marginal lands with marginal resources". Enhanced and sustained crop productivity will, indeed, help to improve human health and rural household food security. However, organizations within R4D partnerships following such a holistic undertaking need to redirect their objectives towards enhancing capacity to incorporate participatory approaches, embracing key principles of multi-scale analysis and using a variety of tools (Sayer & Campbell 2001). Such re-engineering needs integration across scales between component research, stakeholders and professionals (Douthwaite *et al.* in press)

A regional crop research agenda for sub-Saharan Africa should follow priority settings already established by sub-regional organizations (SROs). The main agro-eco-zones in sub-Saharan Africa are the savanna, the humid forest and the mid-altitude zone. Their agro-ecological and socio-economic environments determine the R4D needs of the agricultural systems, which in turn drive the required research agenda (IITA 2001). Hence, following the 2003-2005 Medium Term Plan of IITA (IITA 2003), we propose that the African Challenge Program considers:

- integrating crop-livestock systems in the dry and moist savannas,
- sustaining crop yields and protecting the environment in the tree-crop-natural ecosystems of the humid and sub-humid tropics,
- generating income and promoting agrobiodiversity in the highlands, mid-altitudes and lowlands through agro-processing, markets and trade, and
- intensifying eco-friendly peri-urban agriculture.

Annex 1 lists suggested major outputs and priority undertakings to be included in the African Challenge Program, and their potential impact in African rural development.

Above market- (or demand-) driven agenda should follow an INRM approach that focuses on sustainable production and utilization increases by diversifying crops in the farming systems and increasing commercialization through agro-industrial enterprises in Africa. Great emphasis should be on market analysis in the food systems to ensure responsiveness to changing demands from the rural, urban and expanding commercial sectors as well as on quality and quantity of crop outputs. As a means of alleviating poverty, commercialization of agriculture requires competitive raw materials –from crops as well as marketing and agro-processing –to facilitate and stimulate the expansion of the agro-industry. In this regard, policy research, institutional reform and business development are an integral part of the R4D agenda. Farmers should also get a wide range of options from for coping with potential negative effects of climate change. The African Challenge Program should link agriculture with human nutrition and health and take advantage of advances in Science, particularly in the areas of biotechnology and information technology –both through increased continent-wide capacity and partnerships for implementing its agenda. Likewise, the African Challenge Program must strengthen plant health management capacity in the continent because sometimes eco-friendly sustainable solutions to pests need a regional approach.

V.1. *Sustaining and Enhancing Agrobiodiversity to Impact on Livelihoods.* The conservation of agro-biodiversity and knowledge about biodiversity are vital pillars in agriculture at large and in sub-Saharan Africa in particular. Researchers need the germplasm resources of the major crops grown in Africa and their wild relatives to improve current crops in sustainable farming systems and thus contribute to enhancing the livelihoods of countless farm families in sub-Saharan Africa. Researchers also need the knowledge stored in both living and taxonomic collections of other organisms to help them find sustainable ways to manage pests and diseases so that again those farm families can live better lives. Hence, in the context of a research-for-development approach, agrobiodiversity includes all biological genetic resources required for more productive crops and farming systems. These include crop and other plant genetic resources, insects, mites and micro-organisms, among other living species in agroecosystems. The FARA-led Challenge Program for sub-Saharan Africa should provide a means to assist national governments to fulfill their obligations towards the Convention on Biological Diversity

(CBD) objectives through already well established scientific collaboration throughout tropical Africa. To further this end, existing collections of plant and other genetic resources must be maintained, extended and their materials and associated information made easily accessible to researchers across tropical Africa. In this regards, African genebanks should continue to collect, conserve, evaluate, characterize, enhance, document and distribute plant genetic resources of a wide range of crops and their wild relatives (Ortiz 2002), which are essential for agricultural development and sustainable food production in sub-Saharan Africa. In order to allow the African farmers to benefit from these collections held at genebanks and other biodiversity reservoirs, detailed knowledge and access to updated information on the diversity and distribution of species and their biology, host range and economic status are required. Biological collections contain much of this biodiversity information and thus are of fundamental importance to sub-Saharan Africa as a whole. Unrestricted access to information and expertise will assure that benefits generated from the use of biodiversity can be shared equitably. Information about crop genetic resources their pests and biological control agents are essential to improve quarantine security and strengthen phytosanitary regulations by the national governments and the recommendations by the Inter-African Phytosanitary Council, in line with the international trade conventions and protocols.

V.2. ***Integrated Pest Management for Continent-wide Pathogens*[9].** Environmentally friendly and sustainable plant health management ensues from knowledge on population dynamics, functional biodiversity, biological control, host plant resistance and options for habitat management. This approach must rely on proactive preventive pest control methods rather than on heavy curative chemical pesticides. Hence, appropriate integrated pest management leads to reduce both qualitative and quantitative pre- and post-harvest crop losses. The main research products of such an approach are biological control agents, resistant cultivars, biopesticides and habitat management within crop husbandry that improves both incomes and overall well being by conserving biodiversity and safeguarding the environment and human health. Plant health management deals with healthy planting materials, control of pests (including weeds, termites and migratory pathogens), functional diversity for sustaining agro-ecosystems, and mycotoxins that affect human food and livestock feed in Africa.

