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Unleashing the potential of sweetpotato in Sub-Saharan Africa: Current challenges and way forward

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Unleashing the potential of sweetpotato in Sub-Saharan Africa: Current challenges and way forward

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Comments are invited.

Unleashing the potential of sweetpotato
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Forward

Sweetpotato is one of the most widely grown root crops in Sub-Saharan Africa (SSA), covering around 3.2 million hectares with an estimated production of 13.4 million tons of roots in 2005. But its potential for alleviating poverty and reducing malnutrition has yet to be fully exploited, partly because of its relative neglect compared to grain crops. Just one aspect of this potential is the existence of orange-fleshed sweetpotato varieties (OFSP) with high levels of beta-carotene, the precursor to vitamin A, in the roots. In 2005, an estimated 43 million children in SSA under 5 years of age were still at risk of vitamin A deficiency. The causal link between compromised vitamin A status and increased child mortality is well-established. Only 125 grams of most OFSP varieties can supply the recommended daily allowance of vitamin A for children and non-lactating women. Furthermore, sweetpotato is predominantly grown in small plots by poorer farmers, hence it is known as the "poor man's food". However, as women predominate in sweetpotato production, "poor person's food" would be more accurate. Hence unleashing the potential of sweetpotato automatically benefits the poorest farmers in SSA.

The time is ripe for the sweetpotato community of practice in SSA to come together in a broader commodity initiative to find the best ways to reduce poverty and undernutrition through the effective deployment of improved sweetpotato varieties. To be effective, a commodity initiative of this sort needs to address key constraints at different points in the value chain. Clearly, at the farmers' end of the value chain, functioning delivery systems are essential for growers to obtain the planting material and better management practices they need to translate genetic potential into improved livelihoods. But consumers have also to be considered, as their preferences constrain adoption and shape markets and they receive nutritional benefits from sweetpotato consumption.

The series of thematic papers presented in this working paper were prepared in preparation for a *Sweetpotato Challenge Workshop* held in July 2008 in Addis Ababa. This workshop engaged experts in the areas of agriculture, nutrition, health, animal feed and marketing from all parts of SSA to discuss how to exploit best the potential of sweetpotato to combat poverty and malnutrition. The theme papers were prepared in advance so that participants would have access to an up-to-date literature review as well as exposure to the thoughts of sweetpotato specialists in key areas for the initiative.

The ultimate goal is how to improve smallholder incomes and nutritional well-being through effective implementation of a sweetpotato commodity initiative. The six "Challenge themes" identified were:

Challenge 1. Breeding
How do we improve the yield, resilience, nutritional and market attributes of sweetpotato varieties available to farmers?

Challenge 2. Seed Systems
How do we increase the availability of healthy planting material in a timely manner and sustain vine multiplication efforts?

Challenge 3. Orange-fleshed sweetpotato
How can we get pro-vitamin A rich orange-fleshed sweetpotato (OFSP) into the diet of the most vulnerable groups?

Challenge 4. Value chain
How do we improve the value chain for sweetpotato given its bulky nature, undiversified use, and image as a poor man's crop?

Challenge 5. Crop management
How can we best address the productivity bottlenecks in sweetpotato production and create the conditions for the adoption of improved practices?

Challenge 6. Partnerships and communication
What skills, partnerships and communication strategies are needed to successfully implement a sweetpotato commodity initiative?

Using information from the theme papers combined with extensive discussion and debate among participants, a consensus on what should be the driving vision for the next 10 years for this initiative and objectives was reached. The strategic vision is to **reposition sweetpotatoes in African food economies, particularly in expanding urban markets, to reduce child malnutrition and improve smallholder incomes.**

Scientists, development practitioners and farmers also identified key knowledge gaps in the areas of breeding, seed systems, nutrition, integrated crop management, and markets that must be addressed for the vision to succeed. They also had an opportunity to debate the partnership, management, and governance structures needed for such an initiative to function smoothly.

CIP and other sweetpotato stakeholders deeply appreciate the financial support provided by the Bill and Melinda Gates Foundation to enable the writing of these theme papers and the holding of the workshop. The Challenge Workshop was one stage in a unique process to engage relevant stakeholders in a participatory manner to develop a proposal for submission to the foundation in early 2009. The proposal will support a core component of this initiative – filling the science and technology gaps during the first five years – so that extensive impact can be achieved within the proposed 10 year framework.

At the end of the workshop, many participants commented on the quality of the theme papers and the need to provide a broader audience with access to them. This working paper reflects our response to the participants and we hope through its availability on the internet (www.cipotato.org), the sweetpotato community of practice worldwide will be able to utilize this information.

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Unleashing the potential of sweetpotato in Sub-Saharan Africa: Current challenges and way forward

CHALLENGE THEME PAPER 1: SWEETPOTATO BREEDING

Wolfgang Grüneberg, Robert Mwanga, Maria Andrade, and Harrison Dapaah

Overall Challenge: How do we improve the yield, resistance to biotic and abiotic stresses, nutritional and market attributes of sweetpotato varieties to farmers?

BACKGROUND

According to the Food and Agriculture Organization (FAO) statistics annual sweetpotato production in Africa has increased moderately from 11.6 million tonnes in 2002 to 12.9 million tonnes in 2006. In 2006 the FAO estimated that West-, East-, Central- and Southern Africa had an annual production of 4.2, 7.2, 1.2, and 0.5 million tonnes, respectively. These figures might be underestimated. Sweetpotato is mainly produced by smallholders (the majority of whom are women) and for home consumption. Typically less than 20% of production is traded and reaches rural and urban markets. Data on piecemeal harvested crops such as sweetpotato are difficult to collect. FAO data often do not reflect the true situation. Extreme examples of biased sweetpotato production estimates are Malawi and Mozambique. Nationally representative sample survey data for Mozambique report a production of nearly 500 thousand tonnes and Donor funded Early Warning System Statistics indicate Malawi has a production of 1444 thousand tonnes of sweetpotato, whereas the FAO Statistical Database (FAOSTAT) reports no production in Malawi and only 60,000 tonnes in Mozambique. The yield estimations over the past decades are equally dubious. The FAO statistics indicate that there has been nearly no sweetpotato yield progress in Africa over the past two decades (yield estimations were in the range of 4.0 and 4.5 tonnes per hectare from 1987 to 2006). This implies that there has been no breeding progress, which is unlikely, and reflects the lack of quality statistics for Sub-Saharan Africa (SSA). However, breeding progress has been concentrated in a few countries and there is need for improvement across SSA.

The main reason for slow sweetpotato breeding progress in Africa can be attributed to low investments into sweetpotato breeding in nearly all countries of Africa. In stark contrast, China has increased with moderate investments sweetpotato yields over the past 50 years from 7.1 to 21.3 tonnes per hectare. Rough estimates across crops conclude that about 50% of the yield progress can usually be attributed to breeding progress. Others attribute part of the low breeding progress of sweetpotato in Africa to the inadequate adjustment of breeding objectives and selection procedures to farmer needs (Gibson *et al.*, 2008) by formal plant breeding (on-station breeding managed by a scientist and his technical staff). One additional factor causing low breeding progress for sweetpotato is probably the very complex genetics of sweetpotato: each genotype is a highly heterozygous hybrid and hexaploid, so that the basic set of chromosomes is found six times in a cell nucleus, which means that each gene occurs in up to six different alleles (different states of the same gene) in each genotype. This makes successful breeding for yield progress long term in nature and complicated in designing crossing programs. This burden, however, is also an advantage as the potential for "jumps" in yield improvement can occur in nearly all autopolyploid crops. Moreover, sweetpotato as a clonally propagated crop can be easily multiplied and maintained, which is an advantage as well as a burden, because many diseases (especially viruses) are transmitted in planting material. The cloning characteristic permits rapid and wide dissemination of successful genotypes and varieties, respectively, and the exploitation of heterosis, an important genetic effect for yield, yield stability and adaptability.

Achieving medium to long term yield gains in sweetpotato is a challenge in sweetpotato breeding because the performance of a parent in one generation is not a good indicator for the value of a parent for the next sweetpotato generation. However, the genetic constitution of sweetpotato permits the adaptation of sweetpotato populations to new needs in the broad sense (environments, quality demands, tolerance to pest and diseases) to be achieved quite rapidly from the view point of crop evolution. Examples for this potential abound in the sweetpotato gene pool; it is possible to find many genotypes which are specifically adapted to drought, heat, cold (in tropical highlands), mineral-stress (including acid soils) or extreme salinity. Furthermore, the large differences in taste, protein, starch, sugar, vitamin and mineral content in the sweetpotato gene pool can be easily found provided that the breeder can, and is willing, to screen large numbers of genotypes and has appropriate bioassays. What is required is the development of genetic variation (this is easy in sweetpotato) around higher population means (this is difficult in sweetpotato) which entails screening thousands of samples (this is laborious in sweetpotato). Increasingly elevated population means and a sufficient genetic variation for variety development is the task of medium to long term population improvement within breeding and the engine driving the breeding progress.

The needs of farmers and breeding objectives, respectively, are generally classified into yield and yield stability, quality and resistance. However, sweetpotato has an additional class of need and this is the survivability of planting material (also called vine survival). In contrast to nearly all other major food crops (except cassava) the harvest (storage roots) and planting material (usually vine cuttings) differs in sweetpotato. Additionally, sweetpotato is harvested after a period of about 4 to 5 months and planting material must be available for the next growing season, which can be 5 to 7 months later, especially in those SSA regions with extended drought periods. In contrast, the growing period of cassava lasts about 8 to 11 months and cassava usually stays in the field a short time before the next growing season. Vine or planting material survival is one very important need for sweetpotato in SSA, and has not been a selection criterion to date. In SSA millions of farmers are losing 4 – 6 weeks of the excellent growing period at the beginning of the rainy season while they re-establish sufficient vine production for planting, obtaining initial limited planting material from residual plants, re-sprouting roots, or secondary growth of harvested fields. The limited availability of planting material might explain why the sweetpotato production area is considerably smaller than the cassava production area in SSA. De facto, sweetpotato produces more food energy per unit area and unit time than any other major food crop and sweetpotato has higher protein, vitamin and mineral contents compared to cassava.

As further background to the sweetpotato breeding challenges more general background information is provided about breeding structures and breeding objectives (yield and yield stability, quality and resistance) in sweetpotato for Africa. Yield, yield stability and adaptability (including genotype by environment [G by E] patterns) of crops are often associated with resistance to biotic and abiotic stress. This is also the case for sweetpotato in Africa; however, the effect of stress factors are more pronounced in Africa than in other regions of the world. This results in stronger G by E patterns and more distinct agro-ecological zones in which varieties must have similar adaptation. There are different opinions in breeding for wide adaptation and the necessity to breed for specific adaptation (for a discussion in the frame of sweetpotato breeding see Grüneberg *et al.*, 2005). In the case of sweetpotato it is recognized that it is not possible to breed for adaptation across agro-ecological zones in Africa. For this reason, consideration needs to be given to organizing sweetpotato breeding in a decentralized way. Each country with a significant sweetpotato production should have its own variety development program. Each variety development program should be linked with a "local" short term population improvement program, in which parents are recombined (crossed) in an efficient way according to the local breeding and test capacity (critical test capacity for a local population improvement needs to be defined for SSA). The local population improvement program should aim to generate significant genetic variation and breeding progress within two to three generation cycles and five years, respectively, where one cycle comprises one recombination step of parents and one selection step is defined as selection within genetic variation derived from recombination. However, pre-breeding (the incorporation of specific traits into breeding material that merits use as parents in local population improvement) and to certain extent population development itself can be conducted in fewer, more "centralized", locations. That is, strategic medium to long term population improvement, such as developing and extending the non-sweet sweetpotato gene pool for West Africa (see below), could be carried out at the sub-regional level. It should be noted that pre-breeding and strategic medium to long term population improvement require significant greater capacities, both human and financial, than variety development through short term population improvement. In the short term, crossing and combining parents with medium to high genetic values across all objectives and traits is all that is required. In pre-breeding and medium to long term population improvement, parents are developed by incorporation of new attributes from sources which often only have a high genetic value in one or very few attributes (e.g. excellent disease resistance but poor yield performance and other traits).

Within the sweetpotato gene pool, there is an enormous amount of genetic variation for quality attributes. A renowned example is the concentration of pro-vitamin A in storage roots, which ranges from 0 to nearly 1000 ppm on a storage root dry weight basis (dwb). This corresponds to 0 to 20 mg β-carotene in 100 g of fresh sweetpotato storage roots (about 5 mg β-carotene meets the daily requirement of a pre-school child (400 µg/day RAE)[1]). Similar magnitudes of genetic variation are found for starch, sugars and probably for dietary fiber. Moderate genetic variation is found for protein and minerals such as iron and zinc. It is quite convenient, however, that the attributes, proteins and minerals are positively correlated genetically with β-carotene in sweetpotato storage roots, so that improvement in pro-vitamin A is linked with an improvement in iron, zinc and other minerals such as calcium and magnesium.

