10 YEARS OF CASSAVA RESEARCH AT ETH ZURICH

A critical assessment

Revised Report

submitted to the

Swiss Centre for International Agriculture (ZIL)

by

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From 1994 to 2004, the Swiss Centre for International Agriculture (ZIL) has funded nearly 20 research projects at the Swiss Federal Institute of Technology (ETH Zurich) that are directly or indirectly related to the improvement of cassava agriculture in the tropics. These research projects were part of ZIL's Research Priority Area on Cassava Improvement (RPA Cassava) and ranged from genetic improvement of cassava to the improved understandings of agro-ecological and socioeconomic issues of cassava agriculture.

The goal of the RPA Cassava was to help advance the science of cassava, a crop that attracts only a small research community worldwide, and to contribute to improved and sustainable livelihoods of cassava farmers in tropical regions on a long-term perspective.

In this context, research collaborations were initiated with national and international research institutes in Africa and Latin America. These collaborations enabled Swiss PhD students to gather experience and conduct research in developing countries. In return, qualified young researchers from these countries were awarded with scholarships (within the ZIL's Research Fellow Partnership Program, RFPP) to do their research in well-equipped laboratories at ETH Zurich and international agricultural research centers.

The following impact study on cassava does not just look at the ZIL cassava research projects but also embeds these activities into the global context of cassava agriculture and cassava research initiatives. It will discuss the global trends of international agricultural research and cassava research in particular, and assess the role of advanced research institutes, such as ETH Zurich, in the emerging new networks of international agricultural research.

Moreover, the report identifies the advantages and disadvantages of cassava compared to other crops and shows how the major problems in cassava agriculture are currently addressed with new scientific tools and methods that allow for more interdisciplinary and development-oriented research in the agricultural and food sciences.

The evaluation of the impact of ETH/ZIL cassava research is based on the information collected through literature research, FAO crop data on cassava, as well as a small survey and personal interviews with researchers, policy makers and representatives of farmer organizations in Nigeria, USA, Colombia, Brazil, and Switzerland.

The findings of this evaluation show that ETH Zurich has managed to become a global leader in cassava biotechnology research and a very important contributor and highly appreciated partner in cassava-related agro-ecological research in developing countries. Given the overall importance of cassava as a food and cash crop in tropical regions, ETH's high scientific reputation in this area is a very valuable asset and its role in collaborative cassava networks in developing countries should be enhanced. The results of the small survey show that all ETH projects are considered very important contributions to the science and, to a considerable extent, development. The Cassava RFPP projects were regarded as most important to development. In this context, it is important to support ZIL-funded research fellows also in their efforts to set up initiatives back home. Finally, livestock and cassava research are regarded as ideal complements to improve cassava-derived animal feed.

1 The growing importance of cassava in international agriculture

The following chapter gives an idea of the complex molecular, physiological, ecological, cultural and historical characteristics of cassava, explains the major constraints of cassava as a food and cash crop in Latin America, Asia and Africa, and highlights some of the international efforts to make cassava more attractive for integrated rural development strategies and international investment.

The following section briefly summarizes the content of the chapter:

Cassava is a heterozygous, vegetatively propagated root crop with a wide variety of uses. Only when the Portuguese discovered Brazil in the 16th century, cassava was introduced in Africa and Asia, as a consequence of the Portuguese trading activities in the southern hemisphere. Today, Africa produces more cassava than the rest of the world combined. At the same time, cassava is under siege in Africa from new diseases and pests that were unintentionally imported with planting material from Latin America many decades ago (as a consequence of the falling geographical barriers and lack of quarantine controls). Nevertheless, cassava has become the third most important source of calorie intake in the tropics and is eaten on a daily basis in one of its many fresh and processed forms by an estimated 600 million people. In addition, cassava is a cash crop of growing importance with respect to industrial starch and animal feed.

The major constraints of cassava subsistence agriculture are of particular importance in Africa where cassava is mostly grown on poor and marginal soils and kept as an insurance against food shortage during drought seasons (cassava roots can be preserved in the soil for up to one year). Pest infestation and plant diseases and the lack of access to input and output markets in Central Africa has led to a general decline of production per capita not just of cassava (which experienced one of the steepest declines over the last four decades) but of all major food crops except rice. The high reliance on cassava in Central Africa is also creating a problem of malnutrition because starchy cassava roots may be an importance source of carbohydrates but are very poor in protein content. Moreover, the increasing urban demand for cheap cassava with high cyanid content induces farmers to shorten the detoxifying fermentation process and increase the risk of Konzo, a neural disease that cripples the human body. Research to overcome these major constraints in cassava subsistence agriculture might be one of the most effective ways to improve food security in tropical Africa.

Cassava has also the characteristics of a competitive industrial crop that produces inexpensive high-quality starch, yet most of the investments in starch production and animal feed over the last decades have gone into corn rather than cassava. A joint initiative by the International Fund for Agricultural Development (IFAD) and the Food and Agriculture Organization (FAO) designed 'The Global Cassava Development Strategy' (GCDS). This strategy intends to reverse the declining trend by modernizing cassava agriculture in analogy to the successful case of Thailand (see page 13), making private investments in cassava more attractive, improving marginal farmers' access to markets and creating new product markets for cassava. Once subsistence farmers are able to sell the harvest surplus of cassava rather than just using it as manure, the promotion of cassava cash crop opportunities may also help create new economic opportunities in Africa's marginal regions.

1.1 Cassava, an ancient crop of considerable importance to science and development

1.1.1 A short pedigree of cassava

It is estimated that cassava domestication began 5000-7000 years ago in the Amazon region (Gibbons 1990). The estimate receives support from archaeological findings in the Amazon and the fact that it is cultivated from vegetative propagules (stakes), which is assumed to be an older practice than seed-culture.
The transitional link between the wild ancestor and cultivated cassava may be the discovery of 'Manipeba', a cassava relative with undomesticated characters that was discovered in the cultivated folk variety of the crop in the Amazon. Manipeba is also one of the reasons why Brazil is widely assumed to be the center of origin and the center of domestication of cassava[2] (Allem 2000a). Cassava's gene pool ranges from a great variety of wild species to numerous domesticated species with very specific characteristics.
The methods used to investigate the origin and variability of cassava comprise the taxonomic species concept, the biological species concept, biosystematics and molecular genetics. Today, molecular genetics and biosystematic trials (using molecular markers) provide increasing clarification about the different scientific perspectives on sites of origin and domestication and shape consensual synthesis (Allem et al. 2000a/b). In addition, the use of environmental maps obtained through GIS (Geographic Information Systems) provides information on germplasm origin (collection sites) that complement the studies of plant genetic resources and agro-biodiversity in the proper classification and characterization of large germplasm collections (Burle et al. 1998).
Of all cassava biodiversity, only six broadly defined species qualify as genetic resources of cassava (meaning the part of its biodiversity that is linked to a human economic activity): *Manihot esculenta* (the main food and feed crop), cassava tree (a putative hybrid of *Manihot esculenta* and *Manihot glaziovii*), the *Manihot esculenta* subspecies *flabellifolia* and *dichotoma* (additional regular gene suppliers of breeding programmes), *Manihot caerulescens* (minor rubber producer) and *Manihot glaziovii* (animal feed species). Besides the edible cassava species (*Manihot esculenta*) that are of considerable economic value, there are other minor edible species mainly cultivated by indigenous populations in the Amazon region and Central America such as *Manihot carthaginesis* (Columbia), *Manihot aesculifolia* (Mexico), and *Manihot leptophylla* (Peru) (Allem et al. 2000b).
The agricultural value of cassava genetic diversity must be seen in its contribution as gene suppliers of breeding programs (to improve nutritional quality, pest and disease

[2] Some researchers maintain the possibility that Yucatán in Mexico may be the true center of Origin (Hillocks et al. 2001).

resistance)[3]. Only recently, interesting varieties of domesticated cassava were found to be cultivated by indigenous communities in the Amazon: some of the species are rich in beta-carotene, others produce sugar instead of starch and still others are designed to yield waxy starch (Carvahlo et al. 2000). The use of cassava as part of the dowry in traditional indigenous marriages, as ornamental plant and shading tree in public and private spaces, as well as its scientific (physiological and ecological complexity) and cultural value (embeddedness in indigenous communities) are additional important reasons to preserve cassava biodiversity in-situ and ex-situ. Large Cassava ex-situ germplasm collections are hold in trust at the Centro Internacional de Agricultura Tropical (CIAT) in Columbia, EMBRAPA in Brazil and the International Institute of Tropical Agriculture (IITA) in Nigeria.

1.2 Cassava as a food crop

1.2.1 The crop of last resort

Cassava is produced mostly by smallholders on marginal and submarginal lands in the humid and subhumid tropics. It is efficient in carbohydrate production, adapted to a wide range of environments and tolerant to drought and acidic soils. An estimated 70 million people obtain more than 500 Kcal per day from Cassava and more than 500 million people consume 100 Kcal per day (Kawano 2003). Its ability to grow on poor soils and under difficult climatic conditions as well as the advantage of flexible root harvesting whenever there is a need[4], make it the ‘crop of last resort’ for farmer families and their domestic animals in the tropics (Hillocks et al. 2001). The importance of cassava as a food crop in Africa becomes obvious when its annual consumption per capita is compared to the rest of the world (see Figure 1). While the World average of annual cassava consumption lies around 17 kg/capita in 2001, Africa’s annual consumption is still above 80 kg/capita. Latin America’s consumption has decreased by half over the last 30 years from a peak of above 40 kg/capita in the early 1970s to slightly above 20 kg/capita in 2002. The decrease in consumption of cassava may be a good sign if it indicates that people’s meals have become more diverse and more protein-rich (cassava only provides carbohydrates in form of starch). It is however a matter of growing concern if there are indications that cassava consumption is declining, but not substituted by other food crops. This is likely to be the case in regions such as Central Africa.

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[3] Wild species of Manihot show a discrete participation in breeding programmes of cassava. A relevant exception is Manihot glaziovii, which was used in Africa and Asia as donor of resistant genes against the Cassava Mosaic Virus Disease (CMVD). However, many breeders consider the potential of wild species in genetic improvement to be very limited. A satisfactory compromise between conservation policy and breeding goals is reached with recommendations to conserve wild species for their potential contribution to enlighten processes that led to the domestication and further evolution of the crop or because they partake the very gene pools of the food crop (Allen et al. 1998)

[4] Cassava has no definite maturation point: the root tubers start bulking after about 8 month and can then be stored in the soil for several months. Cassava is therefore the ideal famine reserve (for humans and their domestic animals) and thus an essential food security crop in subsistence farming

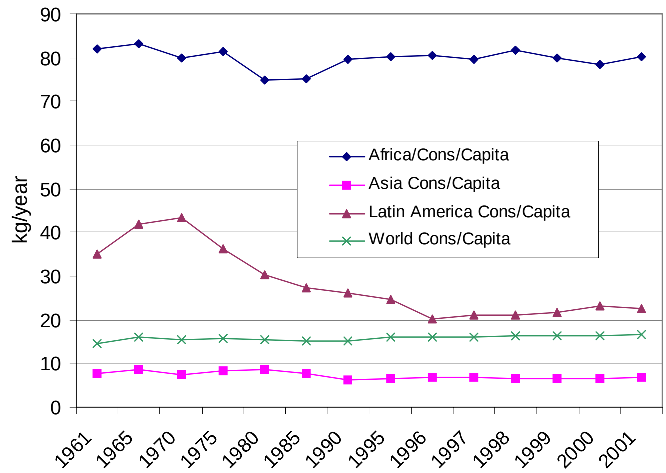

Figure 1***: Cassava consumption per capita, worldwide and by region (FAOSTAT)***[5]

Figure 2 shows the development and distribution of cassava consumption/capita within Africa: Whereas production and consumption of cassava per capita in Africa as a whole slightly increased or at least remained stable, Central Africa experienced a steep decline in consumption and production of cassava for the last 40 years. In Western Africa production and consumption/capita experienced a strong upward trend at the beginning of the 1990s but then remained stagnant; whereas in Eastern Africa, a slight decline in production and consumption/capita can be observed from 1991-1995 which, subsequently reached the previous levels again. The strong decline in Central Africa might be related to plant diseases and pests as well as a breakdown of local cassava trade in the ongoing civil wars.

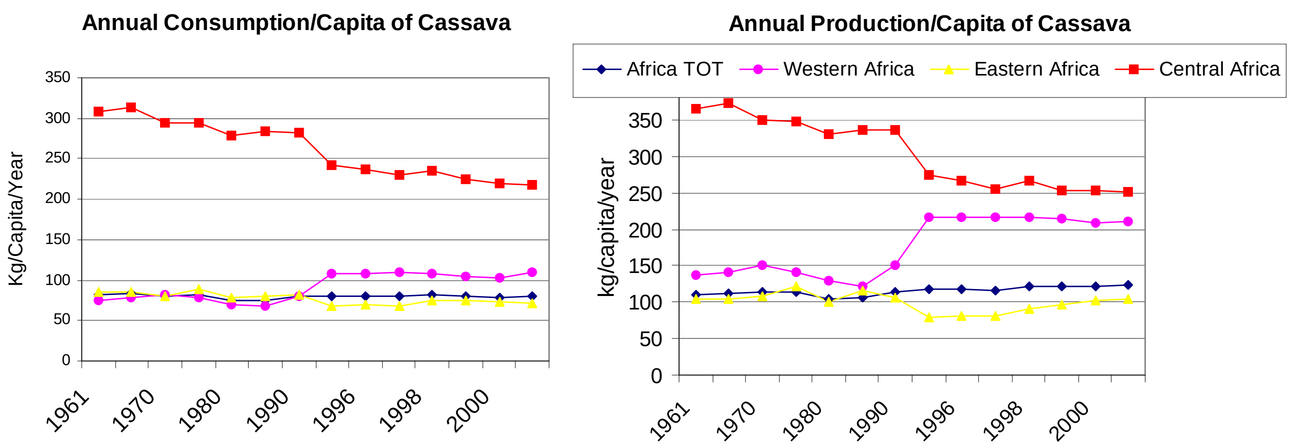

Figure 2: ***Annual Consumption and Production of Cassava per Capita in Africa***[6]

[5] The illustration shows the development of Cassava consumption per capita from 1961-2002. Since the purpose is to show only some rough trends over this period of time but nevertheless discover if there were any interesting bumps in the recent history documented in this paper, the x-axis uses a 5-year-interval until 1995 and a 1-year interval from 1995 to 2005. This also applies to Figure 2, 4, 5, 6 ,7.

Figure 3 shows that not just cassava but almost all major food crops are in decline in Central Africa. This is an alarming sign because the decline of cassava cannot just be explained by food crop substitution or diversification. The recent FAO report on Food Insecurity in the World (FAO 2003) also points out that the numbers of undernourished people decreased in Asia and Latin America but increased in Africa, where Central Africa again shows the strongest increase.

Average cassava consumption per capita in Central Africa continues to be twice as high as the overall average consumption of Africa. At the same time, cassava experienced the steepest decline in production/capita of all major food crops. It indicates the importance of cassava in Central Africa and the seriousness of the current food crisis in this region. This tragedy has a lot to do with the ongoing civil wars and the general neglect of Central Africa by foreign donors and investors; in Congo, 1000 times more people die every year than in Palestine, but annual foreign aid designed for Congo amounts to just half of what Palestine receives (Economist 2003). But it is also related to the genetic erosion of traditional cassava varieties, poor soils, pests and plant diseases, and lack of access to fertilizer. Cassava generally responds well to irrigation or higher rainfall conditions, and to the use of fertilizers. However, the gap between the yield of cassava harvested under optimal experimental conditions (over 80 tons/he) and the average yield harvested by African farmers of around 8-12 tons/he indicate the numerous limiting factors in Cassava subsistence agriculture (Taylor and Fauquet 1997).

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[6] Western Africa comprises: *Nigeria, Niger, Togo, Benin, Ghana, Guinea, Guinea-Bissau, Gambia, Ivory Coast, Liberia, Sierra Leone, Senegal, Burkina Faso, Cape Verde, St. Helena, Mali, Mauritania.*
Central Africa comprises: *Central African Republic, Equatorial Guinea, Dem. Rep. of Congo, Angola, Cameroon, Chad, Sao Tome y Principe, Gabon.*
Eastern Africa: *Kenya, Somalia, Djibouti, Ethiopia, Eritrea, Burundi, Rwanda, Uganda, Tanzania, Madagascar, Seychelles, Comoros, Mauritius, Mozambique, Malawi, Zambia, Zimbabwe*

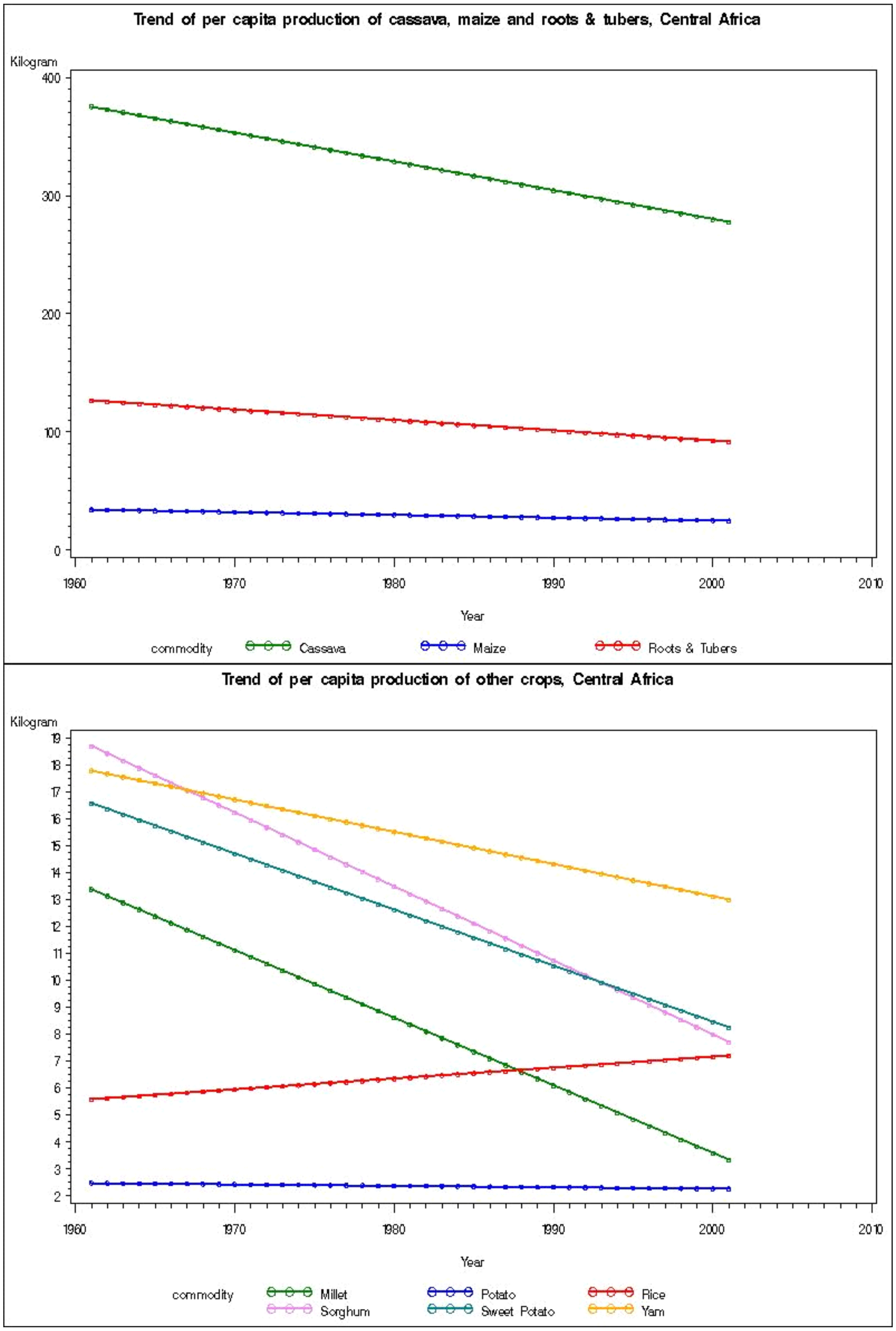

Figure 3*: Production/capita of major food crops. Summary graphs of regression lines of the various crops in Central Africa*[7]

[7] Trends for cassava, maize, and roots and tubers was separated from the rest of the major crops because of their relatively large per capita production values. It would therefore be difficult to recognize some important trends if all the crops were combined in one graph. The use of the predicted regression lines which capture the history of FAO data from 1961 through 2001, show that there is indeed a declining trend for all crops except rice (see also Annex V).

1.2.2 Constraints in cassava subsistence agriculture

Subsistence farmers with poor access to fertile soil, credit, markets and technology are likely to practice low input cassava agriculture, exposed to numerous biotic and abiotic constraints:

Among the biotic stresses, the most serious plant diseases that are ravaging cassava fields in the tropics are

- the Cassava Mosaic Virus Disease (CMVD). It consists of various different strains that easily mix; it is estimated that these geminiviruses devastate 50 million tons of cassava annually in Africa (Taylor and Fauquet 1997)
- Cassava Bacterial Blight (CBB) the most important worldwide disease of cassava,
- Cassava Brown Streak Virus (CBSV), a virus that spreads quickly in Eastern Africa; no resistance has been achieved for CBSV through conventional breeding methods (unlike for CMVD and CBB),
- Fungal and Nematodes diseases (e.g. superelongation disease), and
- Frog Skin Disease (a problem particularly in Colombia and Northern Brazil)

In addition, pests such as

- Whiteflies (that also serve as a vector for virus transmission),
- Lepidoptera (Stem-, Horn-, Rootborers),
- Mealybugs and
- Mites

continue to affect cassava fields worldwide.