For example, arthropod pests of agricultural crops have pathogens that can be exploited as microbial insecticides as alternatives to, or replacements for synthetic insecticides, but particularly as part of an IPM programme. The fungal genera *Beauveria* and *Metarhizium*, the bacterium *Bacillus thurigiensis*, the baculoviruses, the microsporidian genera *Vairimorpha* and *Nosema* and the nematode genera *Steinernema* and *Heterorhabditis* are well known. These pathogens are highly virulent towards their hosts and their familiar shortcomings can be overcome in part by appropriate packaging, formulation, delivery systems. Adoption via commercialisation is an important implementation route, although some of the well known cases of microbial control have taken the classical biocontrol approach. In many parts of the world, pathogens are supplied as commercial products to niche markets by specialized small and medium sized enterprises. In Africa, there are

[9] Information provided by Drs. P. Neuenschwander and A. Cherry (IITA)

remarkably few such enterprises and as a consequence pathogens are not available to growers. This has the consequence that pathogens developed at CGIAR centers do not always find wide adoption. For this reason, at IITA we have tried to put emphasis on stimulating the interest of the private sector to encourage them to invest in biological insecticides. Much more work is required in this direction to establish the kinds of enterprises that could produce biological insecticides. In parallel we have worked with authorities to promote regulatory frameworks appropriate to biological insecticides. Rather few countries have such appropriate frameworks and this may be one constraint to biopesticide implementation. Among African markets, the export and the peri-urban sectors may be most likely to adopt biological insecticides. The export sector because of concerns over maximum allowable residue limits, and the peri-urban sector because consumer concern about residues and the acute problem of pesticide resistance among some keypests such as *Plutella xylostella* in crucifers. Both sectors have the wealth to purchase microbials (the argument that microbials are less expensive than chemical insecticides is not well established) and can afford to take the risk. Adoption in these sectors will create demand and encourage adoption among other groups.

V.3. ***Enhancing and Unlocking Genetic Variation in African-grown Crops through Biotechnology.*** Most of the staple foods of Africa (e.g. cassava, yam, cooking banana, plantain, cowpea, millet) feed tens of millions of poor people daily yet receive relative little attention from the biotechnology industry, because they are not major cash crop commodities. These crops are mostly consumed in the home or villages. Linking African researchers with CGIAR centers and advanced research institutions (ARIs) around the world should bridge both knowledge and technology gaps, and help Africa to share the benefits of biotechnology (Ortiz 2003a). For example, molecular markers are being used to tag specific chromosome segments bearing the desired gene(s) to be transferred (or incorporated) into breeding lines (or populations), i.e., finding genes with DNA markers and magnifying the power of selection in plant breeding. Likewise, many researchers worldwide are transforming crops genetically to overcome pest and disease constraints or producing new diagnostic and fingerprinting tools for identifying pests and pathogens or dangerous food contaminants. Hence, FARA approach to crop biotechnology within this African Challenge Program should consider (i) applying appropriate theory and bio-techniques to address the food needs of sub-Saharan Africa; (ii) transferring in collaboration with partners in Africa or elsewhere, bio-techniques from the laboratory to the marketplace; and (iii) enhancing the capacity of African researchers to apply, control and monitor biotechnology via comprehensive interactions and training at CGIAR centers –particularly those with labs in Africa, or ARIs if appropriate. When biosafety laws are enacted by African governments, and appropriate regulatory frameworks and systems to ensure food safety and human health, and minimize environmental risks are in place, then transgenic crops may be added to the tool-kit of plant breeders working in Africa.

The African Challenge Program should encourage integrating biotechnology in genetic enhancement programs when conventional breeding methods show little or no chance for success (Ortiz 2003a). Functional genomics and genetic manipulations should be seen as tools to overcome barriers to alelle transfer and for an appropriate targeted gene expression in crops grown by African farmers. Therefore, biotechnology in a R4D framework aiming at a sustainable impact on livelihoods should be participatory and driven by end-users (DeVries & Toenniessen 2001). Otherwise it will not succeed to both address the rural development issues of our time and to impact on people –particularly the poor.

Agro-biotechnology advances and its applications in crop improvement, pest and disease control, and crop or natural resources management, will allow acceleration of progress by shortening the breeding cycle or to transform crops to overcome pests. Likewise, biotechnology will facilitate the development of new diagnostic tools to identify food contaminants dangerous to human health, and enhance agro-biodiversity management using new molecular tools. Molecular breeding with DNA markers will assist to find genes, magnify the power of selection in plant breeding, and learn the language of resistance genes to put them into use. Furthermore, gene synteny, advances in genome sequencing and bioinformatics will allow a better understanding or available genes (and their function) in key crops or gene discovery in other research-neglected tropical crop species (Mahalakshmi & Ortiz 2001, Mahalakshmi *et al.* 2002). For example, researchers expect to identify and characterize useful genomic regions conferring a specific trait in crops. The common regions relevant to this trait will be further saturated and annotated. Additionally, appropriate test materials will be chosen to assess the relevance of these genomic regions in each of the targeted crops in relevant environments. In the long-term, this approach should lead to the isolation and characterization of candidate genes for traits of interest if the ordering of DNA loci between chromosomes of two (or more) crops within the same family corresponds well. This gene order conservation between genomes allows genes in an X crop to be isolated by map-based cloning at the homologue in the Y crop, and then by homology in the X crop. Perhaps one day the genes providing extreme drought tolerance of pearl millet can be introgressed into other cereals to achieve more water-efficient crops (Ortiz *et al.* 2000).

V.4. ***More Food per Water Drop: Improving Crops for Drought-prone Environments***. Access and control to water resources are becoming among the most important issues of this 21st century worldwide. For example, drought stress coinciding with flowering and grain filling stages in maize reduce yields by 50% and 21%, respectively, and 12% annual yield loss of maize grain result from drought stress in West and Central Africa (Ortiz *et al.* 2002). Some are advocating an increase of farm water use for sustaining food security and alleviating rural poverty. Environmentalists claim, however, that water resources should drop to be able to protect natural water resources (in rivers, lakes and wetlands). There are distinct options for managing water resources; irrigation was the traditional approach for dealing with water shortages but now that water resources are scarce other solutions are sought. For example, plant breeders are working in the development of crops better adapted to drought-prone environments or in plants with increase water-use efficiency (Ortiz & Saxena 2002). Research suggests that relatively high productivity may be accomplished even in unfavorable environments if selection for adaptation to these environments occurs in targeted crops. Nevertheless, selection for tolerance in stress environments often leads to low yielding genotypes when grown in non-stress environments.