Breeders nearly always want to select for several traits concurrently. If the goal is to select the top 10 among 100 genotypes for each trait and seek a total number of 10 priority traits then 100^{10} genotypes have to be screened. This simple example demonstrates how the number of genotypes to be screened increases exponentially as the number of priority traits desired increases. In practical terms, quality breeding often means to improve quality (three to five traits) and simultaneously maintain sufficient genetic variation for yield, yield stability and adaptability

[1] Plant sources of pro-vitamin A in the form of β-carotene are converted into retinol. Recommended intake levels of vitamin A are expressed in Retinol Activity Equivalents (RAE) with a healthy child 1-3 years old needing 300 µg/day and a

improvement. Fortunately, several high through-put quality screening methods have proven effective for use with sweetpotato. This includes color charts for pro-vitamin A contents, taste tests for starch and sugar contents, as well as Near-Infra-Red (NIR) technology (Pfeiffer and McClafferty, 2007) for assessing levels of protein, minerals and anti-nutritional factors such as phytate. Clearly, quality breeding in sweetpotato is straightforward but labor intensive. The challenge is to incorporate or develop the quality attributes in a genetic background (a population comprising several hundred genotypes) that is adapted to the agro-ecological environment and has sufficient genetic variation for yield improvement.

Stress (biotic or abiotic) principally defines agro-ecological zones and generates distinct requirements for pre-breeding and medium and long sweetpotato population improvement. Key features of the major environments where sweetpotato is produced are briefly summarized below.

The **humid tropical low and mid-elevation regions of Eastern & Central Africa** (0 to 1200 m.a.s.l.) with only very short dry seasons, if any (Uganda, Rwanda, Burundi, Dem. Rep. Congo) have high sweetpotato virus disease (SPVD) pressure, which is extreme in regions where sweetpotato is extensively cultivated. The SPVD occurs after infection of two viruses: the sweetpotato feathery mottle virus (SPFMV) and the sweetpotato chlorotic stunt virus (SPCSV). The SPCSV is the more problematic component of SPVD, because yield losses due to SPFMV - without SPCSV infection – are low and SPFMV resistance (as well as the resistance to many other viruses) of sweetpotato breaks after the plant is infected by SPCSV. SPCSV resistance has been found in germplasm screening programs and the resistance appears to be conferred by a recessive allele which occurs in low frequency in the sweetpotato gene pool. However, this resistance still needs to be proven in extensive field tests in Africa. It is nearly certain that new sweetpotato varieties with resistance to SPVD will result in significantly higher yields and yield stability in East- and Central Africa, at least for a period of 5 to 8 years. After this period, it is likely varieties will need to be replaced because new strains have developed in the chlorotic stunt virus gene pool.

The **humid tropical highland regions of Eastern & Central Africa** (1200 to 1800 m.a.s.l.) are characterized by relatively cold temperatures at nights (Rwanda, Burundi, parts of Western Kenya and Uganda, as well as spots in Tanzania). For decades, these African regions have had very high

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4-8 year old 400 µg/day. The conversion rate commonly used is 12 units of β-carotene to produce 1 RAE. Hence, 5 mg (equivalent to 5000 µg of beta-carotene) provides 416 µg RAE.

levels of sweetpotato production. Moreover, owing to the favorable climate, these regions also support the highest rural population density in Africa. For sweetpotato these regions have the advantage of a nearly whole year round production, and considerably lower SPVD pressure. In this setting, Alternaria dominates as the major sweetpotato disease. Cold nights limit sweetpotato production at around 5°C. National Agricultural Research System (NARS) partners in Rwanda, Tanzania, and Burundi consider the development of pathways for sweetpotato processing and the dual purpose sweetpotato (varieties to be used for direct human consumption and animal feed) as important new needs for sweetpotato by which the crop can contribute to income generation and poverty alleviation. Where land is limited and labor abundant, especially in those countries where zero grazing has been implemented by law (such as in Rwanda), the dual purpose sweetpotato might be the option to feed cattle, pigs and small animals (see the Challenge Paper on Value Chains and background paper on animal feeds) and could also contribute to reducing soil erosion. This might be the major impact potential of sweetpotato in the African highlands. So far, no specific breeding populations for highland sweetpotatoes have been established, but there are sufficient genetic resources in the sweetpotato gene pool (at least in the germplasm collection of the International Potato Center [CIP]) to start a highland dual purpose breeding program. In addition, there is need to select for market quality, although the amount marketed for specific end uses might be only a small proportion of the total production. However, NARS in Rwanda consider value added products in which sweetpotato is used as a secondary or primary raw product (juices, chips, puree, and bread) as an investment needed to change the image of sweetpotato as being a poor man's crop, which contributes towards declining consumption of sweetpotato connected to rising incomes, particularly in urban settings.

The **drought prone regions of Southern and Eastern Africa** (from sea level to mid elevation areas < 1200 m.a.s.l.) have very unstable rainy seasons and an extended drought season of more than 4 months (Mozambique, Malawi, Zambia, Angola, Madagascar, parts of Tanzania, Kenya, and Northern Uganda). Drought effects are associated with high storage root damage by weevils and serious shortages of planting material at the beginning of the rainy season, especially for households with poor access to valley bottom lands. Resistance to sweetpotato weevils does not exist in sweetpotato; however, different degrees of tolerance are reported by farmers among sweetpotato varieties. Farmers consider varieties which expose their storage roots close to the soil surface as highly susceptible to weevil damage. Moreover, there are indications that the latex content in root skin is associated with lower weevil damage. In Mozambique farmers consider availability of planting material and vine survival as key traits for successful varieties. After long dry periods, farmers plant what is available and often these are varieties which produce a lot of vines meaning that access to other attributes gained through breeding will not be available to farmers if this essential trait is missing. Impact in this region by sweetpotato – especially the orange-fleshed sweetpotato (OFSP) – will require breeding populations to exhibit strong vine survival and breeding programs have to address this trait adequately in population improvement.

The **forest and savanna regions of West Africa** (nearly entirely low to mid-elevation areas < 800 m.a.s.l.) have more or less stable rainy seasons with a short to prolonged dry season (2 to 8 months). They are traditionally production zones with high a frequency of root crop production. However, the main root crop is cassava, followed by yam, then sweetpotato. Major sweetpotato production countries are Nigeria, Ghana and Sierra Leone. Agricultural infrastructure in West Africa is more developed than in East, Central and Southern Africa (e.g. laboratory facilities with high output of clean planting material can be accessed in Ghana) and export opportunities are enhanced by closer proximity to Europe. The SPVD virus pressure is moderate, but with the extension of the dry season the problem of weevil damage increases. Moreover, markets for processed root and tuber crops exist – the most well known cassava product is gari which is eaten by millions in West Africa on a daily basis. In spite of this market, sweetpotato is rarely processed because of the sweetpotato flavor. NARS in Ghana emphasize that non-sweet or bland sweetpotatoes are needed to enter into this market chain of root and tuber crops. The contribution of OFSP to income generation and improved vitamin A status could be enhanced by incorporating the non-sweet trait. The major sugars of sweetpotato are sucrose, glucose, fructose, and maltose. The total sugar content in sweetpotato varies widely within the sweetpotato gene pool (<5% and up to 30% on dwb). Moreover, genotypes with lower sugar contents exist within the OFSP gene pool gene. So far no breeding populations for the non-sweet sweetpotato have been established in SSA, but in other regions of the world national programs have successfully bred for the non-sweet sweetpotato [e.g. Sri Lanka, Puerto Rico, United States (Kays *et al.*, 2005).

Breeding is a critical factor in increasing sweetpotato yields and in opening new options for diversified use of sweetpotato in Africa. Moreover, further sweetpotato quality breeding for provitamin A, iron and zinc will increase the impact of sweetpotato consumption on public health (especially women and young children).

This paper is a result of a consultative process among CIP's senior sweetpotato breeder and breeders from seven African countries during the preparatory phase for this workshop. Six major challenges have been identified for sweetpotato breeding in Africa: (i) improving sweetpotato breeding infrastructure, (ii) improving sweetpotato breeding methods (iii) breeding sweetpotato products / varieties for humid topical low and mid-elevated regions (0 to 1200 m.a.s.l.) with high SPVD pressure, (iv) breeding sweetpotato products / varieties for cold topical highlands (> 1200 m.a.s.l.) with attributes for dual use (human consumption and animal feed) and marketable value added products (bread, breakfast food, puree and juice), (v) breeding sweetpotato products / varieties for drought-prone, high temperature regions with high vine survival and some tolerance to weevil damage, (vi) breeding sweetpotato products / varieties for low or no sugar contents and high dry matter content (non-sweet sweetpotato) adapted to West African regions.

PRINCIPAL CHALLENGES

Challenge 1.1. Limited breeding infrastructure

Current knowledge

Several countries in SSA have sweetpotato breeding programs. However, there is only one NARS breeding program with significant medium to long-term population improvement capacity. This is the National Crops Resources Research Institute (NACRRI) in Uganda. A second program with similar capacities is mainly managed by CIP in Mozambique in cooperation with the Mozambique Institute for Agricultural Investigation (IIAM). NACRRI has allocated full time one scientist and six technicians to sweetpotato breeding. Furthermore, two scientists are working at NACRRI with sweetpotato (one agronomist and one entomologist). In the second program CIP, together with IIAM in Mozambique, has allocated two breeding scientists (one PhD CIP senior staff and one MS IIAM junior staff), six field technicians and two laboratory technicians to sweetpotato breeding. Both breeding programs recombine as standard 25 to 40 parents each year. At present NACRRI has an additional crossing block comprising 100 parents. In the past year at least 90,000 polycrosses and 3000 controlled cross seeds were developed at NACRRI. In contrast CIP-Mozambique / IIAM selected from in the past season 30,000 seeds from polycrosses and 25,000 seeds from controlled crosses. It should be noted that CIP-Mozambique obtains on a larger scale controlled cross seed from CIP-Lima (about 516 families in the last season). There is also some limited material exchange between NACRRI and CIP-Lima (e.g. SPVD resistant clones and SPVD resistant populations to NACRRI and African OFSP landraces to CIP-Lima). Both breeding programs use three to six experimental sites. Depending on the potential of the material, 50 to 500 promising clones and 10 to 25 advanced breeding clones are tested each year.

The two programs not only differ in the relative emphasis on polycrosses versus controlled crosses, but also on how they conduct selection in early breeding stages. The program at NACRRI uses a sequential selection in which at the first stage 50,000 to 90,000 clones are screened on a single plant basis for SPVD tolerance. After 3 years the material is reduced to 50 or 500 promising clones. The program at CIP-Mozambique / IIAM uses a sequential selection in early breeding stages for clones from polycross seed, whereas clones from controlled crosses are evaluated in a simultaneous selection scheme. A simultaneous selection scheme is characterized by testing simultaneously all genotypes in very small plots (usually three plants) at two to three locations, of which one is a stress location (in this case a drought stress location). Both breeding programs – NACRRI and CIP-Mozambique / IIAM have plant quality and in-vitro laboratory facilities. However, NACRRI facilities merit improvement, whereas at CIP-Mozambique / IIAM technical staff skills merit improvement. It appears that at both institutions the laboratories need investments to better serve a medium to long term sweetpotato improvement program as well as serve as a dissemination point for "good" parents to other breeding programs working in similar agro-ecological zones.

Several NARS sweetpotato breeding programs have capacities for variety development linked with local short term population improvement programs, including the Agricultural Research Institute (ISAR)-Rubona in Rwanda, the Crop Science Research Institute (CSRI)-Kumasi in Ghana, the Kenya Agricultural Research Institute (KARI) in Nakuru, Kenya, and University of Nairobi at Kabete, Kenya, in cooperation with CIP-Nairobi. These NARS breeding programs have allocated full time one scientist and two to three technicians to sweetpotato breeding. These NARS partners are managing a crossing block in which usually 10 to 25 parents are recombined and 3000 to 7000 seeds are developed. Crossings among parents are mainly conducted by polycrosses (80 to 90% of the total seed production). Selection is conducted sequentially in early breeding stages at one location in which in the first season material is selected for SPVD tolerance and quality characteristics (exclusively for storage root and skin color, dry matter and flesh color). This is linked with observation trials for storage root size, shape and form as well as storage damage due to weevil and other biotic and abiotic stresses. First yield trials are carried out after 2 to 3 years in preliminary yield trials at one to three locations, followed by advanced yield trials conducted in at least three locations each with two replications. Evaluation capacity is usually 20-40 promising clones and 10–20 advanced clones. It is worth noting that CSRI in Ghana has active biotechnology and in-vitro lab facilities, which are stronger than the current NACRRI and CIP-Mozambique / IIAM facilities. Moreover, there is an existing in-vitro sweetpotato maintenance program at the Biotechnology and Nuclear Agriculture Research Institute (BNARI) in Accra, Ghana, which handled in the past campaign the dissemination of 20,000 virus-free plantlets to associations exporting to Europe.