Since cassava stakes and not seeds are used for planting (vegetative propagation), yields are strongly dependent on the use of clean and fresh stakes (diseases are often transmitted through contaminated planting material), and the way the stakes are put into the soil.

Pest management is also facing serious challenges because farmers often don't have the means to buy expensive imported pesticides and time to conduct labor-intensive biocontrol. In spite of some success stories, biocontrol also faces serious agro-ecological limits because of the highly migratory nature of the most important pests such as the Hornworm (natural enemies build up but pests simply migrate after leaving the puppet stages) and it is still not possible, neither with biocontrol nor with intercropping, to break the life-cycle of pests such as whiteflies that feed on cassava and spread plant viruses. Moreover, there are still no effective control measures for soil-born pests (*Phytophtora*)[8].

Cassava cultivated in intercropping systems proved to be a poor competitor for nutrients in the soil compared to other crops and, worse, privileges leaf and stalk growth over root growth under competition stress.

Abiotic constraints such as drought and flood, as well as soil erosion (cassava is grown on highly erosive soils and has itself a very poor retention capacity) are further contributing to the very low yields achieved in the farmer's field, especially in Africa[9].

Cassava is a perennial food crop that produces root (rich source of carbohydrate but poor in protein). Roots are harvested on average between 8 to 12 months after planting. According to the COSCA study (1989), the late bulking of cassava is perceived to be one of the most important food security problem for subsistence farmers who sometimes need

[8] Personal communication with Dr. Anthony Bellotti, Entomologist at the Centro Internacional de Agricultura Tropical (CIAT) in Colombia.

[9] Personal communication with Prof. Dr. Emmanuel Frossard, soil scientist at ETH Zurich.

to harvest earlier (in case of crop failure elsewhere). The other complementary food source derived from cassava is its leaves which are rich in protein content. Yet, usually the leaves fall off at an early stage of cassava development and, consequently, are not used as a complementary food dish to the roots. Moreover, the high cyanogenic content of 'bitter' cassava, grown in many regions of tropical Africa, render its fresh products (leaves and roots) highly toxic for human consumption, especially for malnourished people that lack essential sulfur rich amino acids that allow for cyanid detoxification in the body. The result is a neural disease called Konzo that slowly cripples the human body. The fact, that bitter cassava is often cheaper and more resistant to pests and diseases makes it increasingly popular with poor cassava growers. This is not a problem if bitter cassava goes through a proper traditional fermentation process that ensures proper detoxification (cooking itself is not sufficient) and increases its storage life. But the increasing demand for cheap cassava in the growing African cities induce cassava producers to shorten the time of the traditional fermentation process from four to two days. Since this leaves detoxification of cassava incomplete it heightens the risk for urban consumers to be affected by Konzo (NZZ 1999).

Considering the importance of cassava as the crop of last resort, its poor nutritional value and toxicity is a matter of great concern and needs to be addressed by encouraging plant geneticists and breeders to develop cassava varieties that have a low cyanogenic content but still keep their resistance to pests and diseases. Moreover, farmers must be encouraged to adopt and store more protein-rich food sources, and if that is not possible, to seek ways to increase the nutritional value of cassava roots themselves. The lack of nutritional value of cassava roots is a matter of particular concern in drought periods when no other crops are available for immediate consumption.

Once the roots are harvested they need to be processed and consumed within a couple of days for post-harvest deterioration advances quickly (the same applies to the stakes that need to be planted within a few weeks after harvesting). Moreover, cassava-producing areas often lack reliable post-harvest facilities and infrastructure such as roads, means of communication and input supply systems. These post-harvest and market constraints hamper the development of cassava trade in the tropics significantly and often lead to the situation that any surplus beyond the immediate home consumption becomes waste or manure[10].

1.3 Cassava as a cash crop

The total world production of cassava has reached 183 million tons in 2001 and is projected to amount to 209 million tones (fresh weight) by 2005 according to FAO projections (FAO 1999) assuming the continuation of the past 2.2% annual average growth rate. 60% of the total demand is designed for food, the remainder for feed and other uses. By 2005, global cassava trade is projected to increase annually by 1.6% up to 5.8 million tons, reflecting a moderate growth in import demand for cassava feed (used for chicken, pigs, cattle and fish) and other novel cassava food products (cassava instant

[10] Personal communication with Dr. Alfred Dixon, Plant Breeder at the International Institute of Tropical Agriculture (IITA) in Nigeria.

meals, cassava snacks, and cassava ingredients for sweeteners and prepared foods) and non-food products (starches and flours for sizing textiles and papers[11] (FAO/IFAD 2001). The market potential of most of these products remains largely underexploited in the tropics. The rapid post-harvest deterioration of fresh cassava and the labor- and time-intensive processing of dried cassava and cassava starch represent major constraints that put cassava at a disadvantage to other crops designed for starch and animal feed production such as corn. A comparison of cassava and corn in total production and production designed for the animal feed market clearly shows where investments have gone for the last three decades (see Figure 4).

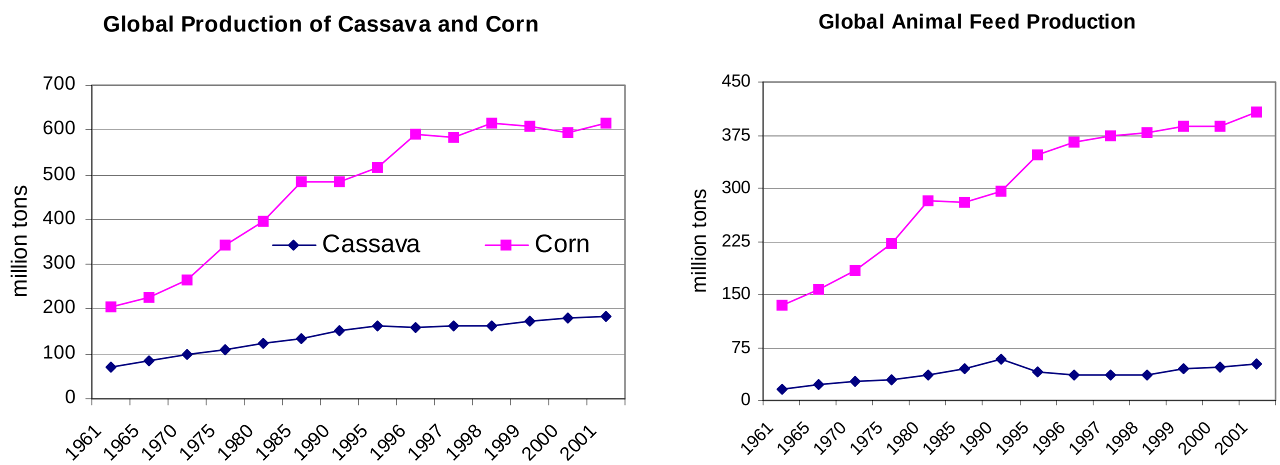

Figure 4: ***Total production and animal feed production of cassava and corn worldwide***

1.3.1 The Thai success story

Nevertheless, Cassava has proven its commercial potential in the case of Thailand where effective public/private partnerships and long-term oriented government policies generated a dynamic cassava industry. Thailand started as a successful cassava starch exporter in the Asian region after World War II. The wastes from starch manufacture became the basis for the development of an export-oriented cassava animal feed industry in the 1950s as a result of an increasing demand from Europe where cassava was seen as an adequate substitute for highly expensive German grains in animal feeding. This new market opportunity induced Thailand's public and private sector to encourage small producers to participate in a flexible and vertically integrated system of cassava production, processing, and marketing of cassava. As a consequence, Thailand became the largest exporter of dried cassava (8 million tons/year until 1994) until the EU was forced to reform its expensive common agricultural policy (CAP) in the second half of the 1990s due to the requirements of the General Agreement on Tariffs and Trade

[11] Other cassava products derived from its extraction of alcohol and oil as well as its starch use for biodegradable products are of negligible quantity.

(GATT). Even though Thai cassava continued to enter the EU at a preferential 6% tariff after this reform, Thailand was no more able to meet its previous quota because European grain production became more competitive in the animal feed market in response to agricultural reform policies. Once again, Thai entrepreneurs responded quickly to shifts in the cassava economy by developing internal feed markets, capturing new markets in Asia and diversifying into starch and starch-based products (FAO/IFAD 2001). The recovery of Thai cassava trade is reflected in Figure 5 in the upward trends of total imports and exports of cassava in Asia from the 1960s to 2001. Latin America has for a long time neglected the commercial potential of cassava and by the end to the 1990s it even became a net importer of cassava. The trend is however reversing after the 1990s: Brazil and Costa Rica, the leading commercial producers of cassava have again become more competitive on the international market (Costa Rica is also benefiting from the increasing demand of cassava as convenience food in the United States due to its ever growing population share of Latinos).

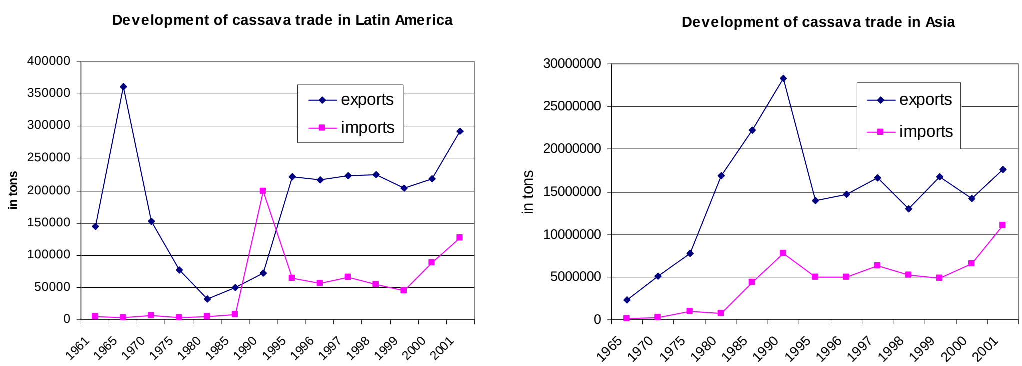

Figure 5: ***The development of cassava trade in Asia***

The Thai success story is also related to the successful breeding partnership between CIAT (who focused on germplasm collection and the generation of basic breeding material) and national Thai research institutes devoted to applied breeding (distribution and selection of improved materials) and the fact that cassava diseases and pests are not as widespread in Asia as in Africa. Fresh root yield was improved by 100% and root dry matter content by more than 20%. The breeding of cassava as animal fodder is easier because highly specific local cassava food quality preferences do not have to be considered (Kawano 2003).

In spite of this success story, the levels of underutilized cassava in Africa, Asia and Latin America continue to be very high. In Latin America waste even exceeds the amount of cassava used for food consumption (FAO/IFAD 2001). In addition, the advantages of cassava as a supplier of high-quality and inexpensive industrial starch and animal feed seemed not to be heeded by the private sector throughout the 1990s since corn has continuously outperformed in these global markets. Latin American and Asian countries that saw the most conspicuous substitution of cassava by corn in animal feed are particularly concerned because of the growing dependence on US corn imports. In Africa however, cassava has caught up with corn as a supplier of animal feed and seems to grow even faster indicating that cassava is playing a crucial role as animal feed in subsistence farming (see Figure 6)

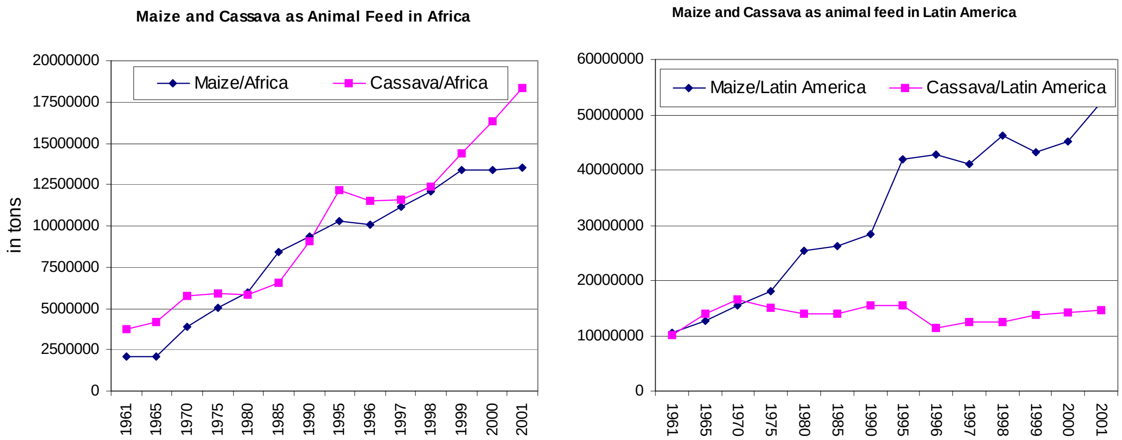

Figure 6: Cassava and corn used as animal feed in Africa and Latin America

1.3.2 A cassava cash crop renaissance?

The Global Cassava Development Strategy and Implementation Plan (GCDS) initiated by the Food and Agriculture Organization (FAO) and the International Fund for Agricultural Development (IFAD) in 1996 aims to counteract the negative trends of cassava in food and cash crop agriculture by using a demand-driven approach to promote and develop cassava-based industries with the assistance of a coalition of groups and individuals interested in developing the cassava industry (FAO/IFAD 2001). Its vision is to spur rural industrial development and raise incomes for cassava producers, processors and traders. This would decrease the vulnerability of subsistence farming and offer new opportunities to improve the livelihoods of people in marginal tropical regions.

Yet, these opportunities largely depend on the availability of labor, capital, land, infrastructure and research partnerships. In countries where the commercialization of cassava has reached an advanced stage such as in Thailand, Costa Rica and Brazil, technologies have been developed in recent years that make planting, harvesting and post-harvest processing more efficient and less time-consuming. Figure 7 indicates that these efforts to make cassava production more cost-effective may have triggered a renewed interest in cassava as animal feed, after a remarkable slump at the beginning of the 1990s.

Despite its central role for the well-being of the poor in the tropics and its proven potential as a supplier of high-quality industrial starch and inexpensive animal feed, cassava remains one of the world's 'orphan crops' that was neglected by public and private sector research and investment, especially in comparison to other crops of similar potential. As a consequence, the resources committed to its genetic and agronomic improvement have been a tiny fraction of the ones committed to the major cash crops such as soybean, corn, wheat and rice. This also highlights the importance of global initiatives to promote cassava agriculture and the few advanced research institutes, such as ETH Zurich that are involved in the small global cassava research community.

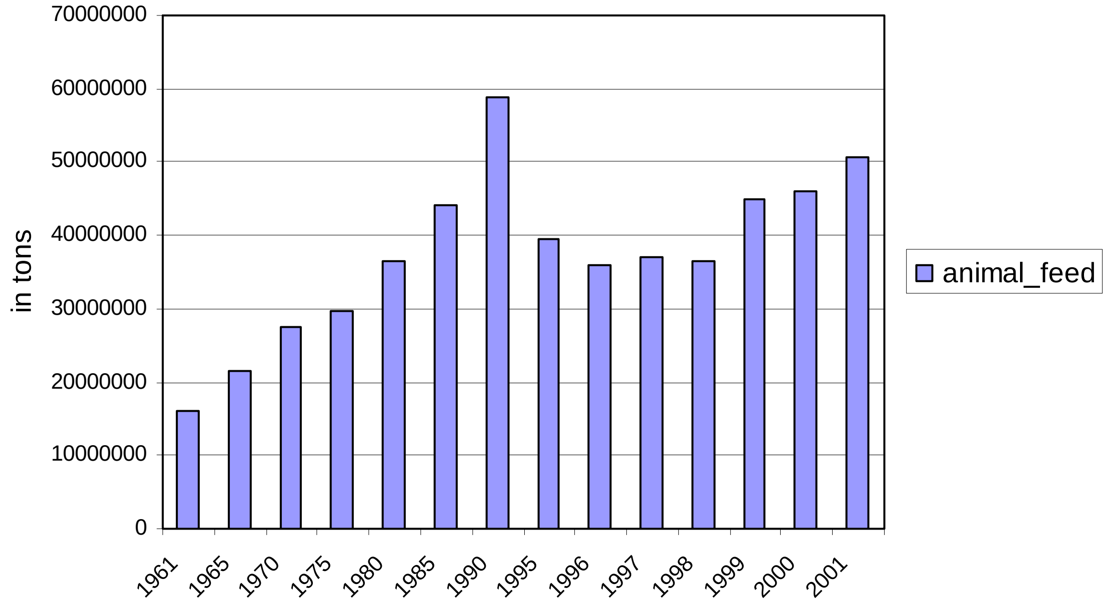

Figure 7: ***Total World cassava production designed for animal feed***

1.4 Summary

- Brazil is widely assumed to be the center of origin and the center of domestication of cassava. Cassava's gene pool ranges from a great variety of wild species to numerous domesticated species with very specific characteristics.
- The agricultural value of cassava genetic diversity must be seen in its contribution as gene suppliers of breeding programs. E.g. species of cassava that were found to be cultivated in the Amazon, proved to be rich in beta-carotene, to produce sugar instead of starch and to yield waxy starch (of industrial value).
- An estimated 600 million people, mostly living in tropical regions, consume more than 100 Kcal of cassava per day.
- Its ability to grow on poor soils and under difficult climatic conditions as well as the advantage of flexible root harvesting whenever there is a need, make it the 'crop of last resort' for farmer families and their domestic animals in the tropics.
- The production and consumption per capita of cassava and all other major food crops (except rice) declined in Central Africa over the last forty years.

- Subsistence farmers with poor access to fertile soil, credit, markets and technology are likely to practice low input cassava agriculture, exposed to numerous biotic and abiotic constraints and low quality of planting material.
- Considering the importance of cassava as the crop of last resort, its poor nutritional value and toxicity is a matter of great concern.
- The rapid post-harvest deterioration of fresh cassava and the labor- and time-intensive processing of dried cassava and cassava starch represent major constraints in the successful promotion of cassava as a cash crop designed for starch and animal feed production.
- Cassava has proven its commercial potential in the case of Thailand where effective public/private partnerships and long-term oriented government policies generated a dynamic cassava industry.
- The levels of underutilized cassava in Africa, Asia and Latin America continue to be very high. In Latin America waste even exceeds the amount of cassava used for food consumption.
- Global Initiatives aim to counteract the negative trends of cassava in food and cash crop agriculture by using a demand-driven approach to promote and develop cassava-based industries.
- Global financial resources committed to the genetic and agronomic improvement of cassava have been a tiny fraction of the ones committed to the major cash crops such as soybean, corn, wheat and rice.
- Efforts to make cassava production more cost-effective in Asia and Latin America have triggered a renewed interest in cassava as animal feed in recent years.

2 The Changing Nature of International Agricultural Research

This chapter starts with a brief look at some of the major advances in cassava research and discusses the general idea of a coming biotechnology-based doubly Green Revolution in agriculture. It will be argued that the geopolitical and ideological climate has changed significantly since the first Green Revolution in the 1960s and 70s and that the major players of a possible second Green Revolution today will not be able to take the first one as a guide of orientation. Today, international agricultural research centers can no more rely on a continuous flow financial support of Western donor agencies; instead they have diversified the sources of possible funding and income by partnering more intensively with local stakeholders in developing countries and advanced research institutes in developed countries. Moreover they are seeking more collaboration with multinational companies and the private sector in developing countries in order to increase the rate of commercially viable products that are to emerge from research activities.

International agricultural research has shifted from a supply-driven to a demand-driven concept of rural development. This shift will be explained by using the examples of the International Institute of Tropical Agriculture (IITA) in Nigeria and the Centro Internacional de Agricultura Tropical (CIAT) in Colombia. Apart from the new orientation of international agricultural research centers, the chapter will also highlight how new networks of cross-continental collaboration are emerging in agricultural research. In this context, the various global initiatives surrounding cassava will be used as an example.

2.1 The cassava research frontier

Even though the global scientific community involved in cassava research is rather small compared to other important crops of similar importance, it has made significant advances on the understanding of the origins of cassava as species and domesticated crop (Allem et al. 2000a), its genetic make-up (Carvahlo et al. 2000), its complex interrelationship with respective local ecosystems (Hillocks et al. 2001) and its use and socioeconomic role in the different world regions (Kawano 2003). At the same time the major constraints of cassava as a food and cash crop in tropical regions are successfully addressed with a wide range of new scientific tools and methods derived from modern biotechnology. These new tools and methods help overcome the constraints faced by conventional methods of breeding and integrated pest management and accelerate the genetic improvement and adaptation of cassava for different ecological and socioeconomic environments.

2.2 A doubly Green Revolution?

These general advances in agricultural research are often identified as a second or a ‘doubly’ green revolution (Conway 1999). However, unlike in the first green revolution, these new efforts to improve basic food crops in the developing world with a new, effective and increasingly affordable biotechnology toolkit have a different driving force. The first green revolution was to a large extent an America-driven effort to improve food security in the non-aligned developing world as part of a global containment strategy against communism (Anderson et al. 1991). Even though this mission boosted agricultural productivity and contributed to improved global food security, the interaction between Western scientists, who developed high yielding varieties, and local farmers in developing countries who adopted these varieties through the national seed distribution programs, was rather poor. This led to some problems on the long run such as inadequate use of pesticides, insufficient maintenance of irrigation systems and little seed choice for farmers (Aerni 1999). In addition, farmers in marginal regions did not benefit to the same extent from these new hybrid varieties because such varieties were designed for favorable agricultural conditions with access to fertile soil, irrigation, markets and essential inputs (Byerlee and Morris 1993).