Germplasm screening for tolerance to drought under naturally occurring drought stress does not seem to be reliable. Lack of uniform drought stress in the field will render screening for drought tolerance ineffective and thus limit progress from selection, Selection must occur under controlled environments, where drought will be reliably induced to distinguish between tolerant and susceptible genotypes, particularly at flowering or grain filling stages in seed crops (Ortiz *et al.* 2002). Greenhouse methods are also available for screening germplasm at early stages of plant development in many crop species. Several lines of some crops with superior performance under different kinds of drought are now available for use in breeding programs. Likewise, genetic analysis in some crops suggests that a few genes may control each of the independent plant mechanisms of drought tolerance. Further marker-aided genetic analysis reveals that most of the variation for responses to drought may be accounted by one or few quantitative trait loci (QTL). Cross-breeding assisted by selection with DNA markers could become a means for a fast and objective selection of new cultivars with enhanced adaptation to water-scarce-environments. Marker-aided selection (MAS) should be regarded as an indirect tool for breeding drought tolerance in crops. As any other indirect selection method, MAS of component traits should be pursued when complex target trait has a low heritability or costly field testing, and classical selection impossible at breeding location for target trait(s). DNA markers will be "landmarks" in the crop genome, assisting on handling large population sizes and fast back crossing of gene(s) into inbred lines or other parental sources. Large scale MAS starting in the F_2 generation may also lead to producing elite parents and further MAS in advanced generations will help in the development on near-isogenic or contig lines lines for further testing of hypothesis in plant physiology associated to drought stress.

With the advances in genomics research, it will be feasible to develop a “consensus species" (i.e., define traits) and genetic control points through comparative mapping and gene synteny of related species within a tribe (Ortiz *et al.* 2002). The outputs of such research will be genetically defined loci controlling trait(s) and candidate genes tolerant to drought. For example, cowpea –the African legume of the dry savanna, appears as a suitable species to determine the genetic potential of legume crops for drought using QTL analysis and germplasm characterization, whereas soybean and *Medicago* are the available tools among legume species for assessing the whole-genome transcriptional response to drought. The characteristics of interest in a drought tolerant “consensus legume” species are root architecture, transcriptional pathways, physiological parameters (e.g., osmotic adjustment), plant development (e.g. earliness), and genetic control points (Ortiz 2003b). Comparative mapping will be the means to determine gene synteny of drought tolerance loci between crop legume genomes. Forward and reverse genetics (in these legume species) may identify key regulators of drought tolerant genotypes. The outputs of this legume genomic research are genetically defined loci controlling this trait, candidate genes (as defined by mapping, mutation and transcriptional investigations) for drought tolerance, and DNA markers for assisted-selection or aided-introgression and germplasm management regarding the improvement of drought adaptation in these crops.

Recent analysis of molecular responses to drought and other abiotic plant stresses suggest that manipulating regulation of gene expression and signal transduction in transgenic crops may enhance their adaptation to drought-prone environments and other abiotic stresses. Nonetheless, germplasm improvement, crop husbandry, and water management should be regarded as complementary approaches for managing water efficiently in drought-prone locations (Yajima *et al.* 2002).

V.5. ***Better Health and Nutrition through Crop Breeding***. Protein-energy malnutrition and micronutrient defficiency are amog public health problems leading to learning disability, impaired work capability, illnes and death in Africa. Population growth, intensive poverty, environmental degradation, poor agricultural services and lack of enabling policy environments are among the factors aggraviating malnutrition in the continent, particularly among pregnant women, nursing mothers and preschool children. Improving genetically the nutrient content of staple food crops represents a sustainable way to alleviate micronutrient malnutrition; e.g. iron-deficiency anemia or corneal blindness owing to vitamin A defficiency. In an effort to identify cultivars high in micronutrient content, crop cultivars grown in distinct locations can be assessed for iron, zinc and ß-carotene content. A crop breeding program for micronutrients needs to assess the occurrence of micronutrient deficiency (e.g. vitamin A, iron, zinc or urinary iodine) in target areas and provide the best germplasm to farmers in each location to address it accordingly. Likewise, fortification with target micronutrients may be appropriate if they are available for mixing in local diets.

Maize lines bred at IITA exhibited significant differences in iron, zinc and ß-carotene content in the grain of one of the main staple food in Africa. One of the maize lines grown at a location in the transition zone showed 45% more iron bioavailability than a control maize cultivar widely grown by farmers in northern Nigeria. The results indicate that a potential exists to breed early-maturing maize cultivars for high and stable mineral content in their kernels across diverse growing environments. Similarly, the Centro Internacional de la Papa (CIP, Lima, Perú) and IITA are providing to East and Southern African farmers orange-flesh sweetpotato cultivars (VITAA) with high ß-carotene –the precursor of vitamin A. These VITAA cultivars can be included in agro-processing entrepreneurs for flour and other products that may flow into regional and export trade.

Research areas suggested in V.3, V.4 and V.5 should link the FARA-led CGIAR Challenge Program for sub-Saharan Africa with the other on-going Challenge Programs of the CGIAR on Genetic Resources/Genomics, Water and Food, and Biofortification. Advances and enusing information, knowledge and technology from the other CGIAR Challenge Programs should be fed into the African Challenge Program components addressing alike issues; i.e., improving crops through biotechnology, crop technology for water management, and breeding crops for better health and nutrition, respectively.

VI. Outlook

Impact of any crop improvement program can only be judged over relatively long periods, covering cultivar development, release, distribution and adoption. Through the introduction of more productive cultivars that are resisting prevailing pests, and the effective biological control of the cassava mealybug and other pests, large-scale famine was avoided in sub-Saharan Africa. Without these research-for-development efforts, 25% less maize would currently be produced in sub-Saharan Africa, equal to 8 million t year^{-1}, or the food requirements of 40 million people. Cassava production would be 50% or less, or over 13 million t year^{-1} of dry cassava, enough to meet the calorie requirements of 65 million people. For both crops alone research-for-development by IITA and African partners meant that over 100 million more people are fed; i.e., one out of six inhabitants of sub-Saharan Africa!