Other NARS breeding programs partially allocate one scientist and one to two technicians to sweetpotato breeding such as Lake Zone Agriculture Research and Development Institute (LZARDI) at Mwanza / Tanzania. These NARS cross only few parents by polycrosses in which seeds are harvested from two to four of the most interesting parents, which were planted together with about 10 – 15 genotypes (usually local adapted material). Selection in subsequent stages for tolerance to biotic and abiotic stresses is conducted in a similar way to that described for the NARS partners above. Moreover, a group of NARS partners such as the Department of Agricultural Research Services (DARS) in Bvumbwe / Malawi, and HortiTengeru in Arusha / Tanzania have partially allocated one scientist and one to two technicians to sweetpotato research, but do not have crossing blocks. These programs occasionally conduct variety selection with introduced clones or seeds, which they obtain from NACRRI, CIP or other sources. However, all these seeds come from polycrosses. It is worth noting that these NARS partners have interesting collections of local germplasm, which include material that has been very successful in farmer fields for decades.

Future areas of work for consideration (order listing does not imply any prioritization):

1) Defining a critical capacity for a NARS sweetpotato breeding program.
2) Defining breeding platforms and their tasks, which are serving an agro-ecological region by medium to long term population improvement for priority traits within the region by providing attractive parents for local population improvement programs.
3) Selection and allocation of sub-regional platforms supporting NARS breeding programs;
4) Selection and allocation of NARS breeding programs (suggestion: 8 to 12 partners).
5) Defining clear breeding objectives on the basis of regional needs and capacities for each agro-ecological zone and milestones and breeding progress, respectively, to be reached in products and varieties respectively.
6) Developing standards to record traits and progress towards objectives, which allow sound statistic analysis.
7) Defining bottlenecks in NARS breeding programs and regional platforms.
8) Stepwise increasing of the NARS breeding capacity to the critical mass, by internal funds and supporting fund raising (e.g. Alliance for a Green Revolution in Africa [AGRA] and the Pan-African Start Secretariat [PASS]).
9) Stepwise increasing of the breeding capacity at regional platforms to fill the bottlenecks, by internal funds and further fund raising for sweetpotato breeding research (e.g. AGRA and PASS).

Challenge 1.2. Poorly developed breeding and selection methods

Current knowledge

Sweetpotato is a clonally propagated crop, meaning that all plants tracing back to the same mother plant are genetically identical. This mother plant once developed from a single seed. In sweetpotato true seed sets occur easily in nature by cross-pollination (due to insects, mainly bees). The general breeding principle underpinning breeding clonally propagated crops is to break the normal clonal propagation by introducing a crossing step, which culminates in sexual seed production and genetic variation. After the genetic recombination, all subsequent propagation steps are again asexual by clonal propagation. The creation of genetic variation in sweetpotato is very easy. When different genotypes are planted together, they naturally cross-fertilize and set seed, because sweetpotato is self-incompatible (seeds cannot develop from self-fertilization) – this principle underlies the development of polycross nurseries. The seedlings are raised in seeding nurseries and each seedling is a different genotype and has the potential to become a new variety, because clone lines are genetically fixed (no further genetic change occurs). To move from seeds to new varieties, selection criteria are applied to a large set of genetically diverse clones based on desired breeding objectives. This is usually carried out over several subsequent evaluation and selection stages. Highly heritable traits (traits which are not very much affected by the environment) are evaluated in early stages on the basis of a very small number of plants for each genotype (such as disease resistance, storage root size, shape and from, storage root skin and flesh color). Lowly heritable traits (traits which are strongly affected by the environment) such as yield, yield stability and adaptability, are evaluated in later stages, when more planting material is available, on the basis of plots, plot replications and information across several environments. Such a multistage selection program can take up to five years or more. In essence, breeding is the art of accelerating crop evolution towards plant characteristics of use by human beings.

Variety selection

Often breeding gets lost in discussions as to which traits have to be considered. The breeder Gerhard Röbbelen wisely said to his students: *There is only one breeding objective: A better product and variety, respectively, and to come with this at least one year before the competitor*. Existing selection theory models are often used with one (usually yield) or very few traits. But, theoretically it is possible for model calculations to capture the practical process of multistage and simultaneous selection in multiple environments for several traits aiming at the identification of a variety. In breeding sweetpotato for variety development there can be as many as 20 traits and attributes desired to determine the quality of a variety and an almost equal number of other traits meriting improvement. What we basically have is an optimization problem: for a given testing capacity and budget, how can we evaluate a large number of traits in a large number of genotypes efficiently?

Some have criticized formal plant breeding - in this context, researcher-managed selection on-station in Africa and for Africa - for concentrating on breeding objectives that do not necessarily correspond to farmer needs. On-station trials conducted on good land, under good management with occasional irrigation access, often produce results that differ substantially from on-farm results. This can be a problem when "crossover interactions" occur, that is when the ranking of genotypes on the basis of on-station performance do not correspond to the ranking of genotypes on the basis of on-farm performance. In the case of sweetpotato breeding, this criticism is at least partially justified. Simple examples of areas where more attention is needed include storage root skin color (acceptable skin color varies tremendously in Africa) dry matter and sugar content (a sweetpotato with a soft sweet mouth taste is usually not acceptable in Africa). More complex examples are piecemeal harvest attributes, especially in varieties for humid tropical low and mid-elevation regions, and planting material availability or vine survival attributes in varieties for the drought prone regions of Southern Africa. The need for varieties for Africa is much more complex than the need for varieties for the developed world, with their industrialized agriculture. Farmer participation in trials of advanced clones is widespread in sweetpotato selection programs in SSA. However, sweetpotato breeding programs in Africa often do not have sufficient farmer participation at the early breeding stages. This is important because errors at the early breeding stage cannot be cleared at later breeding stages, as what is discarded is lost. Having farmers actively involved in at least one early breeding stage could be a key factor for improving selection efficiency in Africa. Breeding programs should aim to select sites that are representative of farmer field conditions and management. However, trade-offs do exist; under moderate to good conditions genotype and variety differences become more pronounced -- especially for yield – which increases selection efficiency increases, but crossover interactions for poorer environments cannot be captured.

It is essential to capture appropriate crossover interactions because well performing products and varieties for well resourced farmers often fail in environments typical of poor households. Most sweetpotato breeding programs in Africa do not select at a hot spot environment in the early breeding stages for extreme low input and extreme high stress conditions due to biotic and abiotic stresses. These environments are risky. In extreme seasons the whole breeding population can be lost. Moreover, yield differences among genotypes are smaller, and experimental errors and least significant differences are larger. However, model calculations show that by using two sites at the first breeding stage, the efficiency of selection (or response to selection) is still close to the optimum. One hypothesis is that if the second environment used is a poor input or "hot spot" for a priority stress condition (e.g. drought; high virus pressure), this will significantly increase the selection efficiency. To reduce resource use, the poor input or hot spot environment for stress is harvested first and all genotypes that fail to perform in this stressed environment are discarded from the selection program regardless of how well they are performing on-station. The resource use-saving comes from not having to record information on these "discarded" genotypes on-station. The inclusion of a low input selection environment can also be linked to farmer participatory selection. This strategy should increase the selection efficiency for sweetpotato in Africa of formal plant breeding programs by reducing the risk of developing varieties which are not adopted by farmers.[2]

To accelerate the breeding process, our proposition is that simultaneous selection of traits is more efficient than sequential selection of traits. In practical terms, this means:

Increasing the number of tested clones at the early breeding stage to the maximum of the test capacity that can be allocated to genotypes at the early breeding stage (about 60% of the total test capacity or breeding budget).

Selecting at each breeding stage about 10% of the material.

Not investing in more than three subsequent selection stages because there will be no further gains in selection efficiency (response to selection).

Allocating about 20% of the total test capacity to the second and 20% to the third selection stage.

Selecting at two environments at the first selection stage does not differ much in its efficiency from selection at one environment; however, with more environments, efficiency becomes increasingly more distant from the optimum selection efficiency.

Increasing immediately at the second selection stage the number of locations to the maximum that can be managed with 20% of the test capacity allocated to this breeding stage. At this stage the greates efficiency is gained by increasing the number of environments instead of increasing the number of replications; hence, no plots at a site need to be replicated.

Using the maximum number of locations that can be managed with 20% of the total test capacity at the third selection stage; noting that differences between trials with two plot

[2] For detailed information concerning selection theory for variety selection, book chapters like "Selection between clones and homozygous lines" and "Selection for several characters" in selection theory textbooks such as Wricke and Weber (1986) are excellent references for breeders working with clonally propagated crops.

replications (reduced number of tested genotypes) do not differ much from trials with one plot replications with respect to the selection efficiency in the multistage selection program.

We recognize that sweetpotato experimental trials have a very large plot error for yield. Estimations show coefficient of variation (CV) values 35 – 45% in 15 plant plots and CV values 25% in plots with more than 60 plants. However, the number of environments is a more important parameter for the efficiency of selection than the number of plot replications. We also assume that the CV plot error can be further improved through specific experimental design, which merits further investigation. Hence, we propose for consideration an accelerated breeding scheme (Figure 1.1) which requires 3–4 selection stages for variety development in which the first two stages are aggregated into one season, so that new varieties with the desired traits can be developed within 2–3 seasons.

Many breeding programs in Africa allocate the majority (>50%) of their total test capacity and breeding budget to the more advanced selection stages and not to the first selection stage. Moreover, the number of tested breeding clones at the first selection stage appears to be too low to reach moderate or high selection efficiency. As mentioned above, this initial selection stage is the most critical for the selection efficiency. The two breeding programs in SSA that are heavily investing in the first selection stage are NACCRI-Uganda and CIP/IIAM-Mozambique. Both programs have at least moderate selection efficiency. Both programs might be improved by speeding up the time needed for variety selection. As the modification of a breeding program is a very sensitive issue, consideration of an accelerated breeding approach will require intensive discussions and exchange of opinions. In addition, use of better statistical tools (e.g. for simultaneous selection of traits) might also significantly improve the efficiency of variety selection programs.

Multistage selection theory needs parameters to calculate the efficiency of selection programs. These are parameters for the variance components due to genotypes, genotype by environment interaction and the plot error as well as assumptions for the test capacity (total number of plots, maximum numbers by location and replications). The most critical parameter is the variance component due to genotypes or the genetic variation, because without significant genetic variation, even the most well designed selection program is inefficient. In the next section, a detailed explanation is provided to help the reader understand the degree of the genetic variation available to draw on for certain traits and attributes in sweetpotato.

Figure 1.1
Planting early selection stages of sweetpotato for the accelerated breeding scheme in San Ramon (one of four locations used at this stage).

Genetic variation of sweetpotato traits: Results from an evaluation of germplasm from the CIP genebank

Genetic variation is a prerequisite for genetic improvement. There is abundant literature for sweetpotato quality attributes (Woolfe, 1992), but earlier findings were based on just a few clones. In this section, preliminary results concerning genetic variation in sweetpotato from at evaluation of 1148 clones from germplasm in the CIP genebank provide a more comprehensive look at the availability of exploitable genetic variation for varietal improvement. The clones have been evaluated in three distinct environments in Peru since 2004: (i) arid irrigated lowland, (ii) humid tropic lowland, (iii) humid tropical lowland without fertilization. Within sweetpotato there are large differences in storage root concentrations of protein, starch, sucrose, total sugars, β-carotene, calcium and magnesium. The differences are less pronounced for iron and zinc (Table 1.1). Storage root starch contents of up to 33.3% (on fresh matter basis) and storage root sugar contents as low as 0.6% (on fresh matter basis) were observed. Storage root β-carotene, calcium, magnesium, iron and zinc contents of up to 154, 4091, 1815, 10.0 and 6.3 ppm were observed in fresh storage roots[3]. This corresponds to 15.4 mg β-carotene, 409 mg calcium, 181 mg magnesium, 1 mg iron and 0.6 mg zinc in 100 g fresh storage roots.

[3] Breeders often report vitamin and mineral concentrations on a dry weight basis (dwb) in parts per million (ppm). In the nutrition literature, it is more common to see concentrations reported on a fresh weight basis (fwb) in mg per 100 gms or µg/g (1 mg=1000 µg). To convert, one needs to know the dry matter content of the roots. For example, 15 µg/g β-

Table 1.1. Quality attributes in the sweetpotato germplasm.
Evaluated in 1146 CIP genebank clones across three environments: (i) arid irrigated, (ii) humid tropic lowland, and (iii) mineral stress humid tropic lowland with two plot replications [plot size 10 plants] per site.