During the first green revolution, the Consultative Group of International Agricultural Research (CGIAR) enabled Western scientists to work in well-equipped research centers in developing countries. The research at these centers (IARCs) contributed to significant productivity increases in agriculture and technology transfer to local universities and national research institutes, but it basically remained a top-down approach with little cultural interaction and little effort to embed the strategy into a comprehensive people-based development concept.

The new initiatives to improve food security after the Cold War faced serious constraints: public sector funding for agricultural research decreased significantly while investment in private sector agricultural research skyrocketed; foreign aid was cut in almost all state budgets of developed countries (New York Times 2001) and many Western policy makers and activists in development co-operation tended to regard science and technology as inappropriate to address the problems of the poor in developing countries (Aerni 2001). These changes in perception had the effect that science and technology tended to be seen as a problem of sustainable development rather than as an essential contribution to it. Even though United Nations Development Program (UNDP) has tried lately to correct this misperception (UNDP 2001), sustainable development policies continue to be separate from science & technology policies in many developing countries[12]. These changed circumstances forced the CGIAR system to adapt quickly to the new and difficult environment in order to stay relevant. In other words, the CGIAR centers could no more rely on a continuous and rather uncompetitive flow of grants from its traditional donors but had to compete for funding with each other and an increasing number of other stakeholders involved in development co-operation. These constraints and the new competition contributed to more innovative strategies to provide real benefits

[12] Surveys on stakeholder perception and collaboration in public debates on agricultural biotechnology in developing countries showed that the national subcommittees on sustainable development (set up in order to address the goals of Agenda 21) are only dealing with environmental but not science and technology issues (Aerni 2002).

to the poor in developing countries: the strict hierarchy in international agricultural research with its one-way communication from the scientist to the farmer was abandoned in favor of mutual learning. Traditional CGIAR activities such as ex-situ germplasm conservation and crop improvement were complemented with more outreach and training activities for local stakeholders. Local partners were no more seen as grateful receivers of useful technology but as partners in technology development and distribution. The increasing partnership of the IARCs and local farmer communities manifests itself in the common insight that a project is only sustainable if local farmers also see opportunities to make economic gains, be it as producers, innovators or traders, otherwise the project is abandoned as soon as external support expires[13].

2.3 Institutions and technologies involved in the global efforts to Cassava agriculture

2.3.1 The International Institute of Tropical Agriculture (IITA)

The new and highly successful strategic re-orientation in international agricultural research is practiced at the International Institute for Tropical Agriculture (IITA) in Nigeria and the Centro Internacional de Agricultura Tropical (CIAT) in Colombia.
IITA has the CGIAR's mandate for Cassava in Africa and developed an approach called 'Research-for-Development End-User-Driven' (Ortiz 2002). The goal of this approach is to bring a technology focus back into development work. But this time science and technology would involve demand-driven strategy, in which research institutions, development organizations, the private sector, development investors, and national governments are partners in sharing the aim of accelerating agricultural diversification in a continuum from subsistence farming needs to commercial farming priorities; as a consequence, IITA has accelerated decentralization efforts in Africa, abolished institutional and ideological barriers between the different local stakeholders and contributed to a significant increase in trust and cooperation between the different players in Africa. Another important emphasis of IITA is on training and outreach activities. The objective of these activities is to allow local people to address the various constraints in tropical agriculture with the new tools of agricultural biotechnology. In the case of Nigeria there is a wide range of quality among national research institutes and universities; some lack even the most essential resources and do not show any initiative of change; others, however, managed to mobilize some funding for modern laboratory equipment and are highly motivated to get access to additional funding sources in order to offer students countrywide the possibility to put their theoretical knowledge to practical use by paying a small fee for an annual course of applied biotechnology[14]. IITA

[13] Personal Communication with Dr. Rodomiro Ortiz, Director, IITA, Nigeria; Dr. Joe Thome, Geneticist, CIAT, Colombia; and Dr. Maria Jose Sampaio, EMBRAPA, Brazil
[14] The contrast between the Unversity of Ibadan, which used to be one of the leading universities in Africa (thanks also to its proximity to IITA) but has lost most of its good people and initiatives, and the nearby University of Agriculture in Abeokuta, which has excellent facilities, modern biotechnology equipment, highly motivated and entrepreneurial people, could not be more striking.

occasionally offers such entrepreneurial universities technical assistance and equipment for their biotechnology courses but would prefer to have formal institutional agreements with a higher share of donor contributions.

Unfortunately, many international donors are not helping to solve IITA's institutional constraints because they think that local universities in Africa do not have the capacities and resources to conduct proper biotechnology training and research. Therefore, they consider it pointless to make these students familiar with a new toolkit that, in their eyes, would be too expensive and inappropriate for Africa anyway. This donor attitude may be changing in the coming years because the price for a biotechnology toolkit has dropped tremendously and biotechnology applications do not have the primary purpose of creating transgenic plants (which may be the most expensive solution anyway due to all the current regulatory hurdles and political polarization) but are designed to improve understanding of biochemical pathways that produce certain wanted and unwanted traits in plants, accelerate breeding by means of selective markers and create clean planting material through micropropagation.

Fortunately, many governments of big countries in the developing world have become aware of the potential of biotechnology research at local universities and research institutes. They try to find ways to stimulate more local research through new domestic institutions[15] and increased South-South collaborations[16].

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[15] *Nigeria* has increased its budgetary allocation for the Federal Ministry of Science & Technology five fold. It is also setting up a Biotechnology Advanced Laboratory (BAL) in Abuja as a component of the national framework for biotechnology development listed in the National Biotechnology Policy Document 2001 (Alhassan 2002). These initiatives however do not correspond with the widespread complaints at National Agricultural Research Institutes (NARS) in Nigeria. According to interviews with representatives of NARS and Universities in the surroundings of Ibadan, no one has yet seen additional money for research. Many even saw their research budgets gradually decreasing in recent years and some even started to sell some of their agricultural research products (e.g. fruit juice) on the local market in order to compensate for the lack of funding. The Nigerian government nevertheless seems to be committed to modernizing cassava agriculture (president Obasanjo himself is a cassava farmer and grew up in Abeokuta) through increased South-South collaborations (with Brazil and Thailand that already have modernized cassava agriculture to a considerable degree) and CGIAR support (IITA and CIAT know-how and technologies).

Brazil has made significant advances in linking universities to the private sector through business incubators and promoting local business initiatives through a new institution called SEBRAE which coaches and teaches small-scale innovators to enable them to become active and successful entrepreneurs. The Brazilian government faces intense internal debates over the use of genetically modified crops. Although the planting of herbicide resistant soybean has become legal thanks to a government decision in August 2003 (valid for at least one year) and President Lula da Silva has now a favorable view of agricultural biotechnology, there is still strong disagreement within the government and between the government and public activists that block further steps.

Colombia has set up various government initiatives that encourage small-scale innovators to create business plans and apply for microcredits at low interest rates. Colombia is eager to create a favorable environment for agricultural biotechnology research and has already approved transgenic crops for field testing and commercial use.

[16] Personal communication with Sotto Pacheco Costa, Bilateral International Cooperation, EMBRAPA Headquarters, Brasilia

2.3.2 Africa's need for more South-South Collaboration

IITA is not seen as a foreign institution by the Nigerian government but an important local agent of change through its effective research, outreach and training activities. However, there is a risk that IITA's increased efforts to collaborate with actors in Africa may go along with a decreased willingness of its executive to collaborate with players from outside Africa. This could hurt the effectiveness of the 'Research for Development' approach in particular because some of the most useful Cassava technologies and market development strategies of interest to African farmers have been developed outside Africa, such at the Rayong Field Crop Research Center in Thailand (applied breeding, marketing), EMBRAPA in Brazil (planting, harvesting and post-harvest technologies of cassava, genomic analysis of useful traits in indigenous cassava varieties) and CIAT in Colombia (the driving engine of innovation in research, management, technology and product development with the largest germplasm collection of cassava).

2.3.3 The Centro Internacional de Agricultura Tropical (CIAT)

CIAT is based in Cali, Colombia and has the global mandate for Cassava in the CGIAR system. It is one of the CGIAR centers that greatly succeeded in transforming itself into a modern development-oriented think tank that churns out useful new ideas, technologies and agricultural products for farmers, local companies, national research institutes, universities and policy makers in developing countries worldwide. As mentioned earlier, CIAT has significantly contributed to Thailand's success as the No 1. exporter of cassava worldwide (Kawano 2003). It has built different networks of collaboration with National Agricultural Research Systems (NARS), universities and companies in Latin America as equal partners in a common effort

- to train and educate people about the use and the potential of biotechnology in agriculture,
- to address agro-ecological problems in cassava agriculture,
- to design new post-harvest technologies (e.g. artificial drying plants),
- to develop improved breeding conditions (e.g. double haploid initiative[17]) that make cassava a viable alternative to corn in the animal feed and starch business, and

[17] The breeding of the most important crops always relies on the use of inbreeding at one stage or another of the process. In the case of self-pollinated crops the end product is an inbred (homozygous) line. Cross-pollinated crops include inbreeding for a variety of reasons related to the reduction of undesirable genes and the fixing of the genetic make-up of parental lines for the production of hybrid seed. But crops with inbreeding depression such as cassava make the process cumbersome. A typical breeding program of cassava starts out with no less than 10'000 botanical seeds and takes about 10 years to eventually release a new variety, which many times proves not to be much better than the existing varieties. Transfer of useful genes from one clone to another is cumbersome and inefficient. The backcross scheme utilized successfully in most crops cannot be implemented in cassava because of the heterozygous nature of the parental lines. The most important advantage of haploid technology is the rapid and complete achievement of homozygosity. This implies a reduction of costs and time for the genetic improvement of Cassava (by reducing the time involved in the production of inbred lines), enables germplasm exchange based on botanical seed, which is much easier than that of vegetative cuttings (reduced risk of disease transmission

- to create new commercial food and industrial products derived from cassava in Latin America in collaboration with the Consorcio Latinoamericano y del Caribe de Apoyo a la Investigación y al Desarrollo de la Yuca (CLAYUCA).

CIAT was also the initiator of the Cassava Biotechnology Network for Latin America and the Caribbean (CBN-LAC), a global initiative to pool the resources for cassava researchers and end users united by the goal of mobilizing the development and application of biotechnology tools for the enhancement of the value of cassava for food security and economic development in the poorest rural areas of Latin America. This network is supported by funds provided by the Special Program on Biotechnology and Development Co-operation (DGIS/BIOTECH) of the government of the Netherlands and the Canadian International Development Research Co-operation (IDRC). The current regional CBN-LAC started activities in 2001 as an offshoot of the erstwhile global CBN (1992-1998), which was also funded by the DGIS. The regionalization was a result of reviews of the parent CBN. CBN-LAC supports cassava crop improvement projects in Colombia, Brazil, Ecuador and Cuba. This includes participatory projects on in-vitro cleaning and multiplication of local and improved cassava varieties by small farmers in Brazil (managed by EMBRAPA-Cassava and Fruits, EBDA, an agricultural extension agency, and Farming Communities in Bahia) and Colombia (managed by local NGOs such as FIDAR in Valle Cauca and PBA in Monterios in collaboration with farmer communities). These projects use low cost cassava in-vitro rapid multiplication techniques developed by the CIAT's Biotechnology Research Unit (BRU). Small tissue culture laboratories, cold chambers and greenhouses were built with local materials in collaboration with local farming communities. This inexpensive equipment costs six times less than the conventional commercial equipment (Escobar et al. 2002). It enables local farmer communities to modify their precarious farming conditions by learning how to use tools of modern biotechnology to address their particular needs in cassava agriculture. In spite of some initial difficulties these participatory projects succeeded in helping the farmers to prevent the genetic erosion of their cassava planting material through in-vitro propagation of improved clones (Escobar et al. 2002). It has also empowered local men and women involved in these projects because they became aware for the first time that biotechnology is not magic practiced by inaccessible Western scientists but a practical tool they can use to address their own particular constraints in agriculture. The self-confidence gained also resulted in increased local entrepreneurial activities, curiosity, and a willingness to share knowledge and information on cassava with other farmer communities[18]. Resource-poor farmer communities benefit from such activities in particular because it is cheaper for them to increase cassava yields by means of their own efforts to improve planting material than to buy expensive planting material,

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through transboundary movements), allows for cleaning planting stocks from viral and other pathogens without the need of meristem culture and many other tricks to improve breeding (Zaida Lentini and Hernan Ceballos 2003)

[18] Interviews with farmers and FIDAR representatives in Cali-Palmira confirmed this newly gained pride and enthusiasm for the new approach. Many entrepreneurial women in the farmer communities started to apply for microcredit schemes with government institutions to start a small local business by offering clean planting material to other farmers in the region. The newly gained self-confidence also makes them more open to innovations in crop management and soil conservation and the additional income allows them to send their children to school and invest more time in education for themselves.

pesticides and fertilizers from agribusiness companies. Tissue culture is also in routine use in numerous laboratories in Africa to generate disease free propagules of cassava, banana, potato, sweet potato and yam (DeVries et al. 2002).

2.3.4 Global Initiatives on Cassava

The FAO Global Cassava Development Strategy (GCDS)[19] that started taking shape in 1996 and the Global Cassava Plan for Genetic Improvement in 21st Century (GCP21) set up in 2002 are recent efforts to join forces to improve cassava agriculture.

The GCDS forms a systematic approach to identifying opportunities and constraints at each stage of the commodity development cycle from production to consumption of cassava. It is also considered as a framework for technical cooperation in research and technology transfer and for future debates on global issues affecting cassava (FAO/IFAD 2001).

The GCP21 was initially set up by CIAT, the Donald Danforth Center for Plant Science (DDCPS), EMBRAPA and IITA to constitute a worldwide, multi-institutional research and development consortium dedicated to employing the power of biotechnology to deliver improved germplasm to end users in the tropics. The following problems are identified as the major obstacles to improve quality and quantity of cassava production:

African Cassava Mosaic Virus Disease (ACMD), Cassava Bacterial Blight (CBB), post harvest deterioration and low nutritional protein content (Fauquet and Thome 2002).

Most recently, CIAT and the International Food Policy Research Institute (IFPRI) were appointed as the leading research institutes for *HarvestPlus*, a US$ 50 million Challenge Program of the CGIAR with substantial funding from the Bill&Melissa Gates Foundation to combat malnutrition by improving the nutritional quality of staple food in developing countries. This biofortification initiative may be supported with an additional US$ 25 million by the World Bank and other international institutions. The first stage of this program will focus on achieving promising results with the help of the new tools of biotechnology but without the use of genetic engineering. If, subsequently, it turns out that genetic engineering may be the only promising approach to address certain crucial problems of malnutrition, it will be included at a later stage. Other research institutes and development organizations are invited to participate in this initiative through competitive grants (which will make up 20% of the total amount).

A major worldwide hub of agricultural biotechnology research is located in St. Louis, Missouri, USA. St. Louis is home to Washington University (one of the leading academic institutions in the United States), Missouri Botanical Garden (the largest botanical garden in the world), Monsanto Company (the most advanced technology company in agriculture) and the recently set up Donald Danforth Center of Plant Science (DDCPS), a new leader in Plant Science in the United States. The DDCPS is also home to ILTAB

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[19] This strategy is based on a vision that cassava will spur rural industrial development and raise income for producers, processors and traders and it will contribute to the food security status of its producing and consuming households. The essence of the GCDS is to use a demand-driven approach to promote and develop cassava-based industries with the assistance of a coalition of groups and individuals interested in developing the cassava industry (FAO/IFAD 2001)

(International Laboratory of Tropical Agricultural Biotechnology), which is one of the leaders in cassava biotechnology research. Washington University, Missouri Botanical Garden and DDCPS are all part of the Cassava Biotechnology Network and the Global Cassava Improvement Plan (GCP21).

Throughout the 1990s, Monsanto has set up various public-private partnerships with national research institutes in developing countries in order to address certain problems with food crops by means of biotechnology (e.g. the Sweet Potato Project with the research institute KARI in Kenya; Virus Resistent Potato Project with CINVESTAV-Irapuato, a national research center in Mexico, etc.). However, in 2003, Monsanto concluded that it was not worth to continue these projects because it is not its core business and did not improve its public image as expected. As a consequence, the Sweet Potato Project was given to the DDCPS (which sublicensed it from KARI for convenience purposes) and the remaining projects are still in the Monsanto's freezers. This is unfortunate because the know-how and the technology developed in these projects contributed a lot to technology transfer and capacity building in developing countries. For example, African research fellows were trained at Monsanto laboratories in St. Louis and national research institutes in developing countries learned a lot about the complexities of bioengineering, biosafety, and product development[20].

For a long time, the CGIAR had a rather naïve view of transgenics ignoring the importance of public perception in politics, the costs and difficulties involved in getting regulatory approval for the laboratory work, field tests and commercial application, and the art of developing a promising laboratory result into a viable commercial product. As a result, transgenic research conducted at the CGIAR has not yet resulted in one single commercial product. Yet, many IARCs have recognized the importance of politics and perceptions, and its impact on public and private investments. They have set research priorities based on cost-effectiveness and likelihood of successful adoption by small-scale farmers and managed to integrate local participatory methods into technology transfer and development projects in order to improve the collaboration with local stakeholders and the private sector. For example, in order to bring new cassava products on the market or disseminate improved cassava planting material to remote places some CGIAR-centers are hooking up with companies that have created and developed highly efficient commodity distribution channels (e.g. Nestlé, Coca Cola) that reach even the remotest areas in developing countries[21].

2.4 ETH research in a multi-stakeholder environment

The joint decision of ETH Zurich, its Department of Food and Agricultural Sciences, and the Swiss Development Co-operation (SDC) in the early 1990s to set up the Swiss Centre

[20] According to Wojciech Kaniewski many of these projects with research institutes in developing countries are likely to be abandoned in the middle of the process. Nevertheless, the knowledge and experience gained in this research projects may well be of importance to other publicly financed research projects. It would therefore be important that universities and international public research institutes make an effort to take over these ongoing research programs.

[21] Dr. Aart van Schoonhoven, Director for Research and Genetic Resources, and Dr. Hernan Ceballos, Plant Breeder, CIAT, Cali-Palmira

for International Agriculture (ZIL) contributed to the strengthening of ETH's international reputation as an advanced research institute in international agriculture and SDC's credibility as a long-term investor in endogenous development in the developing world.
The Swiss Centre for International Agriculture (ZIL), an institution based within ETH Zurich, has an SDC mandate to support ETH research in the area of sustainable agricultural development and thus encourage more interdisciplinary research and international collaboration between ETH Zurich and institutes in developing countries.

The establishment of ZIL enabled Swiss researchers to increase their knowledge frontier and awareness of the complexity of agricultural problems in developing countries. At the same time its strong collaboration with the CGIAR contributed to increased technology transfer and capacity building, via international agricultural research centers (IARCs), for farmers and researchers in developing countries.

2.4.1 Endogenous development in developing countries

Technology transfer and strong collaboration in research, training and outreach activities increase self-confidence of local people and therefore contribute to more active local participation and entrepreneurial activities, which are key to endogenous economic growth. The decision to establish ZIL also coincided with the increasing difficulties of IARCs to secure their traditional annual grants from the different OECD member countries, a steep increase in private sector research, particularly in agricultural biotechnology, and a general decline in foreign aid and public sector research worldwide (New York Times 2001). As mentioned earlier, these new constraints forced the CGIAR system to adjust to these new geopolitical and economic changes by using its resources and know-how more efficiently and setting up a new collaborative model with local stakeholders such as farmer organizations, NGOs, universities, National Agricultural Research Systems (NARS), local companies, and Advanced Research Institutes (ARI) abroad. The goal was to pool resources that allow for the integration of biotechnology research, breeding and seed systems in jointly developing and delivering new technologies and products that are profitable and sustainable for small-scale farmers and local entrepreneurs (de Vries and Toennissen 2001). If technologies and products important to food crop research in developing countries (such as cassava) turned out to be patented by private companies, then NARS, IARCs and ARIs would seek permission from them to use it for particular research purposes and, later on, if a product is likely to emerge from it, to freely distribute it in particular regions where it is expected to improve the livelihood of small-scale farmers.

2.4.2 New collaborative models of international agricultural research

Overall, a new pattern in international development is emerging since the end of the Cold War: It is more difficult today to keep business and academic research in industrialized countries as something separate from international development and poverty in developing countries. In fact, business and academia have become central players in the global management of public goods because these global public ‘goods’ and ‘bads’ are increasingly produced by private actors[22] (Kaul et al. 2000). The disadvantage of these new circumstances is that it is all getting more complex and no blueprints are available from previous experiences. The advantage is that these new networks of collaboration with local partners in developing countries prove to be less bureaucratic, more resource-efficient and more bottom-up-oriented because they include more stakeholders and tap more know-how. The innovations that emerge from such collaborations are therefore expected to be more sustainable for local people in developing countries.