Accumulated knowledge on soil management gathered over the last 10 years, combined with solid crop improvement and plant health research at farmers' level, has brought us to a stage where the FARA-led Challenge Program for sub-Saharan Africa can now address with confidence the intensification of cereal–grain legume - based cropping systems in the dry savannas of Africa in a sustainable and environmentally positive manner. The entry point for solving the problems of natural resource base deterioration has been the availability to farmers of resilient and adoptable germplasm of both cereals and legumes. The major hypothesis has been that adapting improved germplasm to soil problems will lead to resilient and sustainable cropping systems and be a starting point for the transformation of smallholder farmers earning US $1 a day into medium or commercial farmers with incomes above US $10 a day.

Above examples, clearly tell us that Africa can deal with issues affecting both agriculture and rural livelihoods when R4D approaches are led by an end-user demand-driven agenda set up by stakeholders living and working in the continent, who deal with them through their daily interactions. Some argue that Africa needs a fertilizer-based Green Revolution (Quiñones et al. 1997) that may include hybrid cereal (mostly maize) seeds as another input. However, lessons from Malawi show that such an approach may not work sustainably if policy factors such as subsidy on inputs and market liberalization are ignored (Carr 1997).

Furthermore, the recent drought in Southern Africa calls for new undertakings, which will need to rely on more crop options for sustaining agriculture and propelling agro-processing as source of income. It should be worth to determine the potential of cassava and pulses viz. a viz. cereals in such drought-prone environments: Preliminary analysis of crop yield outputs reveals that cassava and pulses suffered considerably less than maize during drought in Southern Africa (Fig. 4). Indeed, cassava should be seen as a crop adapted to drought-prone environments that also grows well in poor soil. Cassava grown under stress reduces water use by following an avoidance strategy of stomatal closure and leaf area reduction. After the stress, recovery of cassava leaf area occurs, which of course, influences root yield in cassava depending on the developmental stage of the crop and the environment where it grows. Moreover, the low labor requirements for cassava provides an alternative to the declining maize subsidy and growing labor shortages in Malawi, Zambia and other African nations with the same constraints. Likewise, native African pulses such as cowpea and Bambara groundnut –the legume with high yield potential and highest area growth rate in sub-Saharan Africa (Table 1) appear to be important options for diversifying agricultural systems that rely on cereals in the drought-prone environments of sub-Saharan Africa.

VII. References

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Table 1. Area (million ha), yield (kg ha^{-1}) and production (million t) of some food crops grown by African farmers in early 1960s[1] and late 1990s[2]

	Early 1960s			Late 1990s			Growth rate (% $year\text{-}period^{-1}$)		
Crop	Area	Yield	Production	Area	Yield	Production	Area	Yield	Production
Cereals									
Maize	10.275	887	9.116	20.844	1266	26.399	1.93	0.97	2.92
Sorghum	12.709	776	9.909	22.532	800	18.025	1.56	0.08	1.63
Millets	11.798	587	6.913	19.770	663	13.088	1.41	0.33	1.74
Rice	2.769	1246	3.450	6.927	1664	11.525	2.51	0.78	3.31
Legumes									
Groundnut	5.946	840	4.993	8.790	868	7.390	1.06	0.09	1.07
Cowpea	2.601	283	0.737	9.118	312	2.843	3.45	0.26	3.72
Bean	1.538	600	0.923	2.954	626	1.851	1.78	0.11	1.90
Soybean	0.204	386	0.079	0.774	841	0.672	3.67	2.13	5.97
Faba bean	0.242	918	0.222	0.424	1078	0.457	1.53	0.44	1.97
Chickpea	0.196	653	0.128	0.330	661	0.218	1.42	0.03	1.45
Pigeonpea	0.170	527	0.089	0.261	722	0.188	1.17	0.85	2.03
Lentils	0.083	461	0.038	0.069	649	0.045	-0.50	0.93	0.46
Bambaranut	0.017	882	0.015	0.067	928	0.048	3.78	0.14	3.17
Root & Tubers									
Cassava	5.663	5670	32.114	10.639	8545	90.908	1.72	1.11	2.85
Yam	1.096	7219	7.916	3.600	9627	34.651	3.81	0.23	4.06
Sweetpotato	0.636	5196	3.301	1.937	4498	8.714	3.05	-0.35	2.66
Cocoyam	0.565	4519	2.684	1.107	5273	5.836	1.83	0.42	2.12
Potato	0.150	6345	0.950	0.598	6919	4.136	3.26	0.78	4.07
Fruits									
Musa	2.576	4859	12.515	4.719	5628	26.559	1.65	0.40	2.05
Coconut	0.431	3112	1.340	0.681	2768	1.886	1.25	-0.32	0.92

Source: FAOSTATS (2003)

[1] 3-year average (1961-1963)
[2] 3-year average (1997-1999)

Table 2. Area (million ha), yield (kg ha^{-1}) and production (million t) of some cash crops grown by African farmers in early 1960s[1] and late 1990s[2]

	Early 1960s			Late 1990s			Growth rate (% year-period^{-1})		
Crop	Area	Yield	Production	Area	Yield	Production	Area	Yield	Production
Cocoa	3.349	258	0.866	4.722	438	2.070	0.93	1.44	2.38
Cotton-seed	3.056	438	1.338	4.201	859	3.607	0.86	1.84	2.72
Coffee	2.494	368	0.917	2.676	458	1.225	0.19	0.59	0.79
Oil palm	3.340	3387	1.131	3.931	3664	14.404	0.44	0.21	0.66
Rubber	0.305	514	0.157	0.547	714	0.394	1.59	0.89	2.52
Tea	0.071	828	0.058	0.211	1880	0.397	3.00	2.24	5.31
Tobacco	0.236	694	0.170	0.367	1301	0.478	1.20	1.71	2.84

Source: FAOSTATS (2003)

[1] 3-year average (1961-1963)
[2] 3-year average (1997-1999)

Table 3. Food per caput supply in sub-Saharan Africa from 1961 (pop. 208 million) to 2000 (pop. 605 million)