	Mean	**Min**	**Max**
Yield (t / ha)	16.2	0.3	54.0
Upper Biomass (t / ha)	22.0	0.5	65.5
Dry matter (%)	35.0	15.9	48.5
Protein (% DM†)	4.6	1.1	10.3
(% FM‡)	(1.6)	(0.3)	(3.7)
Starch (% DM†)	59.5	29.3	75.6
(% FM‡)	(20.0)	(4.9)	(33.3)
Sucrose (% DM†)	8.4	**0**	32.1
(% FM‡)	(2.8)	**(0)**	(7.4)
Total Sugar (%DM†)	14.1	**1.7**	47.2
(% FM‡)	(4.7)	**(0.6)**	(10.1)
Total carotenoids (ppm DM†)	82	0	812
(ppm FM‡)	(26)	(0)	(200)
-carotene (ppm DM†)	38.3	0	**621**§
(ppm FM‡)	(10.8)	(0)	**(154)**
Calcium (ppm DM†)	1281	185	**4091**
(ppm FM‡)	(429)	(76)	**(1110)**
Magnesium (ppm DM†)	642	216	**1815**
(ppm FM‡)	(219)	(57)	**(409)**
Iron (ppm DM†)	16.2	9.0	**27.5**§§
(ppm FM‡)	(5.6)	(2.7)	**(10.0)**
Zinc (ppm DM†)	10.0	4.8	**18.7**§§§
(ppm FM‡)	(3.4)	(1.18)	**(6.3)**

† storage root dry matter basis, ‡ storage root fresh matter basis.
§ up to 1000 ppm, §§ up to 40 ppm, and §§§ up to 29 ppm occasionally observed in clones from breeding population after 2 cycles of recurrent selection.

Overall, significant genetic variation exists for all quality traits (Table 1.2). The magnitude of the genetic variation is large for starch, sucrose, total sugar, β-carotene, calcium, and magnesium storage root concentrations. The magnitude of the genetic variation for iron and zinc is not large; however, the lower confidence limit estimates indicate a genetic variation (σ_G^2) for iron and zinc of at least 1.9 ppm^2 and 0.6 ppm^2, respectively. The genotype by environment interaction ($\sigma_{G\times E}^2$) is low for all quality traits, except protein, iron and zinc. However, it should be note that this study included a large random sample of the sweetpotato germplasm tested in two agro-ecological zones. Hence, it is highly probable that clones specifically well adapted to only one of these agro-ecological zones drive a larger genotype by environment interactions than is usually found in breeding material for a given agro-ecological zone. For protein, iron and zinc we have observed in our current breeding material larger genetic variances and smaller genotype by environment interactions compared to the observations shown here from this genebank material study.

carotene fwb = 15 ppm β-carotene fwb. If the root has a dry matter content of 27%, then 15 ppm β-carotene fwb X (1/.27)= 55.6 ppm dwb.

Table 1. 2. Estimation of variance component due to genotypes (σG2).
Genotype by environment interactions ($\sigma_{G\times E}^2$) and the plot error (σ_ε^2) from 1146 CIP genebank clones evaluated at three locations: (i) arid irrigated, (ii) humid tropic lowland, and (iii) mineral stress humid tropic lowland with two plot replications per site (95% confidence limits of parameter estimates in brackets).

	σ_G^2	$\sigma_{G\times E}^2$	σ_ε^2	**Ratio** $\sigma_G^2 : \sigma_{G\times E}^2 : \sigma_\varepsilon^2$
Yield (t^2 / ha)	36.2	39.4	64.2	1 : 1.1 : 1.8
	(20.6 - 43.6)	(33.8 – 46.9)	(60.0 - 68.9)	
Dry matter ($\%^2$)	14.8	5.7	5.7	1 : 0.4 : 0.4
	(13.3 - 16.6)	(5.0 – 6.5)	(5.3 - 6.1)	
Protein ($\%^2$ DM†)	0.21	0.67	0.73	1 : 3.2 : 3.5
	(0.16 - 0.30)	(0.59 – 0.78)	(0.68 - 0.79)	
Starch ($\%^2$ DM†)	21.5	3.2	16.3	1 : 0.2 : 0.8
	(19.3 – 24.2)	(2.3 – 4.9)	(15.2 – 17.5)	
Sucrose ($\%^2$ DM†)	5.6	2.1	7.4	1 : 0.4 : 1.3
	(4.9 – 6.5)	(1.6 – 2.8)	(6.9 – 7.9)	
Total Sugar (%DM†)	17.0	6.0	9.0	1 : 0.4 : 0.5
	(15.2 – 19.2)	5.2 - 7.1	8.4 – 9.7	
-carotene	6327	2462	1421	1 : 0.4 : 0.2
(ppm^2 DM†)	(5681 – 7091)	2224 – 2740	1323 – 1529	
Calcium (ppm^2 DM†)	74001	95990	157303	1 : 1.3 : 2.1
	(61485-90791)	(82657–112849	(147021–168708)	
Magnesium	143005	9880	17638	1 : 0.06 : 0.1
(ppm^2 DM†)	(12351–16764)	(8360 – 11858)	(16451 – 18960)	
Iron (ppm^2 DM†)	2.33	3.46	3.85	1 : 1.7 : 2.2
	(1.92 – 2.87)	3.0 – 3.97	3.59 – 4.15	
Zinc (ppm^2 DM†)	0.8	1.37	1.72	1 : 1.7 : 2.2
	(0.62 – 0.97)	(1.20 – 1.59)	(1.60 – 1.85)	

The improvement of one trait is not independent from other traits – genetic correlations exist[4] (Table 1.3). There is a strong genetic correlation between storage root dry matter and starch; and both of these traits have a strong negative genetic correlation to sugars. Given the magnitude of genetic variation for dry matter, starch, sucrose and total sugars, and the genetic correlation pattern of these traits, rapid breeding progress can be expected in selecting for non-sweet sweetpotato populations. With two recurrent selection cycles many clones should be available which are non-sweet (< 5 ppm total sugar content on dry matter basis). However, multi-trait index selection should be used and optimized to simultaneously select for desired levels of dry matter, starch, and sugars.

[4] These correlations are estimates based on means of phenotypic correlations across environments and replications; for details on how these are determined see Hill *et al.*, 1998.

Table 1.3. Estimations of genetic correlations in the sweetpotato germplasm.
Evaluated in 1146 CIP genebank clones across three environments (see Tables 1.1 and 1.2) and two plot replications; YLD storage root yield, DM storage root dry matter, PRO = protein, STA = Starch, SUC = sucrose, STOT = sugars total, BC = -carotene, Fe = iron, Zn = zinc, Ca = calcium, and Mg = magnesium storage root concentrations.

	YLD	**DM**	**PRO**	**STA**	**SUC**	**STOT**	**BC**	**Fe**	**Zn**	**Ca**
DM	-.253									
PRO	-.180	-.073								
STA	-.119	**0.748**	-.241							
SUC	0.033	-.450	0.141	**-.559**						
STOT	0.131	-.670	0.094	**-.771**	**0.674**					
BC	0.018	**-.424**	0.168	-.574	0.475	0.562				
Fe	-.150	-.286	0.813	-.433	0.335	0.346	**0.295**			
Zn	-.210	-.219	0.801	-.355	0.286	0.233	**0.275**	**0.860**		
Ca	0.014	-.331	0.262	-.384	0.286	0.367	**0.368**	0.409	0.424	
Mg	-.004	-.297	0.460	-.404	0.388	0.406	**0.311**	0.627	0.595	0.753

The breeding challenge is different in population improvement for high dry matter OFSPs, because a strong negative genetic correlation is observed between storage root dry matter and β-carotene concentrations (Table 1.4). Breeders in SSA are acutely aware that high dry matter, β-carotene-rich materials are hard to find – that is the consequence of the negative genetic correlation between these two traits. Practically, this means that breeding for high dry matter OFSPs requires intensive recombination, i.e. a large number of parents and many cross combinations, to generate the favorable alleles which demonstrate both high storage root dry matter and high β-carotene. Hence, the development of large high dry matter OFSP breeding populations requires more time than the development of non-sweet sweetpotato populations. We estimate that the former will require four recurrent selection cycles, of which one to two of these cycles (depending on the country) have already been carried out during the past few years.

A further challenge for producing micronutrient-rich OFSP is the enhancement of mineral concentrations in OFSP. Fortunately, the storage root β-carotene concentration is genetically positively correlated with calcium, magnesium, iron and zinc storage root concentrations. Moreover, using Near Infrared Technology (NIR) these traits can be determined simultaneously with β-carotene content. The additional cost is minor and this information should be used in selection decisions to enhance mineral contents in OFSP.

Table 1.4. Estimations of genetic correlations in OFSP germplasm.
Evaluated in selected clones with more than 40ppm -carotene in the CIP genebank (N = 1146); YLD storage root yield, DM storage root dry matter, PRO = protein, BC = -carotene, Fe = iron, Zn = zinc, Ca = calcium, and Mg = magnesium storage root concentrations.

	YLD	**DM**	**PRO**	**BC**	**Fe**	**Zn**	**Ca**
DM	-.181						
PRO	-.177	-.216					
BC	0.027	**-.578**	0.300				
Fe	-.152	-.475	0.824	**0.425**			
Zn	-.196	-.405	0.809	**0.421**	**0.897**		
Ca	-.033	-.361	0.368	**0.359**	0.523	0.537	
Mg	-.069	-.410	0.567	**0.366**	0.738	0.710	0.773

Using model calculations, we predict breeding progress of about 3 – 5 ppm iron and 2 – 3 ppm zinc per selection cycle; within four cycles we can reach minimum improved levels of 15 ppm iron and 8 ppm zinc. However, these model calculations do not consider the recombination effect from one generation to the next. Given the large amount of heterozygosity in sweetpotato, the potential for greater progress exists beyond these model estimates. So-called "index selection" is highly recommended for OFSP population improvement, because undesired responses to selection are inevitable due to the strong negative genetic correlation between β-carotene and storage root dry matter concentrations. The currently best index selection procedure for this task is the Pesek Baker index (Pesek and Baker, 1969). With this selection procedure it might be possible to develop many high dry matter OFSPs with high mineral density.

Clearly, model calculations for the allocation of breeding resources are a very helpful tool to demonstrate to breeders "what happens if …." An example is the allocation of breeding resources in a two stage selection (Grüneberg *et al.*, 2004); another urgently needed model investigation is the determination for the optimum ratio between number of cross combinations and number of clones to be raised per cross combination. It is important that sweetpotato breeders throughout SSA become familiarized with the results of model calculations for optimally allocating their resources.

Finally, we need to consider cases where there is no or insufficient genetic variation to achieve our targets through conventional breeding. This should be discussed for three sweetpotato traits: sweetpotato weevil tolerance and iron and zinc concentration of storage roots. It is nearly certain that a significant genetic variation can be observed in sweetpotato (Hahn and Leuschner, 1981) as we have seen above for iron and zinc concentrations of storage roots. The question we need to answer is: is this genetic variation sufficient to achieve significant impact? In the case of iron and zinc, the answer depends on the bioavailability of these minerals once ingested and this is discussed in the Challenge theme paper on OFSP. If the answer to our question is no, there is not sufficient genetic variation in sweetpotato, biotechnology can be useful tool for breeding to incorporate new variation into the sweetpotato breeding gene pool. This can be achieved by the expressing the *Bacillus thuringiensis* (Bt) toxin in sweetpotato in the case of weevil tolerance. This issue is a separate theme paper and will not be discussed here, but suffice to say that research to date in this area appears promising.

For enhancement of iron, there is potential to exploit the ferritin gene (*pfe*). This gene has been isolated from *Phaseolus vulgaris* and used to increase iron in rice grains 2 to 3.7 fold (Lucca *et al.*, 2001; Vasconcelos *et al.*, 2003). Another reference indicates that the ferritin gene (*pfe*) isolated from *Phaseolus limensis* under control of glutelin gene promoter could lead to a 64% increase in rice grains (Liu *et al.*, 2004). Sweetpotato ferritin could be easily isolated, exploiting the available sequence information. Constitutive and storage root-specific promoters exist for sweetpotato that can maximize transgene expression and protein accumulation. Whether the observed iron accumulation in the rice endosperm will be similar or not to that of a sweetpotato root remains to be demonstrated. As revealed in transgenic rice with high and low content of ferritin, optimum iron accumulation may be limited by barriers to uptake and at the transport level (Le *et al.*, 2005). Increase of iron uptake and transport factors may add to the level obtained with a ferritin accumulation in transgenic roots. The expression of nicotianamine aminotransferase genes in rice enhanced iron uptake as well as zinc (Takahashi, 2003). However, impact of enhanced uptake of other minerals has to be carefully monitored to avoid disorders on internal transports and increased accumulation of undesirable chemicals.