The following illustration (Figure 8) roughly portrays such a new collaborative model: At the core of the model is the problem identification (ID) by farmers themselves. The problems are essentially divided in ‘routine’ and ‘intractable’ problems (de Vries and Toennissen 2001). A routine problem may comprise the spread of a new plant disease for which sources of resistance genes have already been identified, or the identification of a regional bottleneck in the market system for which successful examples to address the bottleneck exist from elsewhere. These problems can be effectively addressed by National Agricultural Research Institutes (NARS) and International Agricultural Research Centers (IARCs) in collaboration with local stakeholders.

Intractable problems, however, will most likely require specialized and yet integrated research conducted at ‘Advanced Research Institutes’ (ARIs), as well as technology and know-how developed by the International Business community (IB).

ETH Zurich belongs to the ARI category. The intractable problems that are to be addressed by the ARIs include for example particular agronomic, entomological and nutritional problems, where conventional breeding and pest management methods failed to contribute to provide a satisfactory solution; or socioeconomic, institutional or political problems where previous approaches failed to get farmers durably involved or where political interests and perceptions result in regulations and trade barriers that produce disincentives for local farmers and the research community to embrace innovation.

[22] e.g. the public bad ‘air pollution’ is produced by private actors such as car drivers and factories, the public good of ‘clean air technology and alternative energy production’ is originally developed (as prototype) at universities or start-up companies and then produced on a large-scale by multinational companies. Many such examples apply to the debates of other public goods such as water, biodiversity, public health, food security etc.). The main argument is that technological evolution is changing the public good character: while it was generally assumed that public goods are characterized by non-rivalry and non-excludability, the increasing amount of private sector technologies with the potential to improve global public goods such as public health (new vaccines) or food security (new breeding, harvest or post-harvest technologies) requires new institutional arrangements that encourage private actors to contribute to the management of global public goods without creating disincentives for private investment in R&D and subsequent commercial innovations.

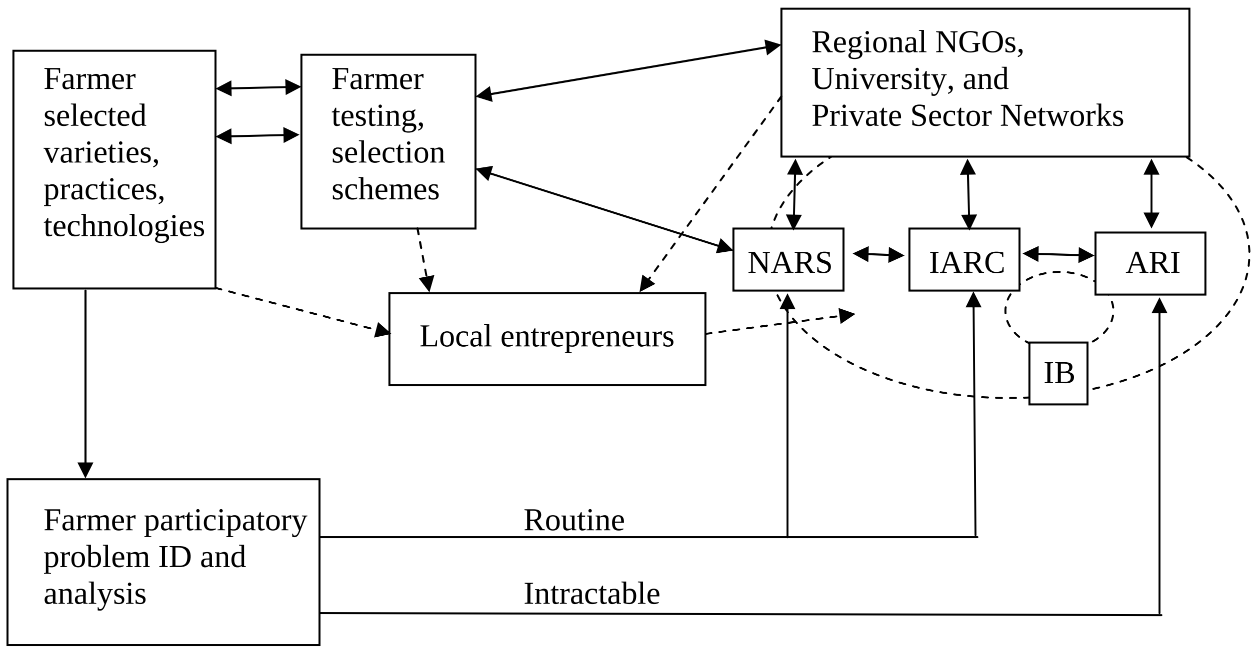

Figure 8*: A new collaborative model to make agricultural research more effective*[23]

2.4.3 The importance of local entrepreneurship

IARCs and NARS will increasingly look for institutes in developed countries that have a proven record and a capacity to contribute to useful solutions of such intractable problems. If necessary (e.g. access needed to IP-protected technology), useful (e.g. well-established distribution channels for innovations) and feasible (effective economic incentives and a willingness to collaborate due to mutual expected benefits) International Business (IB)[24] may also play an increasingly important role as a facilitator of international research and local economic development. The business community knows how to move from interesting R&D to commercially viable new products; a competence that many NGOs and research institutes are often lacking. Apart from the overall goal to obtain improved cassava varieties and useful tools to deal with the constraints of cassava agriculture, the strong involvement of local people in such collaborative models might

[23] The model was originally taken from the book of de Vries and Toennissen (2001) and complemented with the roles of International business and local entrepreneurs.

[24] International Business is already getting involved in a couple of unconventional cassava projects developed at the Center Suisse de la Recherche Scientifique (CSRS) (Nestlé helps eliminating constraints in cassava commercialization), CIAT (Coca Cola might agree to distribute clean planting material in marginal areas – in addition to its Coca-Cola bottles) and McDonalds is likely to offer soon fried cassava (yuca frita) in addition to french fries and thus boosting end-user demand.

result in the emergence of ‘local champions’[25] that become entrepreneurs because they manage to combine the new knowledge gained from the international collaboration with their knowledge about the complex local economic, cultural and political circumstances.
Due to the valuable qualifications and their embeddedness in international networks, they are also more likely to secure funding or micro-credit for their local projects. If the new collaborative model results in the emergence of more entrepreneurial people (at the local farmer, university or business level) then it will contribute to genuine endogenous development.
Endogenous economic development increases self-confidence of local people and creates more business opportunities and gives the bright local people more incentives to stay, articulate their own interests and assume more responsibility in their respective community. This, again, ensures more sustainability since projects that are initiated and managed by local people (which get an opportunity to not just help others but also themselves and their families) are more likely to endure.

SDC’s, ZIL’s and ETH’s commitment to research that is relevant to developing countries led to its firm integration into this new collaborative model. The relevance of ETH in this model increased particularly with ZIL’s early decision to choose cassava as a Research Priority Area (RPA). This led to the financing of several Cassava research projects in various fields of research relevant to science and development over the last ten years and the emergence of ETH as an important player in several ongoing global initiatives related to cassava.

2.5 Summary

- ETH belongs to the handful of advanced research institutes (ARI) that significantly contributed to the development of these new tools and their useful application.
- The changed geopolitical circumstances after the Cold War forced the CGIAR system to adapt quickly to the new and difficult funding environment where they had to compete with each other and an increasing number of other stakeholders involved in development co-operation.
- The new tools of biotechnology help overcome the constraints faced by conventional methods of breeding and integrated pest management, and accelerate the genetic improvement and adaptation of cassava for different ecological and socioeconomic environments.
- In response to its new demand-driven philosophy in development, the International Institute of Tropical Agriculture (IITA) managed to accelerate decentralization efforts in Africa, abolished institutional and ideological barriers

[25] E.g., entrepreneurial farmers have used their collaboration to become innovative themselves by setting up a small business of seed or fertilizer distribution, or skilled local researchers that use their know-how to set up low-cost tissue culture laboratories or to create and sell improved varieties themselves. Experience shows that if local innovators manage to provide a useful service or product to farmers, farmers are happy to pay if the price is affordable and promises gains. If the price is too high local farmers will simply not buy it and the innovator won’t make any profit.

between the different local stakeholders and research communities, and contributed to a significant increase in trust and cooperation between the different players in Africa.

- The Centro Internacional de Agricultural Tropical (CIAT) is one of the CGIAR centers that greatly succeeded in transforming itself into a modern development-oriented think tank that churns out useful new ideas, technologies and agricultural products for farmers, local companies, national research institutes, universities and policy makers in developing countries worldwide.
- Various global initiatives are being set up to improve quality and quantity of major tropical food crops such as cassava. These initiatives consists of large and flexible stakeholder networks (universities, international research institutes, NGOs, companies, foundations etc) that decided to join forces with the objective to develop products out of research that are meeting the demand of the poor cassava growers in tropical regions.
- The goal of these new networks is to pool resources that allow for the integration of biotechnology research, breeding and seed systems in jointly developing and delivering new technologies and products that are profitable and sustainable for small-scale farmers and local entrepreneurs.
- International Agricultural Research Centers will increasingly look for institutes in developed countries that have a proven record and a capacity to contribute to useful solutions of intractable problems in tropical agriculture.
- The strong involvement of local people in collaborative networks (of which ETH has become an integral part) might result in the emergence of ‘local champions’ in developing countries that become entrepreneurs because they manage to combine the new knowledge gained from the international collaboration with their knowledge about the complex local economic, cultural and political circumstances.
- Endogenous economic development through local entrepreneurship increases self-confidence of local people and creates more business opportunities and gives the bright local people more incentives to stay, articulate their own interests and assume more responsibility in their respective community.

3 ETH/ZIL Cassava Research

This chapter briefly assesses the usefulness and the impact of Cassava as one of the first ZIL Research Priority Areas (RPAs) and the associated Research Fellowship Partnership Program (RFPP). The different ETH/ZIL research projects are divided in cassava biotechnology research, cassava agro-ecology research, cassava social science research and cassava food science research. Each part will be described separately.

3.1 RPA/RFPP Cassava Projects

The goal of the Cassava Research Priority Area (RPA) has been to apply both strategic and applied research methods to improve food security in a sustained manner in cassava-based small-scale and subsistence farming systems, and to contribute to poverty alleviation in developing countries via income generation to resource-poor farmers and their families (ZIL 2000).
Over the last decade nearly 20 cassava projects were funded by ZIL covering biotechnology, agro-ecology and social science. In addition, several research fellowships related to cassava were awarded through the Research Fellowship Partner Program (RFPP). ZIL's RFPP for Agriculture, Forestry and Environment offers funding for up to four PhD or post-doc candidates per year. In addition, to scientific quality standards, the research projects have to fulfill the following requirements: the candidate must not be older than 35 (CH citizen) or 40 (developing country resident) and the project must be embedded in a research partnership between a Swiss research institution and an international research institute (CGIAR or equivalent).
Even though the RPA Cassava projects were generally regarded as highly successful, resulting in fruitful cross-disciplinary and cross-institutional intellectual exchange, it was not possible to maintain the funding for this integrated strategy for a third phase. Only research on cassava biotechnology continues to be ZIL-funded up to 2005.

3.1.1 Cassava biotechnology research[26]

The first two phases of ZIL projects (1994-99) related to cassava biotechnology contributed to a significant progress in the field of cassava regeneration and transformation. The protocols for regeneration developed by the ETH cassava biotechnology team comprise regeneration from somatic cotyledons and embryonic suspensions, via shoot organogenesis and somatic embryogenesis, respectively. The team managed to publish the protocol for cassava first in nature biotechnology – a milestone in cassava biotechnology research (Li et al. 1996). Furthermore, the transferability of the shoot organogenesis-based regeneration system was tested and successfully regenerated and established with a number of agriculturally important cassava varieties from IITA. *Agrobacterium*-mediated and biolistic transformation

[26] The detailed information of cassava biotechnology and cassava agro-ecology research were taken from the ZIL research reports from 1999-2002 (ZIL 1999, 2000, 2001, 2002)

methods compatible with shoot organogenesis and embryonic suspensions have then been developed in the laboratory, and efficient selection systems have been established.

In addition to these basic research activities, gene constructs of importance to cassava agriculture have been transferred into cassava, such as resistance to African Mosaic Virus Disease (ACMV) and Hornworm infestation; both traits have been stably expressed *in vitro* and *in vivo*. The studies on the regulation of the ACMV gene expression have laid the basis for the development of novel strategies for engineering virus resistance in cassava; also made possible by the development of a first virus replication assay in cassava.

The improvement of cassava's nutritional quality was another important research focus: It was presumed that over-expression of a nutritious protein gene (ASP1) in cassava plants may increase the levels of essential amino acids and protein content in the storage roots. More than ten transgenic plants have already confirmed the expression of the ASP1 protein both in the leaves and primary roots. Apart from a higher protein content in cassava roots, leaf life prolongation was also considered to have a positive impact on the nutritional quality of cassava. Cassava leaves, that are rich in minerals, vitamins and proteins, would be the perfect food complement to the roots but since leaves fall off in an early stage of cultivation, they are rarely used together with the harvested roots. For this purpose, a gene-construct was developed that would achieve a delay of leaf senescence via an autoregulated senescence system. So far, seven transgenic plant lines containing this particular trait have been confirmed (for references see Annex I).

Most of these activities involved international collaboration with CIAT in Cali, Colombia and IITA in Ibadan, Nigeria. The collaboration enabled local scientists in developing countries, often affiliated with one of these institutes, to be trained at the ETHZ in different aspects of cassava biotechnology research. On the other hand, ETH research results were used at these centers to improve in-house research programs. ETH researchers were also invited to give talks and train people in the respective countries.

Yet, there is a growing need to conduct field trials with transgenic cassava in developing countries and find out more about the effectiveness of the built-in trait and the impact on the environment. The number of recent cassava-related initiatives, the increasingly assertive attitude of African governments and African initiatives (e.g. NEPAD) are likely to accelerate efforts to establish dependable biosafety regulations and increase the future chances of getting approval for field trials with transgenic plants. In Nigeria, a first field trial is expected to be approved for 2004 with pest-resistant cowpea[27]. Colombia has already functioning biosafety regulations in place and approved a first field trial with hornworm resistant transgenic cassava. Nevertheless, in spite of its potential, genetic engineering remains the most expensive solution in agricultural biotechnology due to the uncertainties related to public protest campaigns and general public and consumer concerns in donor countries that often result in preventive regulatory frameworks in developing countries. This makes it necessary to first find out whether the GM solution will indeed be the most effective and inexpensive option for local farmers or whether there are alternatives tools in agricultural biotechnology and agro-ecology that can better tackle the particular problem. The GM solution would then only become important if all

[27] Personal Communication with David Mowry, Head of Communication, IITA, Nigeria

the other alternatives are not able to deliver satisfactory results[28]. The new global initiative 'HarvestPlus' has adopted this principle for its funding priorities: In the first stage of project financing, all options apart from genetic engineering will be explored to increasing nutritional health in developing countries; in the second stage research on GM solutions will be funded in areas where other agro-biotechnology and –ecology solutions were not successful.

RFPP projects

Chileku Mba is a Nigerian who worked for IITA. He was awarded with a research fellowship within the ZIL/RFPP on the basis of his research project on 'lowering the cost of reliable biotechnologies for national cassava programs: Micro-satellite markers to facilitate the use of the cassava molecular genetic map and provide new genetic information'. He successfully completed his work in collaboration with CIAT. Since 2003, he is working for the International Atomic Energy Agency (IAEA) doing research on irradiation technology for relevant food crops.

Bertrand Hankoua is originally from Cameroon. He was awarded with a research fellowship on the basis of his research project on 'regeneration and transformation of African cassava germplasm'. His research resulted in a PhD and the successful attempt to obtain transgenic cassava plants in Africa. It will serve as a model for future testing of the capability of other farmer-preferred cultivars to be transformed and to integrate agronomically useful genes into this germplasm at IITA. He completed his work at IITA and is now working with the International Laboratory for Agricultural Biotechnology (ILTAB) at the Danforth Center for Plant Science in St. Louis, USA. He intends to return to IITA to continue his research on transgenic ACMV-resistant cassava and to train local people.

3.1.2 Cassava agro-ecology research

Cassava agro-ecology research focused on cassava cultivation and its interaction with the natural environment. The projects were conducted in collaboration with CIAT.

Research on the improvement of soil fertility (through application of P isotope techniques and intercropping systems)

The research on the improvement of soil fertility aimed at

- improving the knowledge of the role of phosphorus (P) as the main limiting nutrient for crops and forage plants on acid tropical soils
- exploring how cassava production can be improved by planting cassava cultivar mixtures or intercropping systems. The influence of widely varying soil properties on the performance of cassava production systems would then be quantified.

As for the improvement of the knowledge about the role of phosphorus, P-isotope techniques were used to facilitate insight into the dynamics of different P pools and a tool (isotopic exchange method) was developed to determine available soil P without modifying the system. To enable the application of this tool to low P acid soils, Oxisol

[28] Personal Communication with Dr. Alfred Dixon and Dr. Iwan Inglebrecht, IITA, Nigeria

samples differing in P status were used to carefully analyze the shortcomings in the uptake of phosphorus and test solutions to overcome them. E-values (the quantity of isotopically exchangeable P per kg soil) were measured and verified by the L-value (isotopic composition of the test plant *Agrostis capillaries* grown on labeled soil). Available soil P was then assessed by using the isotope exchange method on low P acid soils. The conclusion was that since E and L values were not identical (even though strongly correlated), they cannot be determined precisely enough to detect in these soils the ability of a plant to access slowly exchangeable forms of P or to quantify the mineralization of organic P.

A comparison of L-values of different plants with varying adaptation to low P soils showed that P uptake from normally unavailable P-pools is possible, if ^{33}P is applied with a carrier (^{31}P as $KH_2 PO_4$). The application resulted in much smaller L-values and there were no significant differences between plants. One conclusion was therefore that the applied P disturbs the system, making it impossible to measure P exchange. However, isotope techniques can be used to estimate the total fraction of added fertilizer P that remains available to the plants. The application of ^{33}P contributed significantly to improve assignment of chemically extracted P fractions to P pools of different availability. Even though organic P fractions are included in the short-term P dynamics of low P tropical soils, most of the label was recovered in the inorganic P fractions, showing that they contained most of the available P (for references see Annex I).

The second project on intercropping revealed that farmers often plant mixtures of cassava cultivars, while bush-beans or maize are traditionally grown as cassava-intercrops. The investigators of cassava intercropping systems concluded that none of the tested systems improved cassava production under hillside conditions compared to cassava cultivar pure stands.

Research on ecological cultivation: behavioral ecology of parasitoids in simple and complex agroecosystems

The goal of this research was to render biological control more reliable and efficacious when confronted with multispecies infestations in mixed Cassava cropping systems.

For this purpose, two parasitoids, a specialist (*Aenasius vexans*) and a generalist parasitoid species (*Apoanagyrus diversicornis* and *Acerophagus coccis*), were investigated to find out how they respond to situations of increased complexity in cassava fields infested by the mealybug (*Phenacoccus herreni*).

A series of factorial experiments compared foraging behavior of the specialist to that of one or both of the generalists. Evidence from small-scale field trials suggested that the foraging behavior of the specialist can be affected in a mixed cropping system with beans, while dispersal was not influenced. Olfactory cues were found to be important for host habitat locations by these wasp species. Olfactometer bioassays showed that the specialist *A.vexans* was attracted to mealybug infested cassava leaves, but this preference disappeared together with the odors of bean leaves (non-host volatiles). The preference of the generalist *A. diversicornis* for infested host plants, however, was not affected by associated non-host plant volatiles.

A subsequent trial showed that preferences of the specialist were significantly affected in the presence of non-host herbivores (either spider mite or white fly) which did not apply for the generalist tested (for references see Annex I).
In conclusion, the research project contributes to improved cassava production by providing evidence for the benefits of parasitoids with a relatively narrow host spectrum (generalists) as compared to a parasitoid with a maximal specificity (specialists).

Complementary RFPP project: Participatory development of cassava green mite biocontrol in the highlands of Cameroon

Christine Zundel from Switzerland is completing her graduate studies at the Swiss College of Agriculture in Zollikofen and the University of Basel. She was awarded with a fellowship on the basis of her research project on: participatory development of cassava green mite biocontrol in the highlands of Cameroon. Her research focuses on biocontrol options against the two most important biotic constraints in cassava agriculture in Cameroon: Cassava green mite (or *Mononychellus tanajoa*) and Cassava Mosaic Virus Disease. The approach to control cassava green mite is based on an exotic predatory mite, the phytoseiid *Typhlodromalus aripo,* which is only rarely spotted in the infested areas in the North-West Province of Cameroon. Cassava germplasm was evaluated for its suitability to these predators and its pest and virus resistance; and a new strain of the predator that might be better adapted to the North-West Province climate was field tested. All field activities of the project involve farmer participation and are conducted in collaboration with IITA.