	1961				2000				Growth rate
Commodity	Total	Calorie	Fat	Protein	Total	Calorie	Fat	Protein	within diet
	Kg year^{-1}	----------per day----------			Kg year^{-1}	--------per day---------			40 year-%
Total		2059	59.6	40.5		2226	54.2	44.4	
Crops		1919	42	31.5		2087	43.7	35.4	
Animals		141	10.6	9		140	10.5	9	
Cereals	112	950	25.1	8	127.3	1057	27.6	7.6	13.7
Wheat	7.5	60	1.8	0.3	19.6	156	4.6	0.6	161.3
Rice	9.3	93	2	0.3	17.7	174	3.6	0.4	90.3
Barley	2.8	23	0.6	0.1	1.6	13	0.4	*	-42.8
Maize	31.8	276	7.2	2.8	40.1	350	8.9	3.2	26.1
Millet	22.4	178	4.3	1.7	17.4	137	3.3	1.3	-22.3
Sorghum	32.2	267	7.8	2.6	23.7	195	5.8	1.9	-26.4
Root & Tuber	157.6	423	3.9	0.6	163.1	438	4.4	0.7	3.5
Cassava	111.8	302	2.1	0.4	103.1	275	1.9	0.4	-7.8
Potato	3.4	7	0.1	0.1	6.5	13	0.3	*	91.2
Sweetpotato	12.6	33	0.4	0.1	13.9	36	0.5	0.1	10.3
Yam	19.6	54	0.9	0.1	28.2	77	1.2	0.2	43.9
Others	10.2	27	0.4	*	11.4	36	0.5	*	11.8
Sugar cane	1.4	1	*	*	2.7	2	*	*	92.9
Sweeteners	5.8	56	*	–	9.8	95	*	–	69.0
Pulses	10.2	94	6.2	0.5	9.5	88	5.7	0.5	-6.9
Beans	3.4	32	2.1	0.1	2.9	27	1.7	0.1	-14.7
Peas	0.9	8	0.5	*	0.5	5	0.3	*	-44.4
Others	5.9	55	3.6	0.3	6.1	57	3.7	0.3	3.4
Treenuts	1.3	12	0.3	0.2	1	7	0.2	0.4	-23.1
Oil Crops	6.7	79	3.1	6.6	5.3	63	2.8	4.9	-20.9
Soybean	0.2	2	0.2	0.1	0.8	9	0.7	0.4	300.0
Groundnut	3.5	52	2.2	4.3	2.5	37	1.6	3	-28.6
Coconut	1.5	6	0.1	0.6	1	4	*	0.4	-33.3
Vegetable Oil	5.4	129	0.1	14.7	7.5	181	0.1	20.5	38.9
Soybean	*	1	*	0.1	0.6	14	*	1.6	≈ oo
Groundnut	1	25	–	2.8	1.9	45	–	5.1	90
Cotton	0.2	5	*	0.8	0.3	8	*	0.9	50
Palm	3.3	81	*	9.1	3.1	74	*	6.4	-6.6

Vegetables	30.6	25	1.4	0.3	29.7	22	1.2	0.2	-2.9
Tomato	2.2	1	0.1	*	3.9	2	0.1	*	77.3
Onion	0.7	1	*	*	2.5	2	0.1	0	257.1
Fruits	54.3	94	1	0.4	48.5	85	0.9	0.3	-10.7
Banana	7.2	12	0.2	*	6.5	11	0.2	*	-9.7
Plantain	23.3	57	0.5	0.1	22	54	0.5	0.1	-5.8
Pineapple	3.2	2	*	*	2.6	2	*	*	-18.8
Stimulants	0.7	1	0.1	*	0.8	2	0.1	0.1	14.3
Coffee	0.5	1	0.1	–	0.4	1	0.1	–	-20.0
Cocoa	*	*	0.1	*	0.2	1	*	0.1	≈ oo
Tea	0.1	*	*	–	0.2	*	0.1	–	100
Spices	0.8	7	0.3	0.3	0.7	6	0.2	0.2	-12.5
Alcoholic Beverages	38.8	45	0.4	0.1	33.6	40	0.4	*	-13.4
Meat	12.7	61	5.3	4.3	11.4	36	4.5	4.1	-10.2
Beef and veal	6.1	32	2.5	2.4	4.6	24	1.9	1.8	-24.6
Mutton and goat	2.3	11	0.9	0.8	2.1	10	0.8	0.7	-8.7
Pig	0.6	6	0.2	0.5	1	9	0.3	0.4	66.7
Poultry	1	3	0.3	0.2	2	6	0.7	0.4	100
Others	2.6	9	1.4	0.4	1.6	6	0.8	0.3	-38.5
Offals	1.7	5	0.8	0.2	1.4	4	0.6	0.1	-17.6
Animal fats	0.5	12	*	1.3	0.5	10	*	1.1	0
Butter, Ghee	0.2	5	*	0.5	0.1	3	*	0.3	-50
Milk	27.9	50	2.6	2.7	27.1	49	2.6	2.8	-2.9
Eggs	1	3	0.3	0.2	1.5	5	0.4	0.3	50
Fish, seafood	5.9	10	1.7	0.3	7.6	15	2.3	0.5	28.8

* Traces

Source: FAOSTATS (2003)

Table 4. Some of the most important food crops in sub-Saharan Africa as per energy supply (billion kcal) or crude protein content (million t)

Crop	Energy (billion kcal)	Crop	Protein (million t)
Cassava	107	Maize	1.9
Maize	86	Groundnut	1.5
Rice	37	Cassava[z]	0.91
Groundnut	32	Rice	0.69
Yam	30	Yam	0.66
Plantain	27	Plantain	0.19
		Cowpea[z]	0.17
		Soybean	0.16

[z] Additional protein supply through cassava leaf and cowpea leaf –consumed as vegetables, are not included

Source: IITA (2001)

Table 5. Area (million ha), yield (kg ha^{-1}) and production (million t) of maize grown by African farmers in early 1960s[1] and late 1990s[2]