In considering any non-conventional breeding approach, there are many non-technical issues that must be considered in the SSA context, due to controversy surrounding the use of genetically-modified organisms and the dearth of bio-safety policies in most African countries. This approach should only be considered when conventional approaches to addressing critical traits have clearly not worked, as is the case for sweetpotato weevil resistance. At the present time, there may be substantial risk to gaining widespread acceptance of OFSP if OFSP varietal development is associated with non-conventional breeding efforts.

Population improvement

As previously mentioned, sweetpotato breeders distinguish between short-term population improvement and medium- to long-term population improvement. Both aim to improve the population mean of important traits. The difference is that the long-term population improvement is focusing on the long term breeding progress, which includes new genotypes clearly out of range of the normal distribution. The latter is defined as a mean at least ± 2 standard deviations from the population mean of the initial breeding population - such as the desired genotypes for iron and zinc storage root concentrations – and developed in the context of selecting simultaneously for many sweetpotato traits and attributes. A "classic" example of a practically non-existent genotype outside the range of existing multivariate normal distributions is a variety that combines high dry matter (> 30%) and very high β-carotene (> 250 ppm on dry matter basis). Such genotypes can only be generated in several cycles of recombination and selection steps. But evidence from long-term maize experiments has clearly demonstrated that such "unbelievable" genotypes can be generated. In contrast, short-term population improvement programs focus on the "near" (< 5 years) future and need to generate sufficient genetic variation around a high population mean. In many respects, population improvement is the most difficult part of any sweetpotato (or any clonally propagated crop) breeding program. Sweetpotato is a hexaploid and each sweetpotato clone is a hybrid. This heterosis contributes tremendously to clone performance in sweetpotato. A cross to generate a genetic variation around a high population mean is recombining two F1's, which are hexaploid and highly heterozygous. Nearly every maize and wheat breeder in the world will say never cross two F1's, as the segregating genetic variance and the population mean derived for such a cross is rather unpredictable. Long-term population selection theory comprising several cycles of recombination and selection stages is very limited[5]. Certainly the matrix of genetic correlations is very critical, because negative genetic correlations can lead to undesired and unexpected genetic responses to selection which can result in whole breeding populations being useless for variety development. Such a critical negative genetic correlation exists in sweetpotato. This is the strong negative genetic correlation between β-carotene and storage root dry matter content. Marker studies have demonstrated that quantitative trait loci (QTLs) for β-carotene and storage root dry matter content can occur in the same linkage groups and occasionally are closely associated with the same genetic marker – which indicates the existence of *pleiotropy*, that is, one gene determining two different traits.

Studies at CIP have shown that there is exploitable heterosis in sweetpotato. So far the largest observed heterosis in an experiment using 4 x 12 parents was 50% above the best parent of well-performing parents. The genetic correlation between parent and off-spring clones was about 0.6

[5] That is, models for the recombination of good attributes (which appear in different genotypes before recombination) into one genotype is still a challenge in population selection theory.

in controlled crossings, which is low compared to parent and off-spring correlations in wheat. The correlation between parent and off-spring clones should be about 0.6 divided by two. These studies should be now carried out in two applied breeding populations to investigate the selection efficiency of a reciprocal recurrent selection scheme. This is a scheme often applied in maize breeding but not in sweetpotato breeding. We do not know much about quantitative genetics and selection theory in autopolyploids aimed at population improvement, even if only one trait is considered. This is reflected by the fact that the first textbook detailing research in this field of selection theory was only published in recent years (Gallais, 2003). In cases where the breeder has no, or only very low, prior knowledge on the value of cross combination, as is the case with sweetpotato, mathematical proof can be given that it is required to make as many cross combinations as can be afforded by the breeding capacity and to minimize the number of seeds developed for each cross combination. For this reason CIP Lima is conducting 6 x 300 cross combinations with the target of 20 seeds per cross combination, of which about 6 x 100 cross combinations are directly discarded due to very low seed set (< 5 seeds per cross combination). The breeding capacity required to conduct such crossings is two well-skilled technicians. Moreover, the ratio between number of cross combinations and number of seeds can be optimized by model calculations, which merits further research in sweetpotato.

A major challenge in population improvement of sweetpotato is to compare polycrosses to controlled crosses. Theoretically polycrosses must be inferior to controlled crosses, but much more seed and genotypes, respectively, can be developed so that the selection intensity in polycross breeding programs is usually higher than in controlled cross breeding programs. However, in cases where in both breeding methods the selection intensity is already high, this effect on the selection efficiency is small. Of much greater relevance is that in polycrosses only half of the genetic variance can be exploited than is the case in controlled cross breeding programs. Moreover, when dealing with polycrosses, one must take the unbalanced seed set and pollination into account – this is complex. Furthermore, when well-performing crosses are identified from polycrosses, this work can not be repeated on a large scale, as would be the case with material generated from controlled crosses. Extending the use of theoretical studies, utilizing them for designing breeding strategies, and evaluating the results based on those strategies, would significantly increase the sweetpotato breeding progress in Africa.

For sweetpotato population improvement we know that the number of cross combinations must be maximized subject to the resources available in the breeding program. Most breeding programs in Africa make few cross combinations (few number of parents). A useful "rule of thumb" is that only one out of 40 cross combinations in sweetpotato is an excellent one. To summarize, in developing sweetpotato breeding programs for SSA, consideration needs to be given to:

- the number of parents used;
- the numbers of seeds and genotypes, respectively, raised for the first selection step, the checking of breeding objectives according to farmer needs by assuring farmer participatory selection is part of early breeding stages; and
- the use of one low or hot spot stress environment together with normal on-station environment as important factors to increase the breeding efficiency in African breeding programs.

The authors recognize that the modification of any breeding program is a very sensitive issue. Other factors such as speeding up the number of recurrent selection cycles, improved multi-trait selection in population improvement in the case of negative genetic correlations, and an accelerated variety development program combining four selection stages for variety development into three seasons, will not be an approach that every breeding program in SSA can or should undertake, given their resource base. Clearly, further research and more interactive design of breeding programs on a country-specific basis would be highly desirable.

Future areas of work for consideration:

1) Defining a critical capacity of genotypes to be tested at the first breeding stage for polycross and controlled cross breeding program. Shall these two breeding programs be kept separate and treated as two breeding programs carried out by the same institution?
2) Defining procedures for farmer participatory selection in an early breeding stage of the breeding programs.
3) Discussion and decision on the incorporation of a low input or hot spot stress selection environment at the early stages of a breeding program.
4) Defining the critical capacity for the number of parents used in population improvement for polycross and controlled cross breeding programs.
5) Discussion and decision to analyze the value of cross combinations (family evaluation) to repeat well performing cross combinations on large scale.
6) Model calculations for the comparison of the efficiency of polycross versus controlled cross breeding programs and estimations of the imbalance introduced by insufficient seed set in polycrosses and controlled cross breeding programs.
7) Potential collaboration of CIP and NARS breeding programs on regional platforms to increase breeding progress for discussion includes:

a. Implementation of near infrared spectroscopy (NIRS) technology on regional platforms to increase selection efficiency for non visible quality traits and to ensure that NARS breeding programs participate in the selection progress for non-visible quality traits by restricting dissemination of parental material to those which have clearly been improved for non visible quality traits.
b. Implementation of multi-trait selection methods that avoid undesired responses to selection or trade off effects in long-term population improvement.
c. Stepwise reduction of the time needed for a recurrent selection cycle to increase the medium to long-term selection efficiency and breeding progress.
d. Open the option to implement a reciprocal recurrent selection by generating two breeding populations which are kept separate; further research on the possibility of exploiting heterosis in sweetpotato breeding programs and design breeding methods to implement this in practical breeding programs.

Challenge 1.3. Lack of sweetpotato virus disease tolerance

Current knowledge

The **humid tropical low and mid-elevation regions of East Africa** (0 to 1200 m.a.s.l.) with only very short dry seasons, if any (Uganda, Rwanda, Burundi, Dem. Rep. Congo, parts of Kenya and Tanzania—the Lake Victoria Crescent) have high SPVD pressure, which is extreme in regions where sweetpotato is extensively cultivated. SPVD occurs after infection of two viruses: the sweetpotato feathery mottle virus (SPFMV) and the sweetpotato chlorotic stunt virus (SPCSV). SPCSV is the more problematic component of SPVD, because yield losses due to SPFMV - without SPCSV infection – are relatively low and SPFMV resistance of sweetpotato breaks down after the plant is infected by SPCSV. SPCSV resistance has been found in germplasm screening programs and the resistance appears to be conferred by a recessive allele that occurs in low frequency in the sweetpotato gene pool. Field resistance to SPVD has been obtained in East Africa by screening large numbers of sweetpotato genotypes from mainly local germplasm, and open-pollinated seed and limited controlled cross progenies, evaluated on-station and on-farm. However, this resistance still needs to be proven in extensive controlled artificial inoculation with SPVD and field tests under high SPVD pressure locations in Africa. It is nearly certain that new sweetpotato varieties with resistance to SPVD will result in significantly higher yields and yield stability in East- and Central Africa, at least for a period of 5 to 8 years. After this period new strains of the sweetpotato chlorotic stunt virus gene pool are expected to emerge.

Future areas of work for consideration (order listing does not imply any prioritization):

1) Defining the critical capacity for the number of parents used in population improvement for polycross and controlled cross breeding programs.
2) Defining critical capacity for a NARS sweetpotato breeding program. Defining critical capacity of genotypes to be tested at the first breeding stage for polycross and controlled cross breeding program.
3) Discussion and defining the percentage of breeding capacity that should be allocated to white-fleshed and OFSP SPVD resistance and high dry matter in East and Central Africa.
4) Discussions and decisions on the number of parents to be used for white-fleshed and OFSP (in combination with other desirable traits) breeding program and the cross design to be used for their recombination.
5) Model calculations for the comparison of the efficiency of polycross versus controlled cross breeding programs and estimations of the imbalance introduced by insufficient seed set in polycrosses and controlled cross breeding programs.
6) Discussion and decision to analyze the value of cross combinations (family evaluation) to repeat well performing cross combinations on a large scale.
7) Defining clear breeding objectives on the basis of regional needs and capacities for each agro-ecological zone and milestones and breeding progress, respectively, to be reached in products and varieties, respectively.
8) Defining bottlenecks and how to address them in NARS breeding programs.
9) Defining procedures for farmer participatory breeding and selection in breeding programs.
10) Agreement to evaluate early breeding stage at two locations, of which one location is an off station high SPVD pressure location in which farmer participatory selection is used to discard clones.

Potential priorities identified during field visits for a CIP and NARS breeding program at a regional platform in East and Central Africa (ECA) to develop product / varieties for ECA (to be discussed):

1) Implementing NIRS technology to improve β-carotene, and mineral storage root concentrations in breeding populations at NACRRI;
2) Improving skills for sweetpotato in-vitro plantlet dissemination to NARS partners within Eastern Africa.
3) Developing procedures for later breeding stages to determine genotypic differences in market quality attributes of OFSP for home consumption and processing, and making

these available to NARS partners (each procedure should allow to evaluate 20 genotypes and a total samples size of 80 (two locations, two replications).

4) Discussion and defining the percentage of breeding capacity that should be allocated to OFSP SPVD and Alternaria resistance in combination with other desirable traits (high dry matter, dual purpose, processing quality, in ground storage) in East and Central Africa.
5) Agreement to evaluate early breeding stage at two locations of which one location is an off station high SPVD pressure location in which farmer participatory selection is used to discard clones (Determine population size at each location).
6) Clarification to determine the value of a cross combination and if elite crosses should be repeated on a large scale (if yes, the size of an elite cross has to be defined).