3.1.3 Cassava social science research

Socioeconomic research funded within the cassava RPA was not directly linked to cassava crop cultivation[29] but contained the broader objective to investigate the potential socioeconomic risks and benefits, public acceptance and priority setting of agricultural biotechnology research in general. These ex-ante impact studies of agricultural biotechnology were insofar relevant that the largest share of the funding within the Cassava RPA went into the genetic improvement of cassava.
The analytic hierarchy process (AHP) was used in the priority setting research project. It offered a useful tool to structure and to visualize complex problems in the decision-making process related to biotechnology projects.
The studies on the risk and benefits as well as public acceptance of agricultural biotechnology in developing countries were mainly focused on questions of perception. The public perception of agricultural biotechnology has become a dominant political issue in many developed countries, particularly in Europe where perceptions, world views and interests significantly influence regulatory decisions on agricultural

[29] Initially, a project was funded that dealt with the potential of cassava for bioplastic production as a contribution to development. However, initial research quickly indicated that cassava has considerable disadvantages in the field of bioplastic production. As a consequence, the project was not further elaborated.

biotechnology. The goal was to find out whether this is also the case in developing countries.
One consumer perception survey and one public acceptance survey on genetically modified crops were conducted in Sri Lanka and the Philippines respectively. The results of these surveys received considerable public attention due to the scarcity of information on that particular subject and the unconventional methodology used to investigate public acceptance of agricultural biotechnology in a developing country. The results showed that the stakeholders in the Philippines did not believe on average that a pest-resistant Bt rice would be a serious problem for consumer health risk and thought that biotechnology is just a new tool in plant breeding that may eventually contribute to future food security in Asia. Yet, they also believed on average that the potential of pests to break the built-in resistance of Bt rice would question the sustainability of such a technology and that organic farming approach in rice cultivation practiced by local NGOs would be a better alternative for resource-poor farmers (for references see Annex I).

RFPP Project

Thomas Braunschweig from Switzerland completed his PhD in agricultural economics at ETH. The title of his ZIL-funded PhD thesis was ‘Priority Setting in Agricultural Biotechnology Research: Supporting Public Decisions in Developing Countries with Analytic Hierarchy Process (AHP)’. His research aimed at developing a systematic approach for prioritizing biotechnology projects. In this context he evaluated the usefulness and feasibility of the Analytic Hierarchy Process (AHP) approach as a multicriteria decision-support tool. A concrete case study that highlighted the benefits and shortcomings of this approach was conducted in Chile. Based on this work, he was awarded with a post-doc fellowship to further ‘enhancing the analytical hierarchy process as a decision tool for biotechnology programs’. In this context, two case studies were conducted in Uganda and the Philippines in which the key stakeholder groups were identified for a participatory decision process and a list of relevant decision criteria was developed and structured. The project was conducted in collaboration with ISNAR.

3.1.4 Cassava food science research

Researchers and PhD students at the ETH food science institute have set up a research program on cassava food processing in collaboration with the Centre Suisse de la Recherche Scientifique (CSRS) based in the Ivory Coast and the local Université Cocody in Abidjan. Even though the program was not part of the Cassava RPA or RFPP, it is has become an important component of ETH cassava research.
This research program investigates the fermentation process of cassava from a microbiological point of view. Poor people in Africa increasingly depend on cheap cassava with a high cyanid content. These cassava varieties are popular with subsistence farmers because they show a relatively high resistance to diseases and pests and as food it can be stored for a longer period of time than the sweet cassava varieties. Moreover, the cheap fermented traditional end product called Atiéke is in increasing demand among poor rural and urban dwellers alike. The objective of the research program is to optimize the cassava fermentation process and to address the problems of toxicity and poor nutritional quality of cassava (see Annex I, Pierre Coulin, 2003).

3.2 Summary

- ETH/ZIL cassava research projects cover biotechnology, agro-ecology, social science and food science research questions.
- The ETH biotechnology team managed to publish the protocol for regeneration and transformation of cassava first in nature biotechnology – a milestone in cassava biotechnology research (Li et al. 1996).
- In addition to basic research activities regarding new gene transfer techniques, the ETH biotechnology team has also transferred gene constructs of importance into cassava (resistance to Cassava Mosaic Virus disease and Hornworm infestation, protein enrichment, leaf life prolongation).
- Two African researchers received RFPP fellowships to make the new techniques and knowledge of cassava biotechnology adaptable to needs in developing countries (micro-satellite markers to facilitate the use of the cassava molecular genetic map, regeneration and transformation with African cassava germplasm).
- The ETH agro-ecology team (Frossard) managed to improve understanding about cassava's capacity for nutrient uptake (especially phosphorous) in poor soils and in competition with other crops in intercropping.
- The ETH agro-ecology team (Dorn/Turlings/Wolf) managed to improve the knowledge about the olfactory-driven behavior of natural enemies (specialists and generalists) to conduct more effective biocontrol in cassava cultivation.
- Food science research investigates more effective and cheap forms of cassava processing that allow for optimizing the time of the cassava fermentation process while ensuring proper de-toxification of cassava.
- Social science research projects were focused on political decision-making, consumer response and public acceptance of agricultural biotechnology in developing countries.

4 Expert Opinions on ETH Cassava Research Projects and Cassava Agriculture in General

This chapter presents the results of a small survey and personal interviews conducted with cassava experts in Nigeria, USA, Colombia and Brazil. The 26 respondents of the small questionnaire consisted mostly of researchers at ETH Zurich, IITA, DDCPS, CIAT and EMBRAPA. In addition, personal interviews were conducted with representatives of national research institutes (apart from EMBRAPA), local universities, farmer organizations and multinational companies.

The survey results showed that the overall importance of the cassava RFPP, biotechnology and agro-ecology research projects was considered to be very high. Although all projects were also considered to be important in terms of contribution to development and science, RFPP cassava projects achieved the highest score for importance to development while cassava biotechnology projects scored highest for importance to science.

Regarding the assessment of the overall importance of the problems in cassava agriculture and the appropriate methods for solving these problems, the survey revealed that clean planting material is perceived to be the most important problem in cassava subsistence agriculture and tissue culture the most effective method to solve this problem. The starch composition of cassava was identified as the most important constraint in commercial cassava agriculture. Investment in technology is considered to be the best answer to the problems of cassava as a cash crop.

4.1 Background information to the survey and personal interviews

A proper impact study on ZIL cassava research requires the assessment of each research area by the collaborators involved in the different research projects, and competitors that do research on similar subjects. For this purpose, scientists at ETH Zurich, IITA, DDCPS, and CIAT were personally interviewed and invited to complete a small questionnaire on cassava. In addition, local stakeholders in the countries mentioned (plus Brazil) that have a great expertise in cassava research, cultivation or commercialization, were invited to participate in the survey[30].

This questionnaire consisted of three parts and each part was presented in form of a one-page-table:

[30] In Nigeria, representatives of the National Centre for Genetic Resources and Biotechnology, the Obafemi Awolowo University, the Institute of Agricultural Research and Training, and National Horticultural Research Institute in Ibadan, and the University of Abeokuta in Abeokuta were interviewed. In the St. Louis, USA, additional personal interviews were conducted with representatives of the Missouri Botanical Garden, Washington University and Monsanto Company. In Colombia, farmer representatives from the organizations FIDAR and PBA were personally interviewed. In Brazil, representatives of EMBRAPA Headquarters, EMBRAPA Cenargen (Biotech branch in Brasilia), and EMBRAPA Cassava and Fruits (in Bahia) were interviewed. EMBRAPA representatives also completed the survey on the importance of problems in cassava cultivation (see also Annex II for more details).

The first part (or table) consisted of a list of the various ZIL-funded cassava research projects from 1992-2002. If the respondent was familiar with the project, he or she was requested to assess the project's importance to science and development as well as its perceived overall importance in a scale from 1-5 (with 1 being no importance at all and 5 very important).

The second part (or table) presented a list of problems in cassava subsistence agriculture (listed in the first column). The respondent was asked to assess the importance of these problems (again in a scale from 1-5) and the usefulness of different approaches for solving these problems (biocontrol, integrated management, conventional breeding, marker-assisted breeding, tissue culture, genetic engineering, and genomics). Each problem and the possible approaches to solve them were rated in a scale from 1-5 (1 being not useful/important and 5 being very useful/important).

The third part (or table) consisted of a list of problems in cassava commercial agriculture. Again, the respondent was asked to give his/her opinion about the importance of these problems and the usefulness of different approaches for solving them (in a scale from 1-5). The approaches presented were: market reform, awareness campaign, improved accountability, global incentives, investment in technology, investment in dialogue.

As Figure 9 shows, out of the 26 respondents that completed the questionnaire, only a few actually rated the specific ZIL cassava research projects. The projects related to social science were not assessed since they did not involve a collaboration with any of the institutes. In turn, most of the respondents were willing to assess the general importance of problems in cassava agriculture and the approaches for solving them.

26 respondents from 5 institutions

- 8 from Embrapa
- 7 from CIAT
- 5 from IITA
- 4 from ETH
- 3 from DDCPS

Number of respondents on each individual project

CSRS	1
Dorn/Ecological Cultivation	3
Frossard/Low phosphorous	5
Gruissem/GTS	7
Potrykus/AMVD	7
Potrykus/GTTs	12
Potrykus/Hornworm	5
Potrykus/Leaf Life	5
Potrykus/Specific Root Promotor	6
RFPP/Mba	6
RFPP/Hankoua	10
Stamp, Wolf	4
Turlings, Dorn	3

Number of respondents assessing the different problems of cassava and the potential of biotech

Diseases	18.5	Primarily Food Crop Problems
Pests	18.3	
Yield	17.3	
Root Quality	19.3	
Abiotic Stress	16.7	
Soil Erosion	15	
Clean Stakes	13	
R&D	17	Primarily Cash Crop Problems
Labor	21	
Capital	21	
Land	21	
Lack of Demand	22	
Infrastructure	22	
Market Structure	21	
Input Costs	23	
Storage facilities	20	
Processing	21	
Policy	19	
Investments	19	
Science Collab.	19	
PP Collab	20	
Low Adoption	21	
Polarization	16	
Starch Comp.	10	

Figure 9*: Participation rates in the survey*[31]

[31] For the detailed titles of the different ETH projects, and the general design of the questionnaire see Annex IV

The generally low number of participants in the survey does not allow for a detailed statistical analysis. Instead only descriptive results will be presented.
The number of respondents who knew about and assessed the different ZIL research projects ranges from 12 in the case of Ingo Potrykus' project on 'General Transformation Techniques of Cassava' to just 1 respondent in the case of projects that were conducted at the Centre Suisse de la Recherche Scientifique (CSRS) at the Ivory Coast. Even though this one single respondent rated CSRS with excellent marks it will not be included in the description of the aggregated results. The unequal distribution in rating frequency makes it more difficult to portray the assessment of this first part in form of an illustration with average values compared to part two and three on general problems and approaches in cassava agriculture. Therefore all the projects were combined in three groups with average values: RFPP (2 projects), Biotechnology (6 projects) and Agroecology (4 projects).

4.2 The assessed importance of ZIL cassava research projects

As the list 'Number of respondents on each individual project' in Figure 9 reveals, the ZIL projects related to cassava biotechnology research are probably better known among those who participated in the surveys than those related to agro-ecology. In spite of the wide differences in the number of respondents who assessed the importance of the respective projects there are some general observations that clearly point toward a favorable view of the RFPP programs related to cassava as well as cassava biotechnology and cassava agro-ecology research projects conducted at ETH Zurich (see also Figure 10):
In a scale from 1 (not important) to 5 (very important) not one project group was rated on average below 3.5 (importance to development) and 4 (importance to science) respectively. This means than none of the projects were considered to be unimportant.

Research projects on cassava were evaluated by grouping them into RFPP programs, agro-ecology projects and biotechnology projects. RFPP projects include the work done by Chileku Mba and Bertrand Hankoua. Agroecology projects include projects of Dorn, Turlings, Wolf, Stamp, and Frossard, and biotechnology projects include the work by done by the groups of Potrykus and Gruissem.

In terms of overall importance and importance to development, RFPP projects were considered to be the most important. Although biotechnology projects ranked only next to RFPP projects in terms of overall importance and importance to development, they were considered to be most important to science. RFPP and agro-ecology projects were considered to be of equal importance to science.

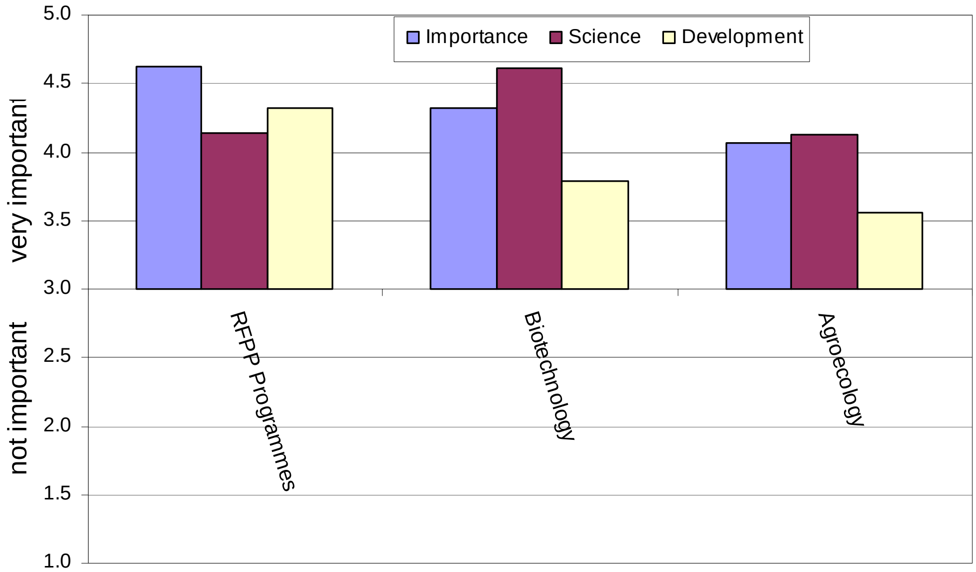

Figure 10: ***Project assessments in terms of overall importance, importance to science, and importance to development***

4.3 Opinions about problems and solutions in cassava subsistence and commercial agriculture

The participation rates in part 2 and 3 of the questionnaire referring to the problems in cassava subsistence and commercial agriculture (revealed in the list ‘Importance of the Problems in Cassava Agriculture’ in Figure 9) are significantly higher than those for the assessment of ETH research projects. This allows for more reliable results in the descriptive analysis.

4.3.1 Cassava subsistence agriculture

Part 2 of the questionnaire consisted of a list of 20 problems related to cassava subsistence agriculture (the problem of clean planting material was added after suggestions made in the very early stage of the survey)[32]. The problems are presented in 4 categories: plant diseases, pests, root quality and abiotic stresses (plus soil erosion and clean planting material). The importance of the problems and the usefulness of 7 different approaches (listed in the first row of the table) to address these problems were assessed in a scale from 1-5. These approaches included biocontrol, integrated management, conventional breeding, marker-assisted breeding, tissue culture, genetic engineering and genomics.

This does not mean that the problems listed and its possible solutions are not applicable to cassava commercial agriculture, but they clearly are of more importance to subsistence farmers who are not able to insure themselves properly against crop failure.

Figure 11 portrays a ranking of the average ratings of all the problems in subsistence agriculture. The lack of clean planting material (*Clean Stakes*) is assessed to be by far the most important problem, followed by low yields (gap between the potential and the real yield/he of cassava), which may be again related to contaminated and genetically eroded stakes. These problems are followed by root quality problems (short *storage life*, *low starch* and *low protein* content, *late bulking*), plant diseases (*CMVD*, *CBB*), abiotic stresses (*soil erosion*, *drought*, *soil nutrient*) and pest infestation (*whiteflies, mealybugs, mites*). The only problem that was considered to be unimportant was ‘*Flood*’.

Cassava Brown Streak Virus (*CBSV*), Fungi & Nematodes (*Fung.Nemat*.) and *Lepitoptera* (e.g. hornborer) may be considered less important problems because they are serious only in certain African or Latin American regions. CBSV is nevertheless considered to be one of the coming serious problems since resistance against this particular virus has not been achieved by means of conventional breeding.

[32] For details see Annex IV

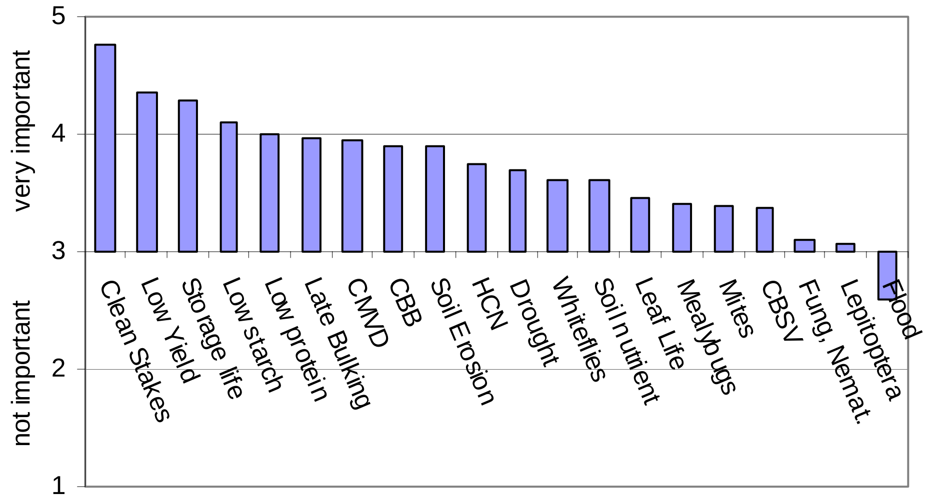

Figure 11: Average *ratings of the importance of the problems in subsistence agriculture*

Whiteflies are probably a more serious problem than it would appear because they are not only causing damage as pests but are also a major vector for virus transmission, and entomologists have difficulties to find any effective mean against them[33].

Figure 12 shows how respondents assess the potential of different approaches to solve these problems in subsistence agriculture. Instead of listing every single problem separately, the problem categories *Diseases, Low Yield, Pests, Root Quality, Abiotic Stresses, Clean Stakes and Soil Erosion* were formed.
The different approaches to address the problems are *Biocontrol, Integrated Management, Conventional Breeding, Marker-assisted Breeding, Tissue Culture, Genetic Engineering and Genomics.*
The results show that respondents believe biocontrol to have only a potential for solving pest problems, while the only potential of tissue culture is seen with respect to the problem of 'clean stakes' – by cloning clean planting material.
Integrated Management methods are seen as a possible answer to pests, diseases, abiotic stresses, clean stakes and soil erosion. Conventional breeding, marker-assisted breeding, genetic engineering and genomics show similar patterns as regards their potential to solve problems; all approaches are regarded as possible solutions to poor root quality, abiotic stresses, diseases, low yield, and, to a lesser extent, pests.

[33] Personal communication with Dr. Anthony Bellotti, Entomologist, CIAT

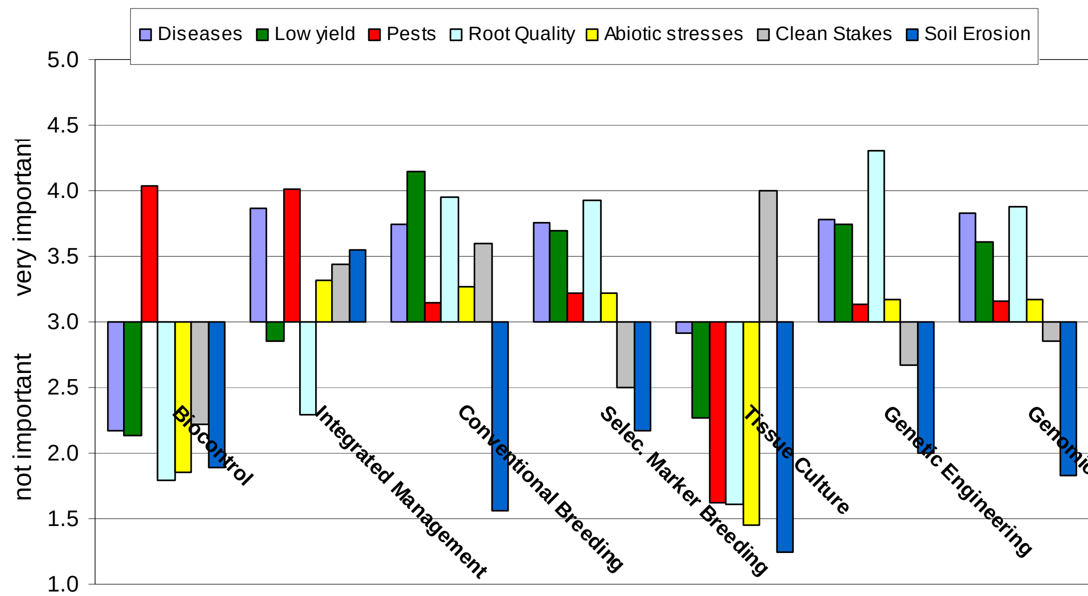

Figure 12: Average ratings of the usefulness of approaches to deal with the problems in subsistence agriculture

The highest potential of the modern tools of biotechnology, that include marker-assisted breeding, genetic engineering and genomics, is seen in the improvement of root quality.

4.3.2 Cassava commercial agriculture

In Part 3 of the questionnaire, 17 problems related to cassava commercial agriculture were listed in the first column of the table (the problem of starch composition was added after initial suggestions). The importance of the problems had to be assessed again in a scale from 1 to 5 and, and the respondents were asked to assess the usefulness of 6 different approaches (listed in the first row of the table) to solve these problems specific to commercial agriculture. These approaches included market reform, awareness campaign, improved accountability, global incentives, investment in technology, investment in dialogue.

As we see in Figure 13, inadequate starch composition for industrial purposes (*Starch Comp*) is perceived to be by far the most important problem in cassava commercial agriculture.