	Early 1960s			Late 1990s			Growth rate (% 40-year period)		
Region	Area	Yield	Production	Area	Yield	Production	Area	Yield	Production
Sub-Sahara	10.28	887	9.12	20.84	1266	26.40	103	43	190
Sub-region									
West	2.64	777	2.05	7.20	1274	9.18	173	64	348
Central	1.58	733	1.16	2.72	974	2.65	72	33	129
Eastern & Southern	5.79	988	5.72	10.60	1344	14.25	83	36	149
(Not included above by FAO)									
South Africa	4.27	1363	5.81	3.72	2312	8.59	-13	70	48
Country									
Cameroon	0.46	761	0.35	0.37	2131	0.78	-20	180	123
Côte d' Ivoire	0.22	666	0.15	0.70	934	0.65	219	40	348
DR Congo	0.51	664	0.34	1.46	816	1.19	189	23	255
Ethiopia	0.76	941	0.72	1.58	1688	2.67	107	79	271
Ghana	0.22	930	0.21	0.68	1489	1.01	202	60	384
Kenya	0.88	1253	1.11	1.52	1513	2.30	72	21	108
Mozam-bique	0.41	861	0.35	1.18	960	1.14	190	11	223
Nigeria	1.21	898	1.09	4.02	1316	5.28	231	46	386
Tanzania	0.85	800	0.68	1.80	1286	2.32	112	61	241
Uganda	0.17	1151	0.20	0.61	1491	0.91	258	30	364
Zambia	0.76	824	0.62	0.55	1480	0.82	-27	80	31
Zimbabwe	0.80	1095	0.88	1.44	1190	1.71	80	9	95

[1] 3-year average (1961-1963)
[2] 3-year average (1997-1999)

Source: FAOSTATS (2003)

Table 6. Annual growth rates (%) of cassava in the World

	Mid-1970s to mid-1980s			Mid-1970s to mid-1980s		
Region	Area	Yield	Production	Area	Yield	Production
Africa	9.7	1.6	2.4	3.1	1.2	4.2
Latin America	-0.5	-0.4	-1.4	0.0	0.7	0.7
Asia	2.5	2.1	4.6	0.1	0.4	0.5
World	0.9	1.4	2.2	1.6	0.4	2.2

Source: CIAT (2002)

Table 7. Area (million ha), yield (kg ha^{-1}) and production (million t) of cassava grown by African farmers in early 1960s[1] and late 1990s[2]

	Early 1960s			Late 1990s			Growth rate (% 40-year period)		
Region	Area	Yield	Production	Area	Yield	Production	Area	Yield	Production
Sub-Sahara	5.66	5670	32.11	10.64	8545	90.91	87	51	183
Sub-region									
West	1.43	7629	10.92	4.43	10337	45.82	210	35	320
Central	2.20	5503	12.08	3.17	7384	23.43	145	34	94
Eastern & Southern	1.98	4509	8.92	3.03	7194	21.64	53	59	143

[1] 3-year average (1961-1963)
[2] 3-year average (1997-1999)

Source: FAOSTATS (2003)

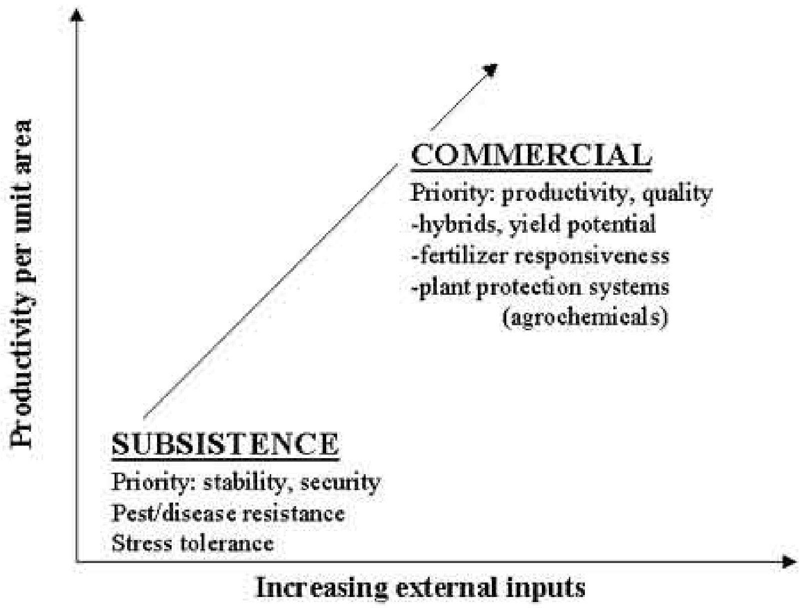

Fig. 1. Landholder development trajectory[10]

[10] After Ortiz (in press)