Challenge 1.4. Lack of varieties adapted to the cold tropical highlands

Current knowledge

Sweetpotato originated in semi-humid regions of Central America, most likely in or close to Nicaragua. However, it rapidly came into cultivation along the arid Pacific coast of South America with relatively cool and hot seasons within the year. The crop crossed the Pacific in pre-Colombian times and became a staple in the relatively cool tropical highlands of Papua New Guinea and adjacent Irian Jaya / Indonesia, where it developed a secondary center of genetic diversity. The crop reached the tropical highlands of Eastern Africa most likely in the mid-19th century. Today sweetpotato is grown in African highlands up to 2200 m.a.s.l. with night temperatures close to 5°C. It is not surprising that the most successful sweetpotato variety in the Arusha highland region of Tanzania originated from Papua New Guinea. Usually sweetpotato responds in cold tropical highlands by extensive upper biomass production and reduced storage root production. Within the sweetpotato breeding program at CIP-Lima, many genotypes have been observed that are yielding storage roots in the cold tropical highland environment at 2700 m.a.s.l. (close to Huánuco) (this location is usually used as an multiplication side with no virus pressure to obtain virus free planting material). In Africa three NARS are conducting sweetpotato breeding or variety selection in cold highlands, namely ISAR in Rubona / Rwanda, KARI in Nakuru / Kenya and HortiTenguru in Arusha / Tanzania. These breeding programs are relatively small and very new or are working only on variety selection with periodically introduced material. Given that the tropical highlands of Africa are densely populated in rural areas and sweetpotato is an important component of the diet, investment in breeding is warranted. Also, some of these areas have close access to larger urban markets, so quality traits for urban consumers will be relevant selection criteria. Soil erosion and zero grazing commitments are also important issues in these highland regions.

Future areas of work for consideration:

1) Identification of new material for Africa from other highland regions of the world and introduction of this material to broaden the genetic basis of African sweetpotato highland material.
2) Increasing the crossing capacity in NARS breeding programs for highland regions; critical mass could be 240 cross combinations to obtain at least 160 families with about 8 to 20 clones per family.
3) Defining lowest acceptable values for storage root and upper biomass production of dual purpose sweetpotatoes.
4) Implementing the accelerated breeding scheme with a test capacity of at least 2500 clones at the early breeding stages and discarding all clones which do not meet the lowest acceptable root formation and biomass formation according to one stress environment for Alternaria by farmer participatory selection.
5) At least four products and varieties, respectively, clearly superior in dual purpose use and acceptable to farmer needs by farmer participatory variety selection in later stages (year 4) of the breeding program.
6) One cycle of pre-breeding in tropical highlands with selection of medium pro-vitamin A contents and intense selection for minerals and value added product quality (first priority if OFSP is to be used as a substitute for wheat flour in bakery products and composite flours).
7) Incorporation of the pre-breeding population into the locally selected material by introducing seed (25,000 seeds) of the second cycle of recurrent selection (seed derived from the “best” of the first cycle), selection for local acceptance among introduced seed and genotypes, respectively, and recombination of selected clones (60 clones) with the best local material.
8) At least 2500 breeding clones (or one breeding population for further population improvement) with improved dual purpose use, quality is sufficient to make a product with a higher value e.g. bread, with elevated mineral concentrations and medium pro-vitamin A concentrations.
9) Repeat the development of the best five families by recombination of their parents on large scale (1500 seeds per family) for further variety development.

Challenge 1.5. Lack of tolerant varieties

Current knowledge

Southern Africa is defined here as including: Angola, Botswana, Lesotho, Namibia, Malawi, Mozambique, Madagascar, Malawi, South Africa, Swaziland, Zambia and Zimbabwe. The region is very diverse, ranging from forest and grasslands to deserts, with both low-lying coastal areas, and mountains. For two farming systems sweetpotato is attractive: (i) Root Crop Farming System (livelihoods depending on: cassava, legumes and off farm work) and (ii) Cereal-Root Crop Mixed Systems (Livelihoods depending on: maize, cassava, legumes, cattle). These are the major farming systems in Angola, Malawi, Mozambique, Swaziland, Zambia and Madagascar (Dixon *et al*., 2001). Sweetpotato fits well into these systems especially in rotation with a legume. However, sweetpotato is not a primary staple in the region (except in parts of Malawi), but is widely grown as a secondary staple on a small scale. The importance of sweetpotato has been increasing over the past decade in Southern Africa for the following reasons: (i) its high nutritional value, (ii) its high energy output per unit land (iii) its ability to produce on low fertility soils, (iv) the potential to be used in small-scale and industrial food processing, and (v) recently due to new breeding activities that combine these characteristics with improved adaptation to drought stress. Owing to climatic change it is expected that drought stress will increase significantly in this region of the world (Hoerling *et al*., 2006). It should be noted that in some regions sweetpotato has reached an importance nearly comparable to maize and cassava (e.g. in 2002 Malawi produced 1.7 and 0.09 million tons of maize and rice, respectively, compared to 1.7 and 1.5 million tons of cassava and sweetpotato, respectively; the estimated production increase for cassava and sweetpotato over the past four years is 15% and 36%, respectively). This trend is expected to continue because the region has a medium risk of frequent exposure to floods due to cyclones and a medium to high risk of frequent exposure to drought. These weather disasters have repeatedly affected the dominant staple crop in the region - maize. Thus, many governments have adopted crop diversification strategies designed to reduce maize dependence. This is reflected by the recent establishment of several small sweetpotato breeding groups at FIFAMANOR (Madagascar), Mansa Technology Assessment Site (Zambia) and DARS (Malawi). The breeding program Agricultural Research Council- Roodeplat (South Africa) is the longest running in the region. In addition, the CIP/IIAM breeding program in Mozambique is relatively young, having been established in 2006 with Rockefeller Foundation support. It is expected that new sweetpotato varieties, improved for yield and quality with specific adaptation to the drought environments of Southern Africa, will contribute to stabilizing the food and nutrition security situation in the region, as it has done in Asia, where it has long contributed as a food security crop when typhoons demolish grain crops.

Most likely owing to the early cultivation centers (Central and the arid Pacific coast of South America) a strong drought and salinity tolerance evolved in the sweetpotato. Drought resistance is most frequently a combination of drought escape, avoidance and tolerance (Blum, 1988). There are many reports describing drought stress resistant varieties (Anselmo *et al.*, 1998; Chávez *et al.*, 2000; Ding *et al.*, 1997; Hou *et al.*, 1999; Wang *et al.*, 2003; Yang *et al.*, 1999). To our knowledge, all studies on drought resistance in sweetpotato have tackled drought adaptation by evaluating total biomass or storage root harvest under drought stress conditions. This is not sufficient. It is very important that breeding programs in Southern Africa (the dry season varies extremely in time and intensity) evaluate adaptation to drought environments considering both root yield and vine survival, the latter broadly defined as the availability of planting material at the beginning of the next rainy season. Farmers are very reluctant to permanently adopt varieties that produce adequate quantities of roots under drought stress if they lack good vine survival. An example is the OFSP variety Resisto that has high β-carotene values and is intensively used in Mozambique because of its good taste and high marketability.

The genetic basis of adaptation of sweetpotato to drought stress is largely unknown. Sweetpotato roots can penetrate to about 2 m in the soil and absorb water from deeper soil layers (Bouwkamp, 1985). Differences in response of genotypes in irrigated and non-irrigated experiments appeared to be correlated with the ability for deep rooting and extensive development of the root system in the early stage (Yen *et al.*, 1964). Relative water content (Chowdhury *et al.*, 1993) and water use efficiency appear (Kelm *et al.*, 2000) to be further important traits adapting sweetpotato to drought. Other traits which are correlated with drought resistance are the relative contents of free amino acids, soluble sugars, ATP and chlorophyll a/b ratio, which indicate the participation of osmotic adjustment with drought resistance in sweetpotato (Zhang *et al.*, 2003; Zhang *et al.*, 2004). However, complicated crossover interactions exist for sweetpotato between irrigated and not irrigated field trials (Andrade *et al.*, unpublished). In other words, what is good under drought stress conditions is not good under humid conditions and vice versa. Hence, breeding for drought adaptation needs its own breeding program and its own long-term population improvement. Furthermore, it is essential to record vine survival and select for this trait. The evaluation of vine survival is laborious because plants or parts of the experimental plot must be maintained quite long into the dry season after harvesting the major plot area. CIP and NARS researchers recently jointly developed breeding procedures for this on the basis of an extended plot size (an area of about 20% of each plot is maintained after harvest). There are no variance component and heritability estimates available for vine survival, but we assume that heritability for vine survival is very high, because extreme differences are easily observed among genotypes. If this is true, breeding populations can be rapidly transformed into populations with good vine survival attributes. However, this requires that the extended plot size principle is applied to the early breeding stages (e.g. instead of 1 m row plot in early stages, 1.5 m row plots have to be planted).

The challenge for breeding for high dry matter OFSP varieties is not as great in Southern Africa when compared to East Africa. The acceptable level of storage root dry matter is lower than in East Africa (about 27% versus 30% in Southern and East Africa, respectively). Nationally representative sample survey data in Mozambique estimated that already 20% of the total sweetpotato production is OFSP. Moreover, considerable work has demonstrated that OFSP can be processed into a variety of products (juice, bread, etc.) acceptable to consumers. For these reasons, and others described in the theme paper on OFSP, breeding resources in Southern Africa should be concentrated on OFSP breeding, including the breeding for improved mineral contents in OFSP. However, this requires investments into a strong quality breeding at CIP-Mozambique and IIAM, respectively, on the basis of NIRS technology (in a first step CIP allocated a dry freezer with a capacity of 30 kg of samples per week at IIAM). CIP- Mozambique / IIAM-Maputo could serve as a platform for NARS breeding programs in Southern Africa (Malawi, Zambia, Madagascar, Swaziland, Angola, and South Africa; only South Africa has a relatively well financed sweetpotato program).

NARS partners should debate whether to allocate at least 80% of the breeding capacity in Southern Africa to OFSP breeding and if the principal goal should be to produce drought adapted OFSP, with high vine survival and moderate to high storage root dry matter. There are at least 60 OFSP clones available in and for the region of Southern Africa, which should undergo intensive recombination. The recombination intensity would need to be increased among these OFSP clones. To ensure a more balanced recombination, breeders in Southern Africa could carry out controlled crosses; for example, a factorial cross design (6 male partners x >54 female parents) with a required test capacity in early breeding stages of 6000 genotypes. This would have the advantage of being able to repeat the best cross combinations (determined on basis of the family mean of a cross combination) on a large scale. To repeat five of these so- called elite crosses with at least 1000 seeds per cross combination would require an estimated test capacity of 5000 to 8000 genotypes. Each NARS partner could evaluate two populations --one with about 6000 genotypes and one with about 5000 to 8000 genotypes in separate years. Provided that these breeding populations are evaluated in the early stage (with active farmer participation) for storage root size, shape and form, storage root dry matter, β-carotene content (using color charts), and vine survival, it is nearly certain that within five years each breeding program could develop at set of at least five OFSP varieties adapted to farmer needs in Southern Africa.

The platform in Mozambique could potentially supply within five years parental material to NARS partners with similar attributes as developed by NARS partners (high storage root yields under drought stress, high vine survival), deep orange-fleshed (about 200 ppm β-carotene on dry matter basis and at least 28% storage root dry matter) that is additionally improved in iron and zinc storage root concentrations. One achievable target could be OFSP parental material with at least 28 ppm iron and 15 ppm zinc on storage root dry matter basis; mineral target levels will require further discussion. The work at the platform in Mozambique could also have spillover effects to other drought prone regions in the world e.g. those in South West and Central Asia (SWCA). Evidence is accumulating that Southern Africa, SWCA regions and the arid Pacific coast of South America represent very similar agro-ecological zones regarding potential sweetpotato performance (e.g. varieties like the OFSP Jonathan, a Peruvian landrace, has been adopted widely in all these three regions of the world). CIP Lima has already identified 50 drought tolerant OFSP clones in a germplasm evaluation of 1300 clones (no breeding clone included) that already have iron and zinc concentrations of 30 ppm and 20 ppm, respectively (Table 1.5).

Table 1.5. Selected OFSP (n=50) out of 1300 CIP germplasm clones evaluated for drought resistance and nutritional quality.

	Mean	Min	Max
Yield (t / ha)	10.2	3.2	34.8
Dry matter (%)	27.6	19.9	36.3
-carotene (ppm DM†)	224	80	542
Calcium (ppm DM†)	1996	1002	3146
Magnesium (ppm DM†)	874	424	1351
Iron (ppm DM†)	17.2	12.1	30.3
Zinc (ppm DM†)	9.1	5.7	17.1

† storage root dry matter basis.

Note: CIP-Mozambique and IIAM will continue to conduct variety development (promising and advanced breeding clone testing) for Mozambique and have the potential to serve - via in-vitro laboratory facilities at IIAM - the region of Southern Africa in germplasm dissemination and exchange.

It would also be beneficial if fast screening procedures could be developed to be able to screen a batch of 20 advanced breeding clones within a few days for market quality attributes of OFSP needed for processing into distinct products such as juice, bread, chips etc. from new varieties. Working groups at CIP-Peru, CIP-Mozambique and IIAM have already demonstrated that some products are acceptable to consumers and that there are distinct differences in the suitability of genotypes for the different product. It would add value if new OFSP varieties could be released with clear information concerning their potential best uses as processed products. This would necessitate developing procedures to evaluate these attributes and ensure that NARS breeding programs are empowered to utilize them as part of their evaluation of advanced breeding material at the later breeding stages.