Analogous to the case of clean stakes in subsistence agriculture, starch composition was added to the list later in the survey. Therefore there are fewer respondents who rated these two problems and the fact that it was given a separate row (added by hand) may have had an impact on its assessment of importance). Inefficient *market structure*, lack of access to *capital* and expensive and time-intensive *processing* of cassava are also perceived to be very important problems; followed by lack of incentives to invest in *R&D* of cassava, discriminating crop *policy*, bad *infrastructure* and low *investment* in the cassava business. The only problem that was perceived to be unimportant was 'Political *Polarization*'. Obviously, there seems to be a consensus about what needs to be done and how public resources must be allocated to improve cassava as a commercial crop.

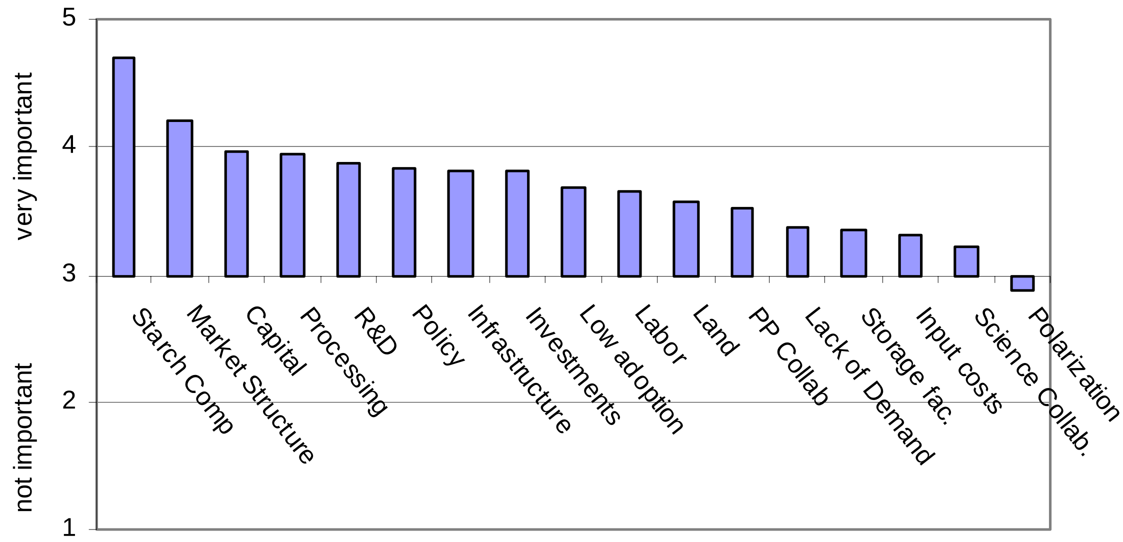

Figure 13: ***Average ratings of the importance of the problems in commercial agriculture***

According to many personal interviews with scientists at IITA, *labor*, even though not at the top in the illustration, is one of the most important constraints in commercial agriculture in Africa[34]. The commercial cassava production is still very labor-intensive in Africa, compared to Asia and Latin America; and the opportunity costs for young people to work in cassava commercial agriculture are high for local people.

Figure 14 presents the average ratings of the usefulness of the different approaches to solve of the most important problems. While 'investment in technology' (*Invest. Tech*.) is considered to be the best solution for inadequate starch composition, processing, R&D and labor, 'awareness campaign' (*Awareness Camp.*) is most important to improve the inefficient market structure and access to capital. The creation of 'global incentives' (*Global Incent*.) is considered to be an important solution for all the different problems. 'Investment in dialogue' (*Invest. Dialog*) is also perceived to be important, except for the problem of labor. 'Improving accountability' (*Improv. Accou*.) is seen important in creating better access to capital, better processing facilities and more investment in R&D. *'Market Reform'* is self-evidently seen as having the biggest potential with respect to inefficient *Market Structure*.

[34] Personal communication with Dr. Patrick Kormawa, Agricultural Economist, IITA, Ibadan, Dr. Alfred Dixon, Cassava Breeder/Geneticist, Prof. B.A. Ogunbodede, Deputy Director, Obafemi Awolowo University, Institute of Agricultural Research and Training. Ibadan

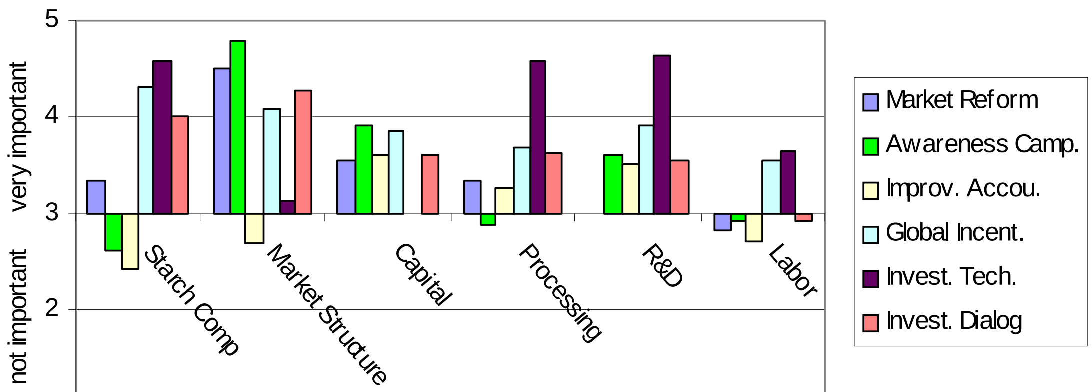

Figure 14: ***Average ratings of the usefulness of approaches to deal with the problems in commercial agriculture***

Since all problems except political polarization were considered to be of considerable importance, Figure 15 now looks at all the problems listed while only picking the three approaches that could be converted most effectively into policy tools: global incentives, public investment in technology, and investment in dialogue. We see that investment in technology and the creation of global incentives to attract the private sector is considered to be essential for many important problems (lack of R&D, expensive processing, starch composition, lack of demand for cassava, insufficient storage facilities, etc.). All three measures seem to be very important (with particular emphasis on investment in dialogue) with respect to encouraging more public-private research collaboration and higher adoption rates. A combination of global incentives and investment in dialogue is considered to be most effective for improving the infrastructure, market structure, more private investment, more interdisciplinary science collaboration and better public policies.

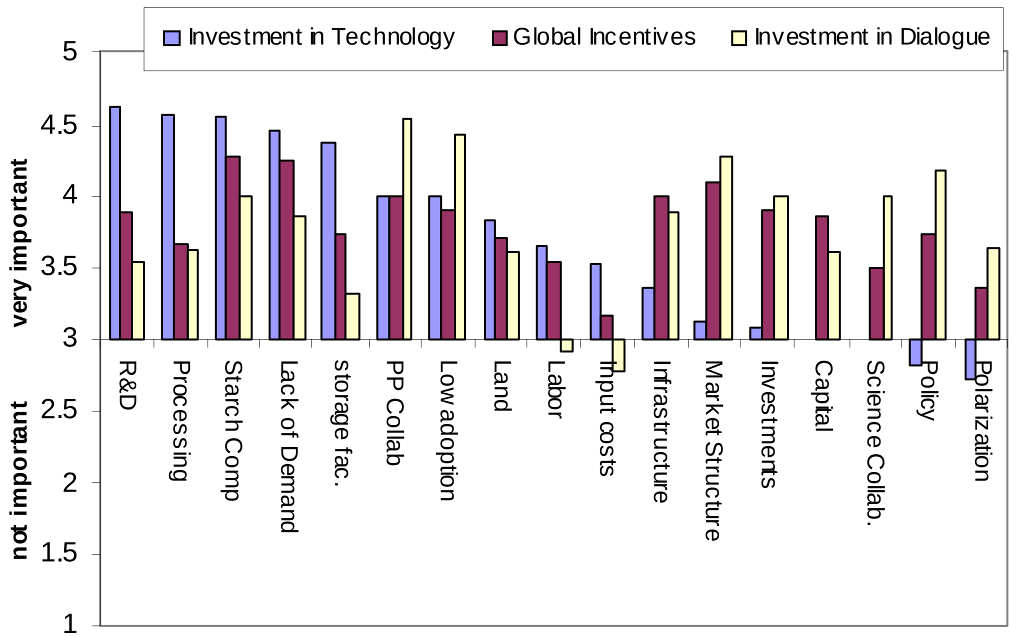

Figure 15: Three approaches to effectively address the problems in commercial agriculture

4.4 Summary

- Respondents of the survey generally expressed a very favorable view of the RFPP programs related to cassava as well as the cassava biotechnology and cassava agro-ecology research projects conducted at ETH Zurich.
- RFPP projects were considered to most relevant in terms of overall importance and importance to development. Biotechnology projects were considered to be most important to science.
- The lack of clean planting material (*Clean Stakes*) is assessed to be by far the most important problem in subsistence agriculture followed by problems related to root quality and low yield.
- Whiteflies are a very important problem in Africa because they are not only causing damage as pests but are also a major vector for virus transmission, and entomologists have difficulties to find any effective mean against them.
- Tissue culture is considered to be the most effective way of addressing the problem of clean stakes, the main cause for low yields in Africa.
- Conventional breeding, marker-assisted breeding, genetic engineering and genomics are regarded as possible solutions for a broad range of problems such as poor root quality, abiotic stresses, diseases, low yield, and, to a lesser extent, pests.
- Biocontrol and Integrated Management are regarded to be a imported tool to manage pest infestation.

- The highest potential of the modern tools of biotechnology (marker-assisted breeding, genetic engineering and genomics) is seen in the improvement of root quality and the management of diseases and abiotic stresses such as drought.
- Inadequate starch composition (for industrial purposes) is perceived to be by far the most important problem in cassava commercial agriculture; followed by inefficient market structure, lack of access to capital and expensive and time-intensive processing of cassava.
- Labor, even though not at the top in the illustration, is one of the most important constraints in commercial agriculture in Africa.
- Investment in technology is considered to be the best solution for inadequate starch composition, time-intensive processing, R&D and labor. An awareness campaign is most seen as most useful to improve the inefficient market structure and access to capital.

5 Discussion and Recommendations

The Swiss Agency for Development and Co-operation (SDC) has manifested its continued commitment to the promotion of science & technology in agriculture by supporting the establishment of the Swiss Centre for International Agriculture (ZIL) in the early 1990s. ZIL's first Research Priority Area (RPA) was on cassava, a food crop that is part of the daily meal of 600 million people in tropical regions and a cash crop that has the potential to get subsistence farmers out of poverty, particularly in Africa. Cassava is called a typical orphan crop because it attracted very little R&D investments for crop improvement over the last four decades compared to other important food crops such as corn or rice. In spite of its poor nutritional quality it still represents the crop of last resort for many marginal farmers in Africa because it grows on poor soils, is more resistant to crop failure, does not require any significant amount of input and allows for flexible harvesting (the roots can be left untouched in the soil for up to one year). These characteristics are particularly valuable to resource-poor farmers who are exposed to a high degree of uncertainty (war, drought, no access to input and output markets).

The importance of improving cassava agriculture

Central Africa is by far the biggest consumer of cassava in the world with an annual average/capital consumption of 280 kg (compared 80 kg in the rest of Africa and 18 kg worldwide). Nevertheless, FAO data clearly show that the production per capita of cassava remained stagnant over four decades in Africa; and Central Africa even experienced a steep decline. The cassava consumption per capita in Central Africa declined 8.8% between 1961 and 2001. Over the same period of time the cassava production per capita in the region even slumped by 31.2%. This would not be a matter of concern if cassava was simply substituted by other, preferably more nutritious, food crops. But data in this report show similar patterns of decline for all basic food and animal feed crops in Africa, except rice.

These facts reveal the alarming tendencies of hunger and malnutrition in this region and indicate the need for more investments in the improvement of cassava varieties, cassava crop cultivation and cassava markets. Improved resistance to pests and diseases in cassava varieties and better forms of integrated management might result in higher yields, while improved cassava root quality might lead to more nutritious food for subsistence farmers; if it can be ensured that clean high-quality planting material (cassava stakes) actually reaches the farmer. However, once the subsistence farmer manages to become self-sufficient in cassava production, any surplus will just be waste, unless there are accessible markets in which cassava can be sold as a profitable cash crop. In response to such market constraints, worldwide initiatives were initiated with the objective to make cassava more competitive in the convenience and fast food business as well as in animal feed and industrial starch markets (e.g. the IFAD/FAO Global Cassava Development Strategy).

ETH research projects

ETH cassava research projects that were funded by SDC through ZIL, were mostly focused on improving traits that address the problems of cassava subsistence farmers such as disease and pest resistance and poor root quality, as well as designing effective low-input pest and soil nutrient management techniques. In addition, socioeconomic research was funded to investigate the acceptance and the impact of the modern tools of agricultural biotechnology in developing countries (many of the ETH/ZIL projects used these tools for the genetic improvement of cassava).
Over the past decade, ETH researchers in the fields of biotechnology and agro-ecology became thoroughly involved in the new collaborative networks of international agricultural research and ZIL has become one of the valuable supporters of the global efforts to improve cassava agriculture. In addition, the ZIL Research Fellowship Partnership Program (RFPP) in the area of cassava research also enabled a number of researchers from developing countries to become familiar with the advanced techniques of agricultural biotechnology at ETH Zurich or at international agricultural research centers such as the International Institute of Tropical Agriculture (IITA) in Nigeria and the Centro Internacional de Agricultural Tropical (CIAT) in Colombia.

ETH and the international cassava research community

Since there are only a handful of advanced research institutes involved in cassava research worldwide, ETH researchers became quickly part of the small research community that is primarily organized in flexible and problem-oriented networks. Many of these networks to improve cassava agriculture were initiated by CIAT. The best known and most effective network is the Cassava Biotechnology Network (CBN), which brings together, among others, biotechnologists, geneticists, soil scientists, entomologists and social scientists to discuss innovations in interdisciplinary cassava research and convert this innovative research into useful products for farmers. Most of the natural scientists involved in cassava research use the modern toolkit of biotechnology to improve understanding of the particular problems they are investigating.

CIAT contributed essentially to the successful production and commercialization of cassava animal feed in Thailand and has initiated an ambitious public-private partnership program (CLAYUCA) to make cassava more attractive as a cash crop in Latin America. Apart from CIAT and IITA, some of the most active members of CBN are Brazil’s National Agricultural Research Organization, EMBRAPA, and Missouri-based Donald Danforth Center for Plant Science, DDCPS.

IITA, CIAT, DDCPS and EMBRAPA are all in one way or another connected to the ETH/ZIL Cassava Research Priority Area (RPA): CIAT and IITA as long-standing partners of ETH Zurich in agro-ecology and biotechnology research, the DDCPS as a partner and competitor in cassava biotechnology research and EMBRAPA, as the center of basic and applied research of cassava in the developing world.

An evaluation of ETH/ZIL cassava research projects

In the course of the survey that was conducted in 2003, a number of cassava researchers that work at one of these institutes were interviewed and asked to complete a semistandardized questionnaire to evaluate ETH research projects, problems in cassava subsistence and cash crop agriculture as well as the different approaches to solve these problems. In addition, local stakeholders ranging from representatives of farmer organizations and NGOs to university professors were interviewed and asked to fill in the part of the questionnaire that dealt with the problems in cassava agriculture and the different approaches to address them.

The collaborators and competitors in cassava research that participated in the small survey rated all ETH/ZIL projects very positive. Through personal communication, many of the interview partners pointed out that ETH has become a global leader in cassava biotechnology research and a great contributor to cassava agro-ecology research. Collaboration with ETH institutes was generally regarded as very useful and of mutual benefit. It was also pointed out that ZIL's decision to combine agro-ecology and biotechnology in its Cassava RPA was a wise choice in view of the complexity of the problems in cassava agriculture, the increasing convergence of molecular biology and agro-ecology through the use of similar biotechnology toolkits, and the global regulatory uncertainty with respect to genetically modified organisms (GMOs). In fact, genetic engineering has become to most expensive option to solve a problem in agriculture due to the increasing global regulatory hurdles and general transatlantic polarization over GMOs. Therefore, there is a general agreement among the research centers that this technology will only be used where all other approaches failed; which may indeed be the case for several problems in cassava agriculture. The general insight that agricultural biotechnology may help solving certain problems in agriculture has changed the attitude of many African governments toward agricultural biotechnology from 'danger' to 'opportunity' according to the view of many interviewed scientists and local stakeholders[35].

Agricultural biotechnology

Agricultural biotechnology is offering many other tools apart from genetic engineering, and they are already widely used in developing countries by farmers and researchers alike. For example, farmers have learned how to clone their clean and improved planting material in accessible low-cost tissue culture mini-laboratories (an approach successful promoted by the CBN network). This is of particular value in the case of cassava which is a vegetatively propagated crop with high exposure genetic erosion and disease contamination. In addition, researchers in developing countries are already using marker-assisted breeding to improve varieties more efficiently, as well as comparative genomics and biochemical pathway analysis to study the location and function of genes, which allow them to explore the value of cassava biodiversity and diagnose disease transmission. For example, a Brazilian geneticist[36] at EMBRAPA has spent months in the Amazon region to explore what kind of cassava varieties were bred by the local indigenous communities. In this context, he discovered numerous new products derived from cassava, such as a 'yellow cassava' that is enriched with beta-carotene, a 'baby food' cassava that produces sugar instead of starch, a cassava variety that produces waxy starch, and a Cassava root-specific protein rich in glutamic acid. The small survey

[35] Personal communication with Alfred Dixon, Iwan Ingelbrecht and Rodomiro Ortiz, IITA Nigeria.
[36] Personal communication with Dr. Luis Castelo Branco Carvalho, Geneticist, Embrapa, Brasilia. His research will also be part of the global biofortification initiative.

conducted with the researchers at the various different institutes revealed that poor root quality is perceived to be the greatest problem in subsistence agriculture (apart from poor planting material) and unfavorable starch composition (low wax content) was seen as the major handicap for making cassava more competitive as a commercial crop. Obviously, the Brazilian geneticist has set his priorities right. His research also shows that biotechnology can be used in two complementary ways, either from the protein to the DNA (e.g. analysis of the biochemical pathway) or from the DNA to the protein (genetic engineering).

ETH Zurich has developed transgenic cassava that is resistant to Cassava Mosaic Virus Disease (CMVD). CMVD-resistant cassava could contribute significantly to food security in Africa, once the resistant gene can be transferred into local land races at low costs and with a minimal impact on the natural environment. Even though there are already IITA cassava varieties resistant to CMVD strains, they are not widely adopted; moreover the virus is able to mutate quickly into different strains. In order to have a real impact on development, at least some of the transgenic varieties that were successfully raised in ETH greenhouses should now be field-tested in Africa to assess the real potential of the technology for African cassava growers.

ETH cassava biotechnology research has gained its worldwide reputation by first publishing the protocol of regeneration and transformation of cassava in 1996 in Nature Biotechnology (Li et al. 1996). To date, it largely managed to meet the high expectations with many additional breakthroughs in CMVD-resistance, hornborer-resistance, protein expression in roots, and leaf life prolongation etc. This also explains why all the cassava biotechnology projects were assessed to be a very important contribution to science and, to some extent, development.

Zhang Peng, a brilliant researcher in the ETH cassava biotechnology team, did also train people in Brazil (part of a CBN project) and is experienced in anther culture, a technique that is required for CIAT's double haploid research. ZIL decided recently to support his participation in the double haploid initiative with a RFPP grant. The goal of this initiative is to create homozygosity in cassava and thus make the breeding process more effective and faster. IITA, DDCPS, CIAT are competing for researchers like Zhang Peng. At the same time he is also the most important asset in the cassava biotechnology team at ETH. The increased competition for skilled researchers became obvious in an interview with Roger Beachy[37], President of the DDCPS, who thinks that it is important for Europe to maintain such beacons of agricultural biotechnology research like ETH Zurich, but nevertheless admits to be primarily interested in hiring its skilled researchers.

Agro-ecology

The agro-ecology research projects also received high marks in the small survey. CIAT and IITA confirmed that the research on Isotope methods for assessing plant available phosphorus in acid tropical soil is already widely used in the field and CIAT researchers like Anthony Bellotti and Art van Schoenhovn praised the ETH/ZIL entomology research that increased knowledge and understanding on the host specificity and comparative foraging behavior of different parasitoids of the cassava mealybug. They hope that this

[37] Personal Communication with Prof. Dr. Roger Beachy, President of the Danforth Center for Plant Science, St. Louis, USA

long-standing research collaboration in agro-ecology will continue in the future[38]. As more transgenic crops will be field-tested in developing countries, agro-ecology will also play an increasingly important role in the assessment of the potential impact of such crops on living organisms in tropical ecosystems.

According to Anthony Bellotti[39], CIAT's outstanding entomologist, the ETH/ZIL agro-ecology research produced many new and unexpected insights in entomology, and research on that subject is continued in Brazil. However, Bellotti is also expressing a certain concern with the results of conventional biocontrol methods over the past three decades. In spite of all the success stories, conventional biocontrol has not been able to reduce the use of pesticides in any significant quantity in developing countries. He argues that the migratory nature of pests often makes it impossible to deploy parasitoids effectively. Moreover, it is still not possible to break the life-cycle of pests, which return year after year. Nevertheless he still believes that more unconventional biocontrol methods (such as the use of Olfactometer bioassays used in the ETH/ZIL project) and more collaboration between genome researchers and entomologists would be able to achieve major breakthroughs in the future. Moreover, in his view, one of the major entomological problems are whiteflies, which do not just damage crops but also serve as the vector of the Cassava Mosaic Virus (CMV). Yet, whiteflies have not received sufficient attention from the scientific community to make any progress on the management of this particular pest. Unlike, in the U.S.A., where the importation of whiteflies is illegal because of their existence in the state of Florida, Europe does not have a problem with whiteflies and therefore would have an advantage in conducting research on this particular subject. A solution to this problem would require more serious collaboration between agro-ecologists and biotechnologists.