Fig. 2. The ring-partnership approach for agric. research-for-development in SSA

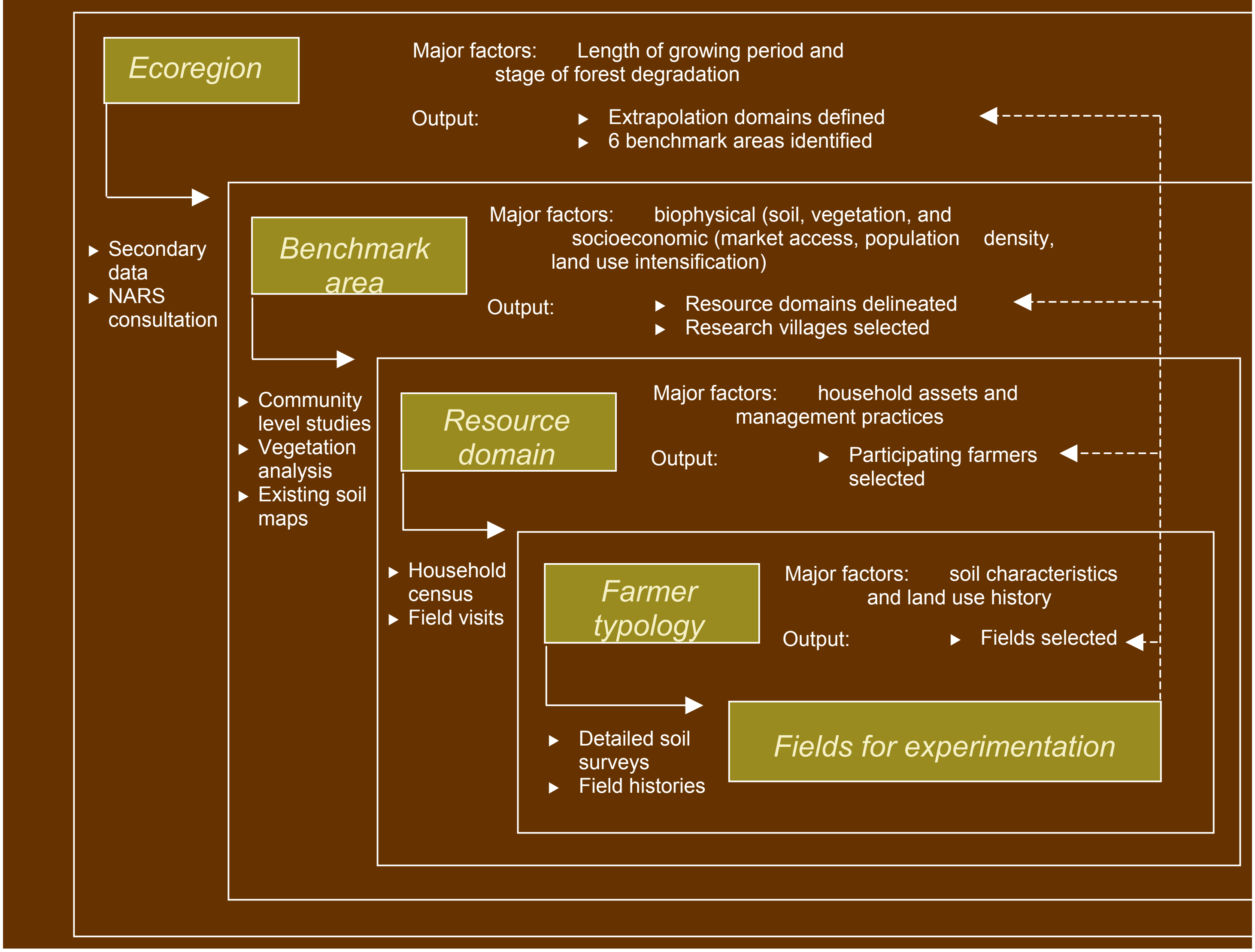

Fig. 3. Framework for benchmark area development[11]

[11] Lukas Brader (personal comm.)

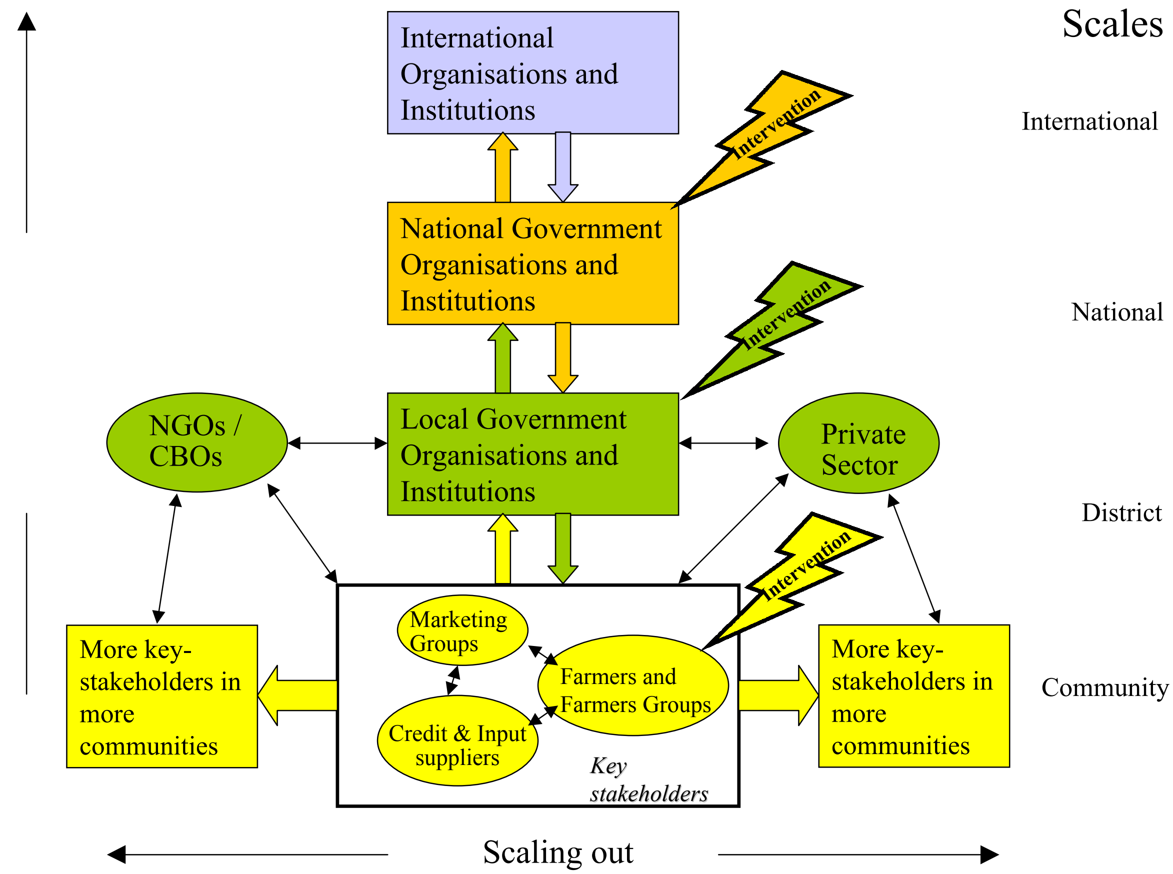

Fig. 4. Scaling –up and out[12]

[12] After Douthwaite *et al.* (in press)