Future areas of work for consideration:
Priorities NARS breeding programs to develop products / varieties for Southern Africa (to be discussed):

1) Discussion and defining the percentage of breeding capacity that should be allocated to OFSP drought adaptation breeding in Southern Africa. Discussion and decisions about the number of controlled crosses versus polycrosses is appropriate for a given program;
2) Discussions and decisions on the number of parents to be used for the OFSP breeding program and the cross design to be used for their recombination.
3) Agreement to evaluate early breeding stage at two locations of which one location is an off-station drought stress location in which farmer participatory selection is used to discard clones (population size about 6000 clones x 2 locations).
4) Agreement to evaluate the vine survival (availability of planting material) on the basis of extended plot size (suggestion 1.5 m row plots in early breeding stages).
5) Determination of the value of a cross combination and whether elite crosses should be repeated on a large scale (if yes, the size of an elite cross has to be defined).

Discussion and consensus on whether elite cross populations can be evaluated at two locations using a farmer participatory approach and on the basis of the extended plot size to determine vine survival within less than 5 years.

Priorities CIP and NARS breeding program at the regional platform for Southern Africa to develop product / varieties (to be discussed):

1) Implementing NIRS technology to improve β-carotene, and mineral storage root concentrations in breeding populations at the regional platform in Mozambique;
2) Improving skills for sweetpotato in-vitro plantlet dissemination by NARS partners within Southern Africa.
3) Increasing the capacity for controlled crosses to 7 x 200 cross combinations (by using the population ZapalloSPK-Tanzania (available at CIP Mozambique), which has recently been developed and improved by one recurrent selection cycle for dry matter, β-carotene, iron and zinc storage root concentrations) – target 40 seeds per cross combination.

4) Maintaining and further recombination of the local population "Resisto-Jewel", which has been developed at CIP-Mozambique and IIAM during the years 2006 and 2007 – target 40 seeds per cross combination.
5) Multi-trait selection based on new tools for population improvement (software) to be developed by CIP-headquarters (see Challenge 2) for drought stress yield, vine survival, storage root dry mater, β-carotene, iron and zinc concentrations in the population "Resisto" and ZapalloSPK on the basis of 16,000 genotypes for each population evaluated at two locations.
6) Providing NARS partners in Southern Africa with the top 10 clones of each population (Resisto and ZapalloSPK) to be used as parents by NARS partners to elevated iron and zinc in their breeding populations.
7) Developing procedures for later breeding stages to determine genotypic differences in market quality attributes of OFSP for processing and making these available to NARS partners (each procedure should allow evaluation of 20 genotypes and a total samples size of 80 (two locations, two replications).

Challenge 1.6. Lack of non-sweet sweetpotato varieties

Current knowledge

West Africa is defined here as including: Benin, Burkina Faso, Cameroun, Cote d'Ivoire, Cape Verde, The Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone and Togo. The vast majority of the region consists of plains lying less than 300 meters above sea level. The northern section of West Africa is known as Sahel (150–500 mm of rainfall per year); the savannas (500 – 1000 mm of rainfall per year) form a belt (160 km to 240 km in width) between the Sahel and the southern coast; the southern coast region receives rainfalls of over 1000 mm per annum.

For two farming systems sweetpotato is attractive: Root Crop Systems (livelihoods depending on: yams, cassava, legumes and off-farm work) and the Cereal-Root Crop Mixed Systems (livelihoods depending on: maize, sorghum, millet, cassava, yams and cattle). These farming systems in which sweetpotato can play its greatest role, are major farming systems in all countries, except Mali, Mauritania, and Niger, in which the Agro-Pastoral Millet/Sorghum System (livelihoods depending on: sorghum, pearl millet, pulses, cattle, sheep, goats) is the major farming system (Dixon *et al*., 2001). Sweetpotato is often not considered an important crop in many countries in the region; however, production in Nigeria increased by nearly 200 000 tons each year over the past five years. While this is likely to be an over-estimate due to poor agricultural statistics, it also reflects demand for low-cost calories due to increasing population pressure. There is broad consensus among stakeholders in West Africa that one major reason for low sweetpotato consumption in some West African countries is due to sweetpotato not matching dominant regional taste preferences – the roots are too sweet and too low in dry matter compared to cassava, the dominant root and tuber crop. The Ghanaian national program is specifically selecting for non-sweet materials. Non-sweet sweetpotatoes have been developed in the United States and CIP has started a germplasm screening for this sweetpotato type on the basis of NIRS technology. A non-sweet sweetpotato type could potentially exhibit a major advantage over existing materials because it could be developed into a wide range of bland food products such as gari (small processed granules), which is eaten by millions of people in West Africa on a daily basis. Given the increasing land-constraint in West African farming systems sweetpotato has clear agronomic advantages over cassava due to its much shorter maturity period. An early maturing, non-sweet sweetpotato appropriate for processing could potentially transform the cost structure and diversity of staple food products in West Africa. The FAO estimations for sweetpotato storage root production in West Africa are given in Table 1.6.

Drought is, and has been, across human history, a major production constraint in the Northern regions of West Africa. This will not change, although modeling exercises suggest that the region will receive higher rainfall in the coming decades compared to the recent past (Hurrell *et al.*, 2005). There is a short and a long rainy season in many parts of West Africa. This rainfall pattern suits sweetpotato, as many potential clones fit into short crop duration requirements of 3-4 months. NARS partners in the region consider the weevil damage associated with periods of drought stress a greater problem than the drought stress itself, as it restricts the period where quality sweetpotato can be harvesting for sale. Sweetpotato weevils are in all regions and are a significant constraint in all areas with dry seasons lasting more than 3-4 months. We distinguish between *Cylas formicarius elegantulus*, which is observed in all parts of the tropics, *C. puncticollis* and *C. brunneus*, which are additionally observed in Africa, and *Euscepes postfasciatus*, which occurs so far only in the West Indies. It has been an objective to find weevil resistance for more than 50 years, but differences observed in the degree of weevil attack are likely driven by preference factors of the weevil. Farmers in Malawi believe that dense storage roots developed deep below the soil surface are less susceptible than less dense, moist-fleshed storage roots. Moreover, observations indicate that specific varieties (New Kawogo from Uganda, Santo Amaro from Brazil) are less affected by weevils due to chemical compounds in the root skin. This merits further investigation; as this compound is organic there is a very high probability that it would be possible to develop NIRS calibrations for it and to conduct fast-throughput screening in the sweetpotato germplasm to identify genotypes with similar attributes. However, the dominant opinion is that no effective weevil resistance exists. For this reason a transgenic approach by Bt genes has raised research interest for more than a decade.

Table 1.6. Sweetpotato production in West Africa.

	Annual in 1000 tones				
Country	**2001**	**2002**	**2003**	**2004**	**2005**
Benin	57.00	74.51	51.12	50.00	64.01
Burkina Faso	41.65	37.00	28.51	40.86	70.82
Cameroun	175.11	181.98	185.90	190.07	190.00
Cote d'Ivoire	43.00	43.00	43.00	44.33	45.18
Cape Verde	n.a	n.a	n.a	n.a	n.a
The Gambia	n.a	n.a	n.a	n.a	n.a
Ghana	90.00	90.00	90.00	92.83	94.62
Guinea	135.00	86.54	60.00	98.31	109.01
Guinea-Bissau	n.a	n.a	n.a	n.a	n.a
Liberia	18.00	18.00	19.00	19.03	19.3
Mali	n.a	n.a	n.a	n.a	n.a
Mauritania	n.a	n.a	n.a	n.a	n.a
Níger	29.45	44.80	44.80	42.92	42.67
Nigeria	2473.00	2631.00	2800.00	2996.00	3205.0
Senegal	41.89	41.89	26.85	26.49	27.81
Sierra Leone	25.00	25.45	25.50	25.50	26.00
Togo	1.35	5.45	1.43	0.43	2.40

Source: FAOSTAT 2007. n.a. = not available.

NARS partners in the region usually have no or only very small sweetpotato breeding programs, concentrated on adaptive testing of introduced varieties or evaluation of local landrace performance. An exception is CSRI at Kumasi in Ghana. The breeding capacity for sweetpotato breeding in Kumasi is similar to that found in ISAR in Rubona, Rwanda. The crossing block comprises 11 parents, seed production is about 5000 seeds from polycrosses; the capacity for preliminary and advanced yield trials is roughly between 20 and 40 entries which can be tested at three locations. However, CSRI has very strong biotechnology and in-vitro laboratory facilities. In cooperation with the Biotechnology Nuclear Agriculture Research Institute, 24000 in-vitro plantlets of the variety Beauregard were provided to farmers in South Ghana to produce roots for the export market in France. The capacity of the institute is the production of 200 000 plantlets annually. Such large capacities could service large scale private-public sector initiatives to disseminate adapted OFSP varieties in the region via NGO. With investments in NIRS technology, CSRI could become a breeding platform in West Africa that aims for long term population improvement for West African growing conditions. We feel that focusing completely on OFSP breeding in West Africa is risky. Moreover, there are no experiences to develop non-sweet OFSP varieties. One approach to consider is to allocate 50% of the breeding resources into the development of white or cream non-sweet sweetpotato and 50% into OFSP breeding adapted to West African growing conditions. In terms of population development this means that two populations must be developed. However, it appears that NARS germplasm collections are very small e.g. 150 accessions at CSRI, so that it might be difficult to find sufficient parental material to open a non-sweet sweetpotato recurrent selection gene pool. In contrast, the OFSP material is substantial due to larger seed introductions from NACRRI as part of the HarvestPlus program and there is sufficient adapted OFSP material to increase the number of parents and the number of cross combinations as needed. The critical capacity of both breeding programs (non-sweet sweetpotato and OFSP) should be 80 parents, 400 cross combinations (it must be kept in mind that about 1/3 of all cross combinations do not result in sufficient seed set in sweetpotato) and 6000 genotypes in the early breeding stages to be tested at least at two locations --one location with farmer participatory selection. In the case of the non-sweet sweetpotato breeding population, 5% of the existing germplasm at CIP has total sugar contents below 8% on dry matter basis (< 3% fresh matter basis). This material could be pre-bred for one cycle of recurrent selection for low sugar storage root concentrations and sent as seeds to NARS partners in the sub-region (Table 1.7). It should be noted that this pre-breeding strategy (gene pool ZapalloSPK) has been successful in broadening the OFSP breeding gene pool in Mozambique. However, we feel that pre-breeding and a germplasm screening in and for West Africa should be integrated in the development of the non-sweet sweetpotato breeding programs in West Africa.

Table 1.7. Selected non-sweet sweetpotato clones.
(n=50) out of 1146 CIP germplasm clones evaluated across three environments: (i) arid irrigated, (ii) humid tropic lowland, and (iii) mineral stress humid tropic lowland and two plot replications [plot size 10 plants].

	Mean	**Min**	**Max**
Yield (t / ha)	11.3	1.0	28.5
Dry matter (%)	40.3	34.7	44.8
Protein (% DM[†])	4.6	1.1	10.3
Starch (% DM[†])	65.2	39.3	75.6
Sucrose (% DM[†])	4.0	0	6.7
Total Sugar (%DM[†])	6.9	1.7	47.2
-carotene (ppm DM[†])	5	0	91
Calcium (ppm DM[†])	1058	185	1805
Magnesium (ppm DM[†])	545	320	874
Iron (ppm DM[†])	15.9	9	32.2
Zinc (ppm DM[†])	10.1	6.6	13.7

† storage root dry matter basis

Priorities for NARS breeding programs to develop products / varieties for West Africa (to be discussed):

1) Discussion and decisions to develop two breeding sweetpotato gene pools (one for the non-sweet sweetpotato and the other for the OFSP).
2) If agreement is reached, work with the non-sweet sweetpotato and an OFSP gene pool defining the percentage of breeding capacity that should be allocated to these two programs in West Africa (suggested 50% to each program).
3) Local germplasm evaluation to identify at least seven potential parents for each the non-sweet and the orange program in each NARS breeding program.
4) Agreement to conduct germplasm introductions into each country mainly as seed to select introduced material on a larger scale for local adaptation (target to select 40 out of 1000 to 2000 seed introductions).
5) Discussions and decisions on the number of parents to be used for the non-sweet and the OFSP breeding program including the cross design to be used for their recombination (suggestion factorial 7 x 40).
6) Agreement to evaluate the early breeding stage at two locations of which one location is an off station location in which farmer participatory selection is used to discard clones (suggested population size about 3000 clones for each the non-sweet and the OFSP population).
7) Clarification to determine the value of a cross combination and if elite crosses should be repeated on a large scale (if yes, the size of an elite cross has to be defined).