Biofortification

In addition to crop management, productivity and plant protection problems, the improvement of nutritional quality of basic food crops has been identified as one of the most urgent challenges to improve public health in marginal rural areas. CIAT is currently co-chair of the global biofortification initiative (Harvest Plus), together with the International Food Policy Research Institute (IFPRI). This initiative was started in August 2003 with the generous support of the Bill and Melissa Gates Foundation and the World Bank. It aims to improve the nutritional quality of the basic food crops in Africa, such as cassava. This opens a potential new niche for ETH researchers who are interested in improving the nutritional quality of cassava and other basic food crops in the developing world.

Product delivery challenges

The last and probably biggest challenge in international agricultural research is how to convert promising research results into cheap and useful products for local farmers. This is the area where social science research should play a more important role in the cassava

[38] Some may interpret the praise for ETH/ZIL research and the wish to continue co-operation in the future as just a way for these research centers to tap the Swiss funding pool for development. Yet, currently none of the mentioned research institutes is short of funding thanks to the various new initiatives of governments and private foundations.
[39] Personal Communication with Dr. Anthony Bellotti, Entomologist, CIAT, Colombia.

research community. CIAT has given more attention to this challenge in recent years through an ambitious public-private partnership program (CLAYUCA) to make cassava more attractive as a cash crop in Latin America and bring research priorities closer to market priorities.

Importance to science and development

The survey revealed that the contribution of ETH/ZIL cassava research projects to science is considered to be higher than its contribution to development; this applies to both, biotechnology or agro-ecology research projects. This is not a surprising result since ETH is after all a leading research institute and the interest in science has to be the major driving force. Yet, as was explained earlier, advanced research institutes, like ETH Zurich, are today firmly embedded in the flexible networks of international agricultural research. This closer integration with national and international agricultural research institutes is of mutual benefit considering the knowledge and advanced techniques that are developed in these centers and the advantage of having intellectual exchange in general. Moreover, if problems are generally perceived to be of high relevance to development it is also more likely to get scientific results (related to the respective problem) published in top-journals. Therefore, there must not necessarily be a trade-off between relevance to science and relevance to development. This should also be taken into account in the ETH/ZIL research priority setting process.

Cassava and livestock systems

ZIL decided in 2001 to shift the RPA focus towards livestock systems and to extend funding for the period 2002-2005 only to the cassava biotechnology research. Many of the interviewed scientists welcomed this new focus on a previously neglected part of research. Yet, they were surprised that cassava research, in which ETH has become a global center of competence, was not more explicitly combined with livestock research, for example by doing research on the improvement of cassava as animal feed. Cassava animal feed is a key component in poverty reduction in Africa where it is the only fodder available for the domestic animals of subsistence farmers in periods of drought. Unlike in Latin America and Asia where cassava is increasingly replaced by corn in animal feed production, Africa relies even more on cassava today. Cassava is also considered to be the ideal fodder for fish in extensive aquaculture, because it is cheap and swims longer on the surface than any alternative. Aquaculture has still a tremendous potential in Africa considering the thousands of underutilized land-locked ponds.

Making RFPP work for development

The Research Fellowship Partnerships Program (RFPP), linked to cassava biotechnology research, were the only ZIL-funded projects where importance to development surpassed importance to science. Especially the support and training of Bertrand Hankoua was considered to be an extremely valuable potential contribution to development. Yet, ZIL has to make sure that this potential contribution converts into a real contribution to development by continuing to assist Hankoua in his efforts to return to Africa and impart his knowledge to other promising African researchers. Joe Thome (CIAT)[40] emphasized

[40] Personal Communciation with Dr. Joe M. Thome, Geneticist, Agrobiodiversity and Biotechnology Project Leader, CIAT, Colombia.

the problem of lack of opportunities and lack of capital that often prevents skilled researchers from developing countries to return to their home country and contribute to development after the completion of their training and research at leading research laboratories in Europe and the United States. CIAT trained 18 local researchers that subsequently got fellowships to continue their research in the US. Only one researcher returned to his home country. Possibly, part of the fellowship package should include the option of an additional credit to encourage the trained researcher to articulate a clear idea (by means of a business plan) on how he or she wants to put his/her knowledge to use in the private sector or at the university of his/her home country. Or the scholarship is to be linked to a sort of conditional approval (confirmation of an employer in the home-country to hire the researcher after the completed training or PhD).

ZIL should also seek closer co-operation to local research institutes or universities with an excellent record in education and research. The lack of integration in international research and the poor financial endowment of national research institutes in Africa are seen as one of the major problems in agricultural and economic development in general. Moreover, as it was explained in detail in this report, African universities can be a handicap *or* a catalyst of economic development depending on their function in society (educating bureaucrats vs. entrepreneurs) and how they are integrated in national private sector and international research activities. In this context, the many research stations of IITA and other international agricultural research institutes in Africa may play a crucial link to connect ETH with local institutes that are relatively well-endowed and show a high degree of motivation.

A potentially interesting future partner for ZIL and ETH in Latin America could be EMBRAPA. Especially in the field of cassava, EMBRAPA has excellent scientists and a large experience in research. It may help strengthening ETH's image as a center of competence in Cassava research and contribute to the identification of interesting and relevant scientific challenges in the future.

ZIL and the global cassava initiatives

Since ETH Zurich is the only European Institute that takes part in all the different global initiatives on cassava, SDC and ZIL may also reflect upon the possibility to give a more active support to one of the new emerging networks, the Global Cassava Plan for Genetic Improvement (GCP-21), which is building upon the Cassava Biotechnology Network (CBN) and the Global Cassava Development Strategy (GCDS), by contributing to the funding of a global coordinator for this network – maybe with the condition that agro-ecology is playing a more important part in this initiative. This may result in more investment in cassava technology, more global incentives to conduct cassava research, and more dialogue between the different stakeholders involved in cassava research and cultivation. According to the survey of this report, 'investment in technology', 'global incentives' and investment in dialogue' were considered to be essential to make cassava agriculture a success story and, consequently, contribute to endogenous and sustainable economic development in developing countries.

6 Summary of the Conclusions and Recommendations

Main Results and Conclusions:

- Cassava is often identified as an orphan crop that was largely ignored by private and public sector R&D over the past decades, but is of tremendous importance to food security in tropical regions.
- The complex genomic, morphological, physiological and ecological characteristics of cassava are a challenge to the relatively small international cassava research community.
- The global initiatives, set up in the 1990s to address the problems in cassava subsistence and commercial agriculture, resulted in innovative and effective collaborative models on cassava R&D.
- Thanks to the generous support of ZIL and SDC, ETH researchers have become part of the small but vibrant and innovative cassava research community that is making a difference to many cassava farmers in the developing world.
- FAO data show a stagnation of annual cassava production per capita in Africa (and a decline in Central Africa) over the past four decades. At the same time, the importance of cassava as basic staple food for poor Africans and inexpensive fodder for domestic animals has increased.
- The Centro Internacional de Agricultura Tropical (CIAT) in Colombia has become the basic driving force for innovation in cassava agriculture.
- The International Institute of Tropical Agriculture (IITA) in Nigeria has developed a new demand-driven approach (‘Research for Development’) that make it the most adequate institution in Africa to spread innovation in agriculture in collaboration with local and international partners.
- The small international survey on ETH cassava research showed that ZIL’s Research Priority Area on Cassava (RPA Cassava) and its associated Research Fellowship Partnership Program (RFPP Cassava) are generally considered to be success stories.
- RFPP projects were considered to be most relevant in terms of overall importance and importance to development. Biotechnology projects were considered to be most important to science and very important to development. The contribution of agro-ecology projects was assessed to be significant terms of overall importance, importance to science and importance to development.
- Lack of clean planting material was generally considered to be the most important problem in cassava subsistence agriculture, while inadequate starch composition (low wax content) was seen as the most important problem of cassava commercial agriculture.
- The new tools of agricultural biotechnology (marker-assisted breeding, tissue culture, genetic engineering, genomics) were considered to be most effective in addressing the most important problems in cassava subsistence agriculture.

- Global incentives as well as investment in technology and dialogue were considered to be the most effective means to address the constraints in cassava commercial agriculture.

Recommendations:

- According to the respondents of the survey, ZIL funding has allowed ETH Zurich to become a global center of competence in cassava biotechnology and agro-ecology research. It is important to maintain this high reputation in the face of the growing global interest in cassava.
- ETH Zurich has become an important partner and collaborator of IITA in Nigeria and CIAT in Colombia, two of the best-equipped and most influential cassava research centers in the developing world. It is important that ETH strengthens the collaboration with these two institutes to the mutual benefit.
- ZIL's decision to build its cassava RPA on basically two pillars, biotechnology and agro-ecology, is widely seen as a wise one due to the regulatory uncertainties related to agricultural biotechnology. ZIL should make sure it maintains these two pillars and encourages more collaboration between them.
- ZIL's current research priority area (RPA) on livestock systems would complement its cassava research to a large extent, since cassava animal feed is of great importance to commercial farmers and subsistence in Africa alike. More efforts to combine these two areas would be desirable.
- ZIL's policy changes (related to the set up of new RPAs) often appear to be inconsistent to its partners abroad. More efforts to seek advice from partners abroad may be desirable and may contribute to more development-oriented research.
- Apart from the successful collaboration with international agricultural research institutes, ZIL may also explore the possibilities of collaboration with advanced national research institutes in developing countries (e.g. a collaboration with EMPBRAPA, Brazil would be of mutual benefit).
- ZIL should contribute more to the strengthening of capacities and better integration of national agricultural institutes, universities and local business in Africa. For example by linking its RFPP program also to a microcredit scheme that would allow the selected research fellows to return to there countries and get the opportunity to succeed as entrepreneurs and agents of change either in the private sector or at universities.
- ZIL and SDC may also reflect upon the possibility to assume a more active role in the flexible, multi-stakeholder and interdisciplinary international cassava initiatives and thus further deepen the integration of ETH Zurich in global cassava research.

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Zhang, P. (2000) Studies on cassava (Manihot esculenta Crantz) transformation: Towards genetic improvement. PhD thesis. Federal Institute of Technology, Zurich, Switzerland. Diss. ETHZ-No. 13962.

ANNEX I: Cassava RPA Publications

ETH Dissertations related to Cassava

Frey P.M. 2000. A study of African cassava mosaic virus gene expression for the development of virus resistance. PhD thesis, Swiss Federal Institute of Technology, Zurich, Switzerland, Diss. ETHZ-No. 13557

Zhang P. 2000. Studies on cassava (Manihot esculenta Crantz) transformation: Towards genetic improvement. PhD thesis, Swiss Federal Institute of Technology, Zurich, Switzerland, Diss. ETHZ-No. 13962

Coulin, P. 2003. Optimierung der traditionellen Cassava fermentation in Westafrika. PhD thesis, Swiss Federal Institute of Technology, Zurich, Switzerland

Heuberger, C. 2003. Blausäuregehalt von Cassava und fermentierten Produkten mit Schwerpunkt Attieke. PhD thesis, Swiss Federal Institute of Technology, Zurich, Switzerland.

Aerni, P. 1999. Public Acceptance of Transgenic Rice and its Potential Impact on Future Rice Markets in Southeast Asia. Ph.D. thesis. Federal Institute of Technology, Zurich, Switzerland. Diss ETHZ-Nr: 13471

Bühler, S. 2001. Application of P isotope techniques to low P acid tropical soils. PhD thesis. Federal Institute of Technology. Zurich, Switzerland. Diss ETHY-Nr. 14319.

Dorn, B. 2001. Ecological Cultivation of Cassava: to render natural enemies of sucking pests more efficient and reliable. Ph.D. thesis. Federal Institute of Technology, Zurich, Switzerland. Diss ETHZ-Nr: 14415.

Braunschweig, T. 1999. Priority Setting in Agricultural Biotechnology Research: Supporting Public Decisions in Developing Countries with the analytic hierarchy process. Ph.D. thesis. Federal Institute of Technology, Zurich, Switzerland. Diss ETHZ-Nr: 13051.

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Cassava Biotechnology 1999-2001

Bohl, S., Potrykus, I, and Puonti-Kaerlas, J. 1997. Searching for root specific promoters in cassava. African Journal of Tropical Root Crops 2: 172-174

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Bertschy, C, Turlings, T.C.J., Bellotti, A., Dorn, S. 2000. Host stage preference and sex allocation in Aenasius Vexans, an encyrtid parasitoid of the cassava mealybug. Entomologia Experimentalis et Applicata, 95: 283-291.

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Cassava Socioeconomic Issues 1999-2002

Aerni, P. and Rieder, P. 2000. Acceptance of Modern Biotechnology in Developing Countries - A Case Study in the Philippines. International Journal of Biotechnology 2 (1/2/3): 115-131.

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Braunschweig, T. and Sengooba, T. 2001. Inventory of agricultural biotechnology research capacity in Uganda. Uganda Journal of Agricultural Sciences 6(1): 37-41

Braunschweig, T., Janssen, W. and Rieder P. 2001. Identifying criteria for public agricultural research decisions. Research Policy 30: 725-302.

ANNEX II: List of institutions visited and people interviewed in October 2003

Visits

Nigeria:

- International Institute of Tropical Agriculture, Ibadan
- National Centre for Genetic Resources and Biotechnology, Ibadan
- Obafemi Awolowo University, Institute of Agricultural Research and Training, Ibadan
- National Horticultural Research Institute, Ibadan
- University of Abeokuta, Abeokuta

USA:

- Donald Danforth Center for Plant Science, St. Louis
- Missouri Botanical Garden, St. Louis
- Monsanto, Chesterfield
- Washington University, St. Louis

Colombia

- Centro International de Agricultura Tropical (CIAT), Cali-Palmira
- Corporación Para El Desarrollo Participativo Y Sostenible De Los Pequeños Agricultores (Foundation PBA), Bogota
- Fundación para la Investigación y el Desarrollo Agrícola (FIDAR), Valle de Cauca

Brazil

- Embrapa Headquarters, Brasilia
- Embrapa Genetic Resources and Biotechnology (CENARGEN), Brasilia
- Embrapa Cassava and Fruits, Cruz los Almas, Bahia

Interviews

Nigeria:

- Iwan Inglebrecht, Head Biotechnology Laboratory, IITA, Ibadan
- Rodomiro Ortiz, Director Research for Development, IITA, Ibadan
- Alexander Schöning, Project Officer, Contracts and Grants, IITA, Ibadan
- Yvonne Lokko, Biotechnologist, IITA, Ibadan
- Patrick Kormawa, Agricultural Economist, IITA, Ibadan
- David Mowbray, Head, Communication and Information, IITA, Ibadan
- Alfred Dixon, Cassava Breeder/Geneticist

- Prof. B.A. Ogunbodede, Deputy Director, Obafemi Awolowo University, Institute of Agricultural Research and Training, Ibadan
- Mondiu B. Sarumi, National Centre for Genetic Resources and Biotechnology, Federal Ministry of Science and Technology, Ibadan
- Olagorite Adetula, Assistant Chief Research Officer, National Horticultural Research Institute, Federal Ministry of Agriculture and Natural Resources, Ibadan
- Prof. Sylvia Uzochukwu, Director of the Biotechnology Centre, University of Agriculture Abeokuta, Abeokuta

USA:

- Lawrence Kent, International Programs Manager, Donald Danforth Center for Plant Science (DDCPS), St. Louis
- Roger Beachy, President, DDCPS, St. Louis
- Karel R. Schubert, Vice President, DDCPS, St. Louis
- Claude Fauquet, Director International Laboratory of Tropical Agricultural Biotechnology, ILTAB, DDCPS, St. Louis
- Kathy Kahn, Visiting Scientist, ILTAB, DDCPS, St. Louis
- Bertrand Hankoua, Visiting Researcher, ILTAB, DDCPS, St. Louis
- Jan Salick, Curator of Ethnobotany, Applied Research Department, Missouri Botanical Garden, St. Louis
- Prof. Barbara Schaal, Division of Biology and Biomedical Sciences, Washington University, St. Louis
- Wojciech K. Kanieswki, Former Principal Scientist, Monsanto Company
- Gary F. Barton, Director, Public Affairs International, Monsanto Company
- Dannette Connor-Ward, Science Information Spezialist, Monsanto Company

Colombia:

- Joe M. Thome, Geneticist, Agrobiodiversity and Biotechnology Project Leader, CIAT, Cali-Palmira
- Anthony Bellotti, IPDM-Cassava Entomologist, CIAT, Cali-Palmira
- Aart van Schoonhoven, Director for Research and Genetic Resources, CIAT, Cali-Palmira
- Paul Chavarriaga, Biologist, Agrobiodiversity and Biotechnology Project, CIAT, Cali-Palmira
- Alfredo Alves, Plant Physiologist, Coordinator Cassava Biotechnology Network (CBN), CIAT, Cali-Palmira
- Elisabeth Alvarez, Pathologist, Cassava Program, CIAT, Cali-Palmira
- Lee Calvert, Virologist, CIAT, Cali-Palmira
- Roosevelt Escobar, Biologist, Biotechnology Research Unit, CIAT, Cali-Palmira
- Martin Fregene, Cassava Geneticist, CIAT, Cali-Palmira
- Hernan Ceballos, Cassava Breeder, CIAT, Cali-Palmira
- Jose Restrepo, Director FIDAR, Valle de Cauca
- Santiago Perry, Director PBN Foundation, Bogota

Brazil:

- Sotto Pacheco Costa, Bilateral International Cooperation, Embrapa Headquarters, Brasilia
- Maria Jose Sampaio, Scientific Advisor, Cenargen, Embrapa, Brasilia
- Luis Castelo Branco Carvalho, Geneticist, Cenargen, Embrapa, Brasilia
- Haroldo Domingo Reinhardt, International Articulator, Cassava and Fruits Center, Embrapa, Cruz los Almas
- Wania Fukuda, Phytosanitary Protection, Cassava and Fruits Center, Embrapa, Cruz los Almas
- Adilson Kenji Kobayashi, Biotechnologist, Cassava and Fruits Center, Embrapa, Cruz los Almas

ANNEX III: Abbrevations

ACMV	African Mosaic Virus Disease
AHP	Analytic Hierarchic Process
ARI	Advanced Research Institute
ASP1	Asparaginase (intracellular isozyme)
BAL	Biotechnology Advanced Laboratory
BRU	Biotechnology Research Unit
CAP	Common Agricultural Policy
CBB	Cassava Bacterial Blight
CBN-LAC	Cassava Biotechnology Network for Latin America & Caribean
CBSV	Cassava Brown Streak Virus
CGIAR	Consultative Group of International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical
CIMMYT	Centro Internacional para el Mejoramiento de Maiz y Trigo
CINVESTAV	Centro de Investigación de Estudios Avanzados
CLAYUCA	Consorcio Latinoamericano y del Caribe de Apoyo a la Investigación y Desarrollo de la Yuca
COSCA	Collaborative Study of Cassava in Africa
CSRS	Centre Suisse de la Recherche Scientifique
DDCPS	Donald Danforth Center for Plant Science
DGIS/BIOTECH	Director-General for International Co-operation. Special Dutch Program on Biotechnology and Development Co-operation
EBDA	Empresa Bahiana de Desenvolvimento Agricola
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuaria
ETH	Eidgenössische Technische Hochschule
FAO	Food and Agriculture Organization
FIDAR	Fundación para la Investigación y el Desarrollo Agricola
GATT	General Agreement on Tariffs and Trade
GCP-21	Global Cassava Improvement Plan for the 21st century
GIS	Geographic Information System
GMO	Genetically Modified Organisms
IAEA	International Atomic Energy Agency
IARC	International Agricultural Research Centers
IARS	International Agricultural Research System
IB	International Business
IDRC	International Development Research Corporation
IFAD	International Fund for Agricultural Development
IFDC	International Fertilizer Development Center
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
ILTAB	International Laboratory for Tropical Agricultural Biotechnology
IPR	Intellectual Property Rights
KARI	Kenya Agricultural Research Institute
MARDI	Malaysia Agricultural Research and Development Institute

NARS	National Agricultural Research System
NEPAD	New Partnership for Africa's Development
NGO	Non-Governmental Organization
OECD	Organization for Economic Co-operation and Development
P	Phosphorous
PBA	Corporación para el desarrollo participativo y sostenible de los pequenos agricultures
R&D	Research and Development
RFPP	Research Fellowship Partnership Programme
RPA	Research Priority Area
SDC	Swiss Agency for Development and Co-operation
TRIPS	Trade-Related Aspects of Intellectual Property Rights
UNDP	United Nations Development Programme
UPLB	University of the Philippines, Los Banos
ZIL	Swiss Centre for International Agriculture

ANNEX IV: Layout of the Questionnaire

ETH Cassava Research Evaluation

Scale Rating from 1 -5 (1=totally insufficient, 5=excellent)

Name: Institution:
Date/Location:

ETH Projects	familiar with the project?	Collaboration	*Potential contributions to*		Research Stage	Adoption Rate (com)	Importance of the project	Personal Comments
			Science	Development				
1994-1996 (ZIL I)	*Yes / No*	*Scale:*	*Scale:*	*Scale:*	*lab/ /field/com*	*Scale:*	*Scale:*	
IPW1/PB1 (Potrykus) gene transfer techniques								
IPW 2/AE1 (Stamp, Woll) plant health/quality								
IPW 3/AE2 (Turlings, Dorn) parasitoids								
IAW1 (Rieder) socioec/bioplastic production								
1997-1999 (ZIL II)								
IPW4/PB1 (Potrykus) gene transfer techniques								
IPW5/PB 2 (Potrykus) Resistance to AMVD								
IPW6/PB 3 (Potrykus) Resistance to Hornworm								
IPW7/PB 4 (Potrykus) Root specific promoters								
IPW8/PB 5 (Potrykus) Leaf live prolongation								
IPW9/AE 3 (Dorn) Ecological Cultivation								
IPW10/AE4 (Frossard) Low phosphorous adaption								
IAW2 (Rieder) AHP/Acceptance								
2000-2002 (ZIL III)								
IPW/PB1 (Gruissem) gene transfer techniques								
2003-2005 (ZIL IV)								
IPW/PB1 (Gruissem) gene transfer techniques								
RFPP								
IPW/CIAT (Mba/Thome) Biotech for natl. Progr.								
IPW/IITA (Hankoua) Regeneration and Tranform.								
IAW/ISNAR (Braunschweig) AHP Decision Tools								
CSRS (Integrated, South-South)								

ETH Cassava Research Evaluation

Scale Rating from 1 -5 (1=not important, 5=very important)

Name: Institution: Date/Location:

		Potential contribution for solving the problem						
Problems in Cassava Subsistence Agriculture	Global Importance of the problem *Scale:*	Bio Control *Scale:*	Integrated Management *Scale:*	Conventional Breeding *Scale:*	Selective Markers *Scale:*	Tissue Culture *Scale:*	Genetic Engineering *Scale:*	Genomics Scale:
Plant Diseases								
Cassava Mosaic Virus								
Cassava Brown Streak Virus								
Cassava Bacterial Blight								
Fungal, Nematodes Diseases								
Pests								
Lepidoptera (Stemborer, Hornworm, etc)								
Mites								
Mealybugs								
Whiteflies								
Yield								
Low Yield (gap of potential and real)								
Late Bulking								
Leaf Aenenescene								
Root Quality								
Cyanogenic glucosides (HCN)								
Low starch content								
Short storage life								
Low protein content								
Abiotic Stresses								
Soil nutrient uptake								
Drought								
Flood								
Soil Erosion								
Clean Planting Material								
Others								

ETH Cassava Research Evaluation

Name: Institution:

Date/Location:

Scale Rating from 1 -5 (1=not important, 5=very important)

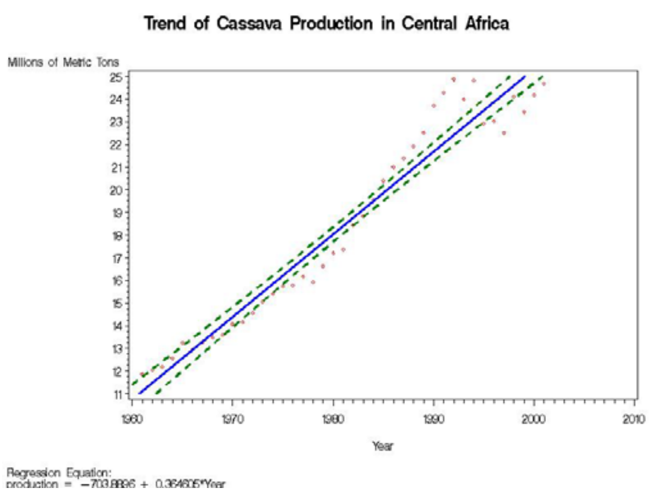
Constraints of cassava as a complementary cash crop	Global importance of the problem *Scale:*	*Ways to address the constraints*						
		Market system reform	Awareness Campaign	Improved Accountability	Global Incentives	Investment in Technology	Investment in Dialogue	Others
R&D Disincentives (abiotic/biotic stresses)								
Labor (opportunity costs)								
Capital (lack of microcredit)								
Land (fertile land)								
Lack of demand for Cassava products								
Inadequate Infrastructure (Roads, Markets)								
Inefficient market structure								
Input Costs (Fertilizer, Pesticides)								
Insufficient storage facilities								
Expensive Post Harvest Processing								
Discriminatory National Policies								
Decreasing public investments								
Lack of cross-disciplinary collaboration								
Lack of public-private collaboration								
Low adoption rates of innovation								
Political and Ideological polarization								
Starch composition								
Others								

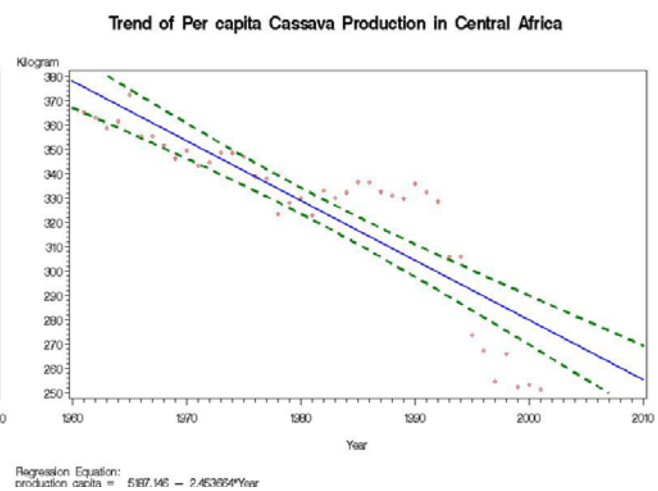
ANNEX V: Regression lines of food crops in Central Africa

Regression analyses of the production and production/capita of nine important food crops in Central Africa from 1961-2002

The predicted regression lines capture the history of production and production/capita of each single food crop from 1961 through 2001 data in Central Africa
The blue line in the different figures represents the regression line.
The red diamond points represent the actual values over the years
The green broken line represents the 95% confidence limits on the mean production/per capita production.

Cassava.

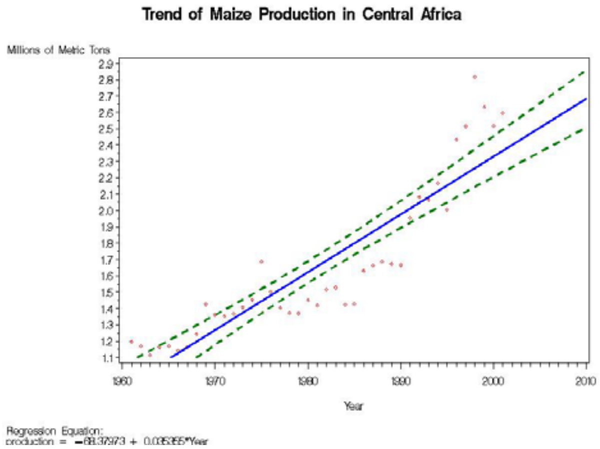


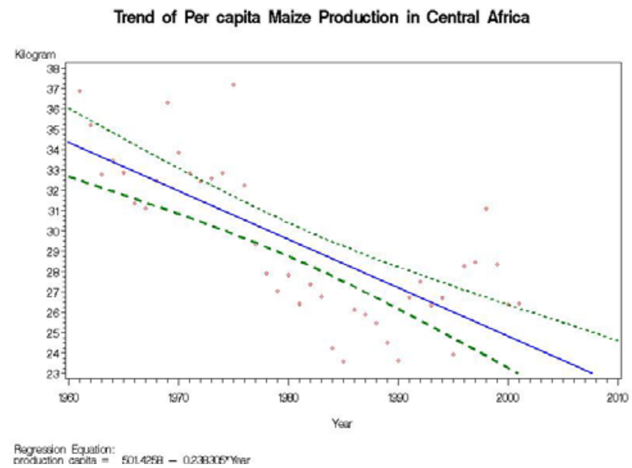


Regression coefficient for production is significant at 1%.
Regression coefficient for per capita production is significant at 1%.

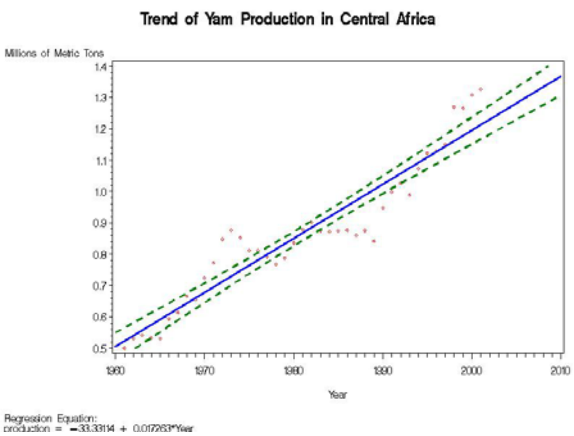
There is a significant positive trend in cassava production (r=0.36) in the case of Central Africa. Considering per capita production, there is a significant declining trend (r=-2.45). This is because cassava production is not increasing sufficiently in proportion to increasing population. Similar trends are also significant for Maize, Yam, Root&Tubers, and Sorghum, yet not significant for Sweet Potato and Potato. Rice is the only crop that shows an increasing trend in per capita production (see figures on the following pages).

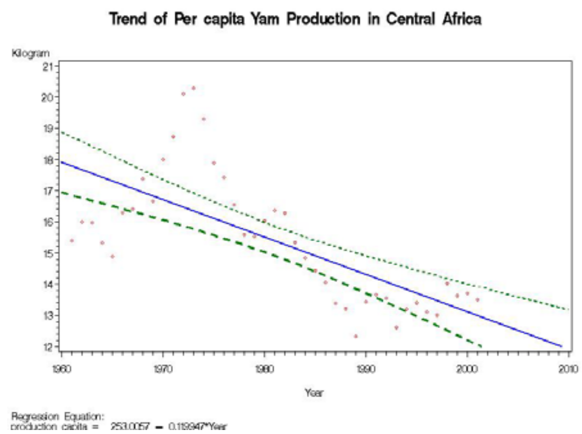
Maize



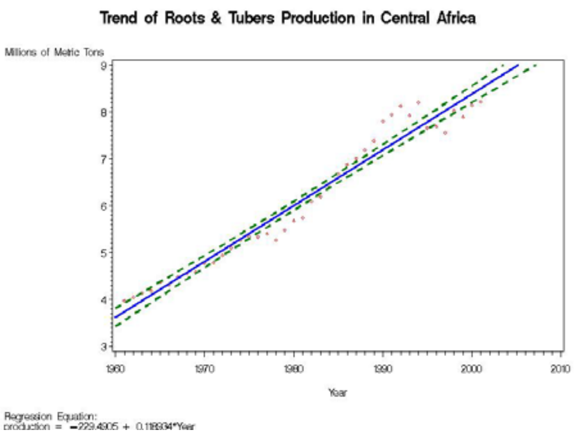


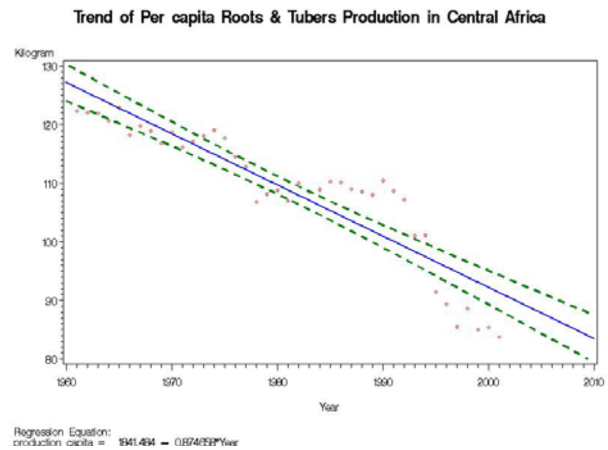
Regression coefficient for production is significant at 1%.
Regression coefficient for per capita production is significant at 1%.



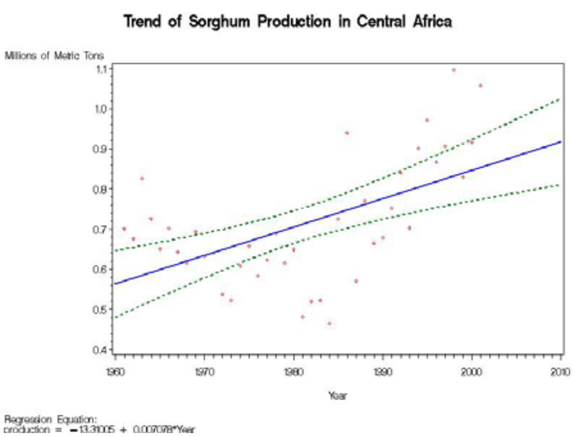


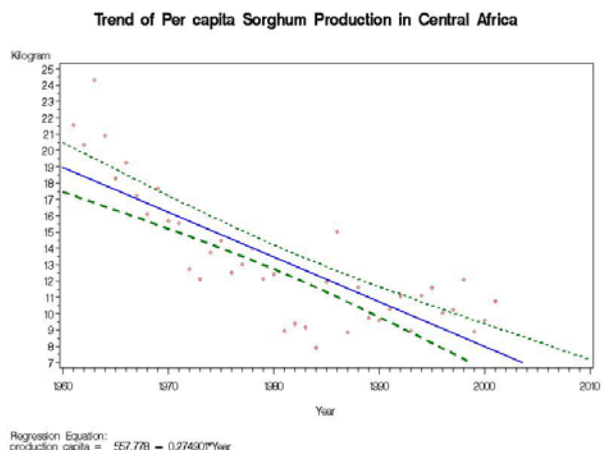
Yam:
Regression coefficient for production is significant at 1%.
Regression coefficient for per capita production is significant at 1%.



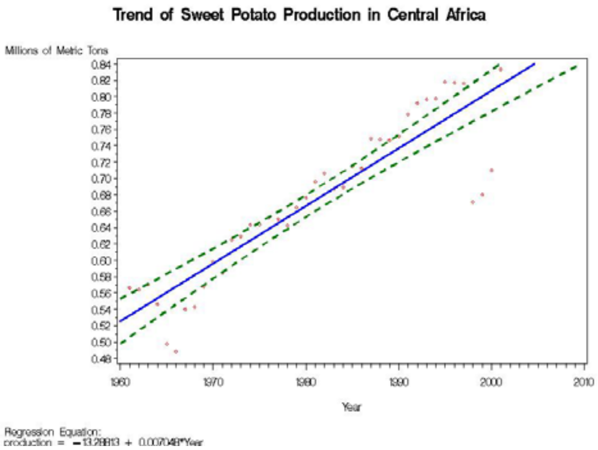


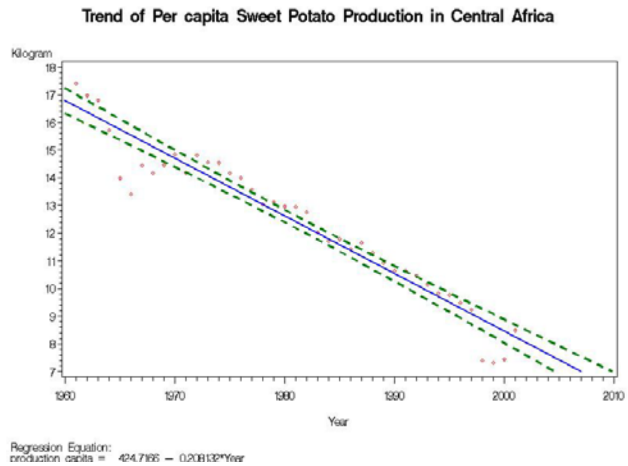
Roots and Tubers:
Regression coefficient for production is significant at 1%.
Regression coefficient for per capita production is significant at 1%.



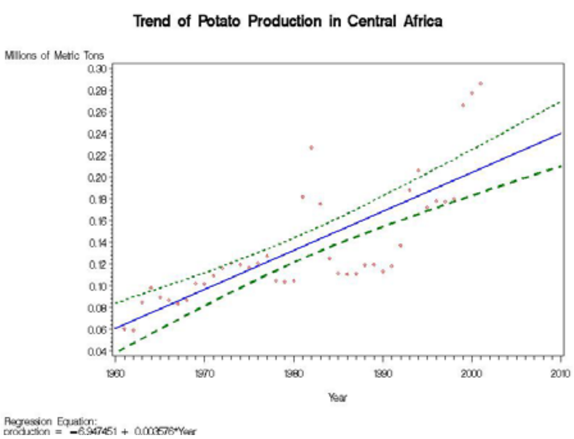


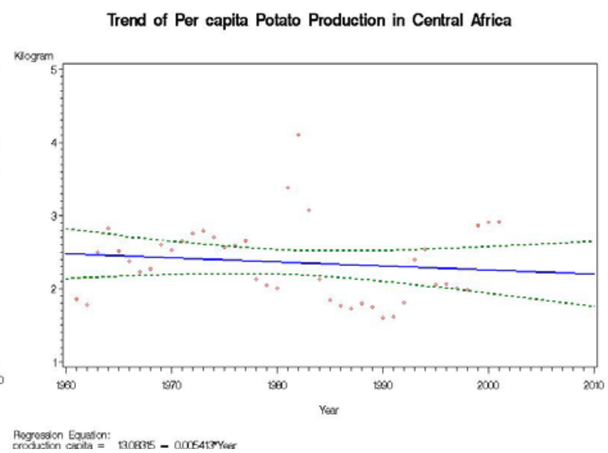
Sorghum:
Regression coefficient for production is significant at 1%.
Regression coefficient for per capita production is significant at 1%.



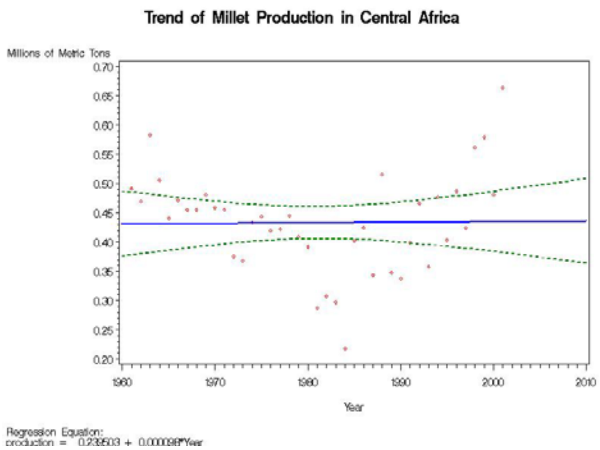


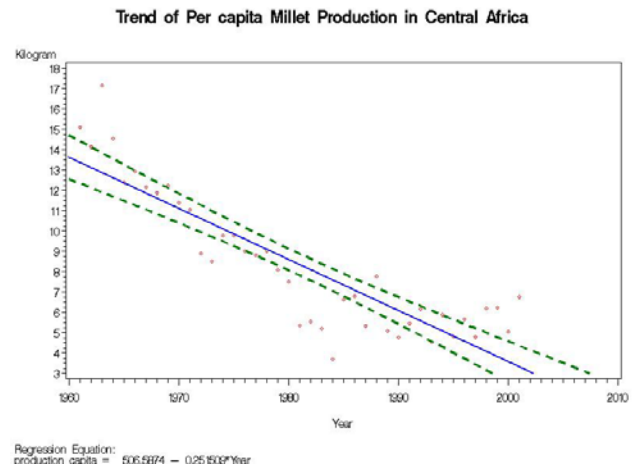
Sweet Potato:
Regression coefficient for production is significant at 1%.
Regression coefficient for per capita production is significant at 1%.



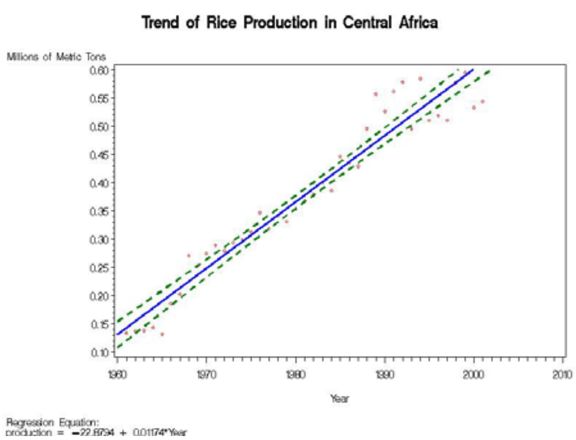


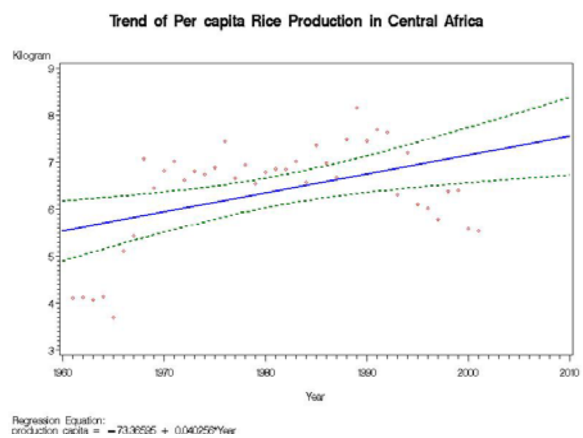
Potato:
Regression coefficient for production is significant at 1%.
Regression coefficient for per capita production is NOT significant.





Millet:
Regression coefficient for production is NOT significant
Regression coefficient for per capita production is significant at 1%.





Rice: (among 9 crops, only rice has increasing trend in per capita production!)
Regression coefficient for production is significant at 1%.
Regression coefficient for per capita production is significant at 1%.