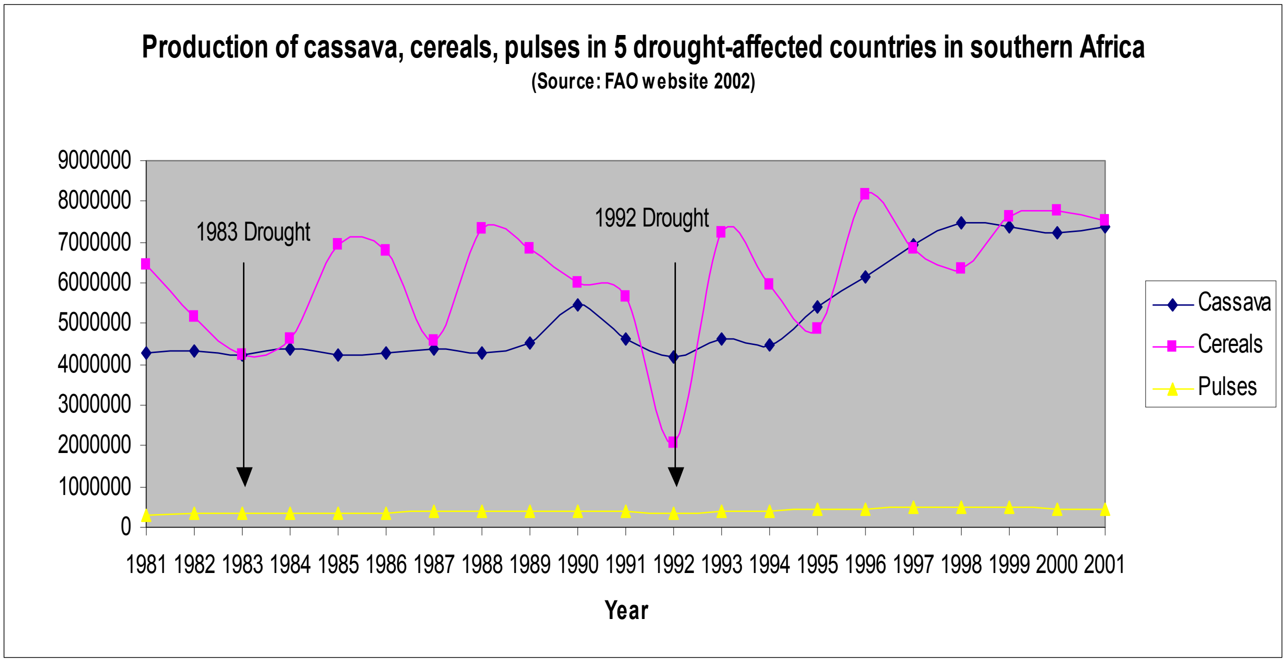

Fig. 5. Total output for crops in southern Africa from 1961 to 2001

Annex 1. Suggested crop-led technology outputs and priority undertakings for the African Challenge Program

Goal

African farmers, mostly rural poor, adopt improved food systems that result in increased agricultural productivity, higher income, and environment protection

Outputs

- Market opportunities identified for setting R4D agenda and formulating policy options
- Commercially viable small and medium scale agro-enterprises that expand trade of the starchy, grain, fruit and vegetable staples enhanced
- Key drivers of intensification understood to formulate, target and prioritise researchable issues to respond to stakeholders' needs
- Broad-based and special trait genotypes and populations targeting the major production systems and market opportunities developed and disseminated
- Environmentally safe integrated plant protection technologies that reduce pre- and post- harvest losses due to pests and diseases developed and applied
- Crop and natural resource management practices for sustainable, competitive and commercially based production systems developed and disseminated
- Public and private sector partnerships that promote information and technology exchange with emphasis on a scaling-up strategy for increased trade developed and strengthened
- Local, national and regional capacity among stakeholders to generate, evaluate and disseminate appropriate knowledge and intervention technology for target sub-sectors enhanced

Priority Undertakings

- Characterization of agri-food systems and markets to identify opportunities and constraints to expansion of utilization in the food, feed and industrial sectors
- Increased knowledge base for effective prioritisation, planning, implementation, monitoring and impact assessment of R4D activities
- Development, evaluation and promotion of improved postharvest technology for expanded utilization in viable commercial enterprises
- Evaluate value adding opportunities within selected market chains to strengthen agro-enterprise linkages between producers, processors and emerging markets to expand commercial options
- Development, evaluation, and promotion of improved and adapted germplasm for the different production systems and market opportunities with emphasis on food, feed and industrial characteristics
- Maintenance and improvement of broad-based and special trait populations, delivery of seed populations and in vitro plantlets of elite germplasm to local or national partners and other regional stakeholders
- Integration and application of environmentally safe plant protection technologies to reduce pre- and post-harvest losses caused by pests and diseases

- Development of natural resource management practices to ensure sustainable commercially competitive production systems
- Fostering broader interaction with the public and private sectors to promote information and technology exchange and their application towards increased national and regional trade

Potential Impacts

- Diverse and multiple disease and pest resistant cultivars with superior and stable yield performance and acceptable food, feed and industrial quality characteristics increasingly available and utilized by African farmers and entrepreneurs
- Increased value addition to improved germplasm within the food, feed and agro-industrial sectors for expanded commercialization and trade
- Effective technology delivery system by broad public and private partnerships, which promote widespread and successful information and technology exchange that meets farmer, processor, and consumer requirements to enhance increased production, utilization, commercialization and national and regional trade
- Resource-poor farmers using these technologies significantly improve and sustain their production systems with less dependence on pesticide and chemical inputs
- Increased productivity with genetic traits that enhance utilization in the food, feed and industrial sector would provide additional source of cash income for those households especially women, who produce and process these crops
- Increased low cost carbohydrate staple for low-income urban and rural consumers, and food security in vulnerable areas
- Collaborating stakeholders will benefit from enhanced human resource development and capacity to undertake research and development activities towards increased productivity, utilization, commercialization and national and regional trade