Priorities CIP and NARS breeding program at the regional platform (Ghana) to develop product / varieties for West Africa (to be discussed):

1) Implementing NIRS technology to improve β-carotene, and mineral storage root concentrations in breeding populations at the regional platform, Ghana.
2) Discussion and decisions if a regional germplasm evaluation and pre-breeding should be conducted aiming at a broader repatriation of West African germplasm from the CIP genebank pre-breed for low sugar high dry matter.
3) Introducing drought adapted OFSP germplasm in form of seed for Southern Africa Agreement to conduct germplasm introductions mainly as seed (speed up, risk minimization) and to evaluate introduced seed populations in a farmer participatory approach.
4) Agreement to conduct germplasm introductions into West Africa mainly as seed (speed up, risk minimization) and to evaluate introduced seed populations in a farmer participatory approach.
5) Discussion and decision concerning increasing the capacity for controlled crosses to 7 x 150 cross combinations for each of the non-sweet and the OFSP breeding population – target 20 seeds per cross combination.
6) Multi-trait selection [with new tools for population improvement (software) to be developed by CIP-headquarters, see Challenge 2] for yield, yield stability, vine survival (extended plot size), storage root dry matter, and low sugar or high β-carotene, iron and zinc concentrations in the non-sweet and OFSP breeding population, respectively.
7) Providing NARS partners in West Africa with the top 10 clones of each population (non-sweet, OFSP) to be used as parents by NARS partners to elevated iron and zinc in their breeding populations.
8) Developing procedures for later breeding stages to determine genotypic differences in market quality attributes of non-sweet and OFSP varieties.

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CHALLENGE THEME PAPER 2: SUSTAINABLE SEED SYSTEMS

Ian Barker, Maria Andrade, Ricardo Labarta, Robert Mwanga, Regina Kapinga, Segundo Fuentes, and Jan Low

Overall Challenge: How do we assure the timely supply of adequate quantities of quality sweetpotato planting material, including improved varieties, to smallholder farmers in Sub-Saharan Africa (SSA)?

BACKGROUND

Seed systems for vegetatively or clonally propagated crops such as sweetpotato fulfill a number of critical roles, namely:
The timely provision of planting material of appropriate quality for smallholders.
The efficient dissemination of new improved varieties from breeding programs.
The provision of replacement planting material following natural disasters or in times of crisis or unrest.

The provision of improved planting material for clonal crops has a proven track record in poverty alleviation through raising crop productivity, both through improved seed quality and through the dissemination of improved varieties with their associated pro-poor traits. The provision of planting material of appropriate varieties is also often seen as a key intervention to rehabilitate farming systems following natural disasters such as drought, civil unrest or conflict, and in assisting the return of displaced persons. An example of the potential impact of improved seed systems in clonal crops is given by the adoption of the International Potato Center (CIP) sweetpotato seed technology (virus testing and tissue culture) in the Shandong province of China in the period 1988 to 1998. The technology was adopted over 80% of the production area of the province, which represents 12% of global sweetpotato production, amounting to some 17 million tons per annum, and resulted in average yield increases of 30%. The economic impact of this intervention was later estimated as providing an annual productivity increase valued at $145M per annum by 1998 (Net present value [NPV] $550M; Internal rate of return [IRR]of 202%), and the agricultural income of some 7 million smallholder farmers had been raised by some 3-4% (Fuglie *et al.*, 1999).

Recent survey evidence also indicates that the lack of sustainable seed systems is one of the key constraints to improving sweetpotato productivity in Sub Saharan Africa (SSA). For example, a CIP survey of National Agricultural Research Systems (NARS) priorities in 2005 reported that "virus management, seed quality and supply systems" was ranked as the highest priority for future research and development (R&D) against all other listed sweetpotato technologies by 91 respondents from 34 developing countries (Fuglie, 2006). CIP pro-poor research targeting further indicates that research on virus control in sweetpotato through provision of clean planting material alone could yield rates of return of between 56-84%, depending on rate of adoption and adoption ceiling. The anticipated aggregate impact of the technology (assuming a *status quo* adoption ceiling) was calculated to be $74 million per annum, with annual benefits to the rural poor calculated to be $49 million per annum. The maximum potential aggregate benefits and benefits to the rural poor for SSA (assuming adoption on all affected areas i.e. no adoption constraint) were calculated to be $434 million per annum and $287 million per annum, respectively (Fuglie, 2007).

A comprehensive background paper on sweetpotato seed systems, with particular relevance to Eastern Africa, has been prepared by Richard Gibson for this project and provides an excellent account of the biology and agro-ecological requirements of the crop.

The provision of seed systems for vegetatively propagated crops in SSA remains a challenging and controversial subject. Debate continues over the relevant merits of "formal" and "informal" seed systems and important parallels exist with Irish potato and cassava.

PRINCIPAL CHALLENGES

Challenge 2.1. Efficient mechanism(s) for introducing and multiplying new improved varieties?

Sweetpotato planting material is traditionally obtained from previous crops or exchanged between local farmers. Against this background, what is the most efficient mechanism(s) for introducing and multiplying new improved varieties: will farmers ever pay for vines?

Current knowledge

The Sweetpotato Community of Practice survey questionnaire carried out as part of this exercise clearly indicated that respondents ranked "quality and availability of planting material" as the most important limiting factor in developing the sweetpotato crop in all three sub-regions. Interestingly, and perhaps surprisingly, 63% of the same respondents **disagreed** with the premise that commercial vines sales are not sustainable.

Vegetatively propagated crops such as sweetpotato present a challenge as the conventional multiplication rate for vines (15:1) pales in comparison to most cereal crops (200-300:1). Rapid multiplication techniques have been developed (attaining rates of 90:1) and are constantly being improved, but dissemination of these technologies has been limited due to their management intensity. As well, removing viruses from infected materials provides “clean” planting material which can result in impressive yield increases.

It would be attractive to simply extrapolate from what was achieved by Chinese NARS to the sweetpotato situation in SSA. However, it is apparent that the task in SSA is very different from China with its stronger institutions and command economy. Work by CIP and others in SSA, Latin America and South East Asia has demonstrated that smallholder growers will purchase vines where the crop has been commercialized, when only one growing season is available (leading to seasonal shortages of planting material) or where new varieties are available. Work by Agri-Biotech in Zimbabwe has also demonstrated the potential commercial and profitable multiplication of clean vines resulting in very significant yield benefits to smallholders (see Challenge 4). The creation of increased demand for clean planting material is probably also critical to the outcome of achieving the productivity potential of the crop.

The typical three stage public sector/donor financed campaign approach of primary, secondary and tertiary multiplication sites is described in the attached Appendix and also in the Gibson background paper which gives examples from Malawi and Tanzania of successful programs. Recent CIP work on different strategies for sweetpotato vine multiplication and the feasibility of commercial production in SSA was reported by Barker (2008) and these and other programs are also well described in the Gibson background paper.

More recent work (German Agency for Technical Cooperation (GTZ) funded; M. Potts, principal investigator) aimed at giving farmers access to improved varieties, and effective systems for the multiplication and distribution of sweetpotato planting material was undertaken in Kenya, Uganda, Tanzania and Ethiopia. Seven novel strategies of vine multiplication were compared to the conventional strategy of dissemination through individual non-governmental organizations (NGOs) and their farmer groups. Each method had merits and drawbacks but demonstrated the need for a flexibility of approach linked to local conditions. Over 40 million vines were distributed by primary partners during the project and over 600 senior research and extension personnel, “trainers of trainers” and other facilitators were trained in vine conservation and multiplication. Primary multiplication sites were set up and well maintained by commercial farmers in Kenya and Uganda but less well in Tanzania and Ethiopia. Alternative approaches to mass vine production and dissemination involved a variety of actors including large NGOs, five farmer vine producer associations, primary schools, prisons, hospitals and small entrepreneurs (including training unemployed and landless youths). In the end a range of strategies proved successful in large scale vine distribution and the price of improved vines was a major factor in determining success. The high prices paid by many often transitory organizations often disrupted attempts to establish long term prices.

Successful farmer-based vine multiplication schemes have thus been well documented but questions remain over best strategies to promote commercialization of vine production in the sweetpotato crop. Thus, particularly for seed systems that focus on new varieties or farmers who are linked to markets, is it possible to move beyond the so-called "campaign" approach, as characterized by the (albeit very successful) examples described? Banana tissue culture in East Africa has succeeded in part because of the yield advantage both from clean material but also the "juvenile" growth performance associated by being generated from meristems instead of corms. That is, there is a yield advantage that will motivate a clean seed system. Equally there are clear signs of emerging small specialist private Irish potato seed producers in Kenya and Ethiopia and of successful community based seed associations in Uganda. It is also clear for these other crops that a linkage of farmers to markets (such as in Malawi) is a key to promoting more intensive and specialist seed multiplication programs.

A “willingness to pay” study conducted in Mozambique provides important insights into this problem. The study (Labarta, 2008) is an experiment set to elicit farmers’ willingness-to-pay for orange-fleshed sweetpotato (OFSP) vines, conducted in January 2008 in six communities of Mozambique. In these areas, farmers face significant dry seasons and limited access to valley bottoms with residual water supply during the dry season. The availability of adequate quantities of vines at the beginning of the rains is a major constraint. This experiment was conducted in six villages where the 121 participant households had received OFSP vines over two years ago. Given that only 37% had managed to retain their OFSP vines for planting in 2008 is indicative of the difficulty of vine conservation (note that there was a severe drought in 2005). Thus, understanding whether farmers are willing to pay for vines and their varietal preferences is critical for evaluating whether it will be possible to establish de-centralized vine producers with a commercial orientation. The latter is envisioned as a more sustainable strategy than continued reliance on free or heavily subsidized public sector and NGO distribution systems. The “real-choice” experiment with four OFSP varieties and the dominant local variety is currently being promoted in Zambézia and revealed that willingness to pay was higher for any OFSP variety than for local varieties; the latter are considered to be readily available. The two varieties clearly preferred by farmers were Resisto, for its yield and taste properties, and MGCL01 (Persistente), for its yield, taste, and most importantly, its being the most drought resistant of the OFSP varieties. All OFSP varieties were considered to be superior to the local variety in terms of taste. On average, farmers invested 2.1 MTn per kg of OFSP bought but there was a group of five farmers that invested more money than the six MTn received for their participation in the experiment. Seventeen percent of participants decided to invest the total six MTn in vine purchase and 49% invested at least half of the money they received. These results are encouraging, given that the trend was to buy and invest more than the minimum required. Many farmers seem willing to pay more for varieties with characteristics they prefer. Farmers growing the OFSP variety Jonathan are willing to pay 70% more to switch to Resisto, and 71% more to switch to MGCL01. Consistent with economic theory, the higher the difference between alternative prices for varieties, the more likely the farmer is to purchase the cheaper product. Among the third of respondents selecting more expensive varieties in a given scenario, the price difference was about 0.75 MTn. In contrast, in 28% of the scenarios respondents selected the cheaper alternative, with the average difference between varieties being higher: 1.21 Mtn. The prospect for viable de-centralized vine producers of OFSP are encouraging, especially for varieties under demand such as Resisto and MGCL01 (Persistente). The cost of production of these vines will need to be within the range that Zambézian farmers are able to pay, and the demand for OFSP vines will likely be driven by the demand for roots in accessible markets.

In summary, much knowledge has been gained in the mass distribution of sweetpotato vines through conventional as well as rapid field multiplication processes. In moving the debate forwards there is a need to understand how to optimally structure primary multiplication (perhaps including tissue culture), hardening sites, and secondary nurseries, and what mix of private and community based approaches are appropriate. It is likely that different agro-ecologies will have a big bearing, with more willingness to pay likely in drought prone areas as well as when associated with new varieties, and when farmers are linked to markets. Innovative work being undertaken by organizations such as the Catholic Relief Services (CRS) for the dissemination of cassava planting material using voucher based schemes and variants of seed fairs also seem very relevant to future sweetpotato vine multiplication and dissemination activities. Such schemes permit parallel extension and participatory demonstration activities to take place along side dissemination, which should also help build more sustainable systems.

Future areas of work for consideration (not necessarily in order of importance):

1) Systematically study and compare different models of sweetpotato vine distribution including seed fairs, voucher schemes etc., drawing parallels where appropriate with other clonal crops such as cassava.
2) Develop strategies for the wide scale dissemination of successful technologies for farm based vine health conservation (positive and negative selection etc.), developed particularly in Uganda and Tanzania, to other important sweetpotato producing countries in SSA.
3) Understand how major varieties in use in multiple countries have been disseminated – especially Simama (Chingova). The perception is that it has been mostly by farmer-to-farmer spread, but it could be that it has been enhanced (for example in Malawi) by initial project funded dissemination efforts. What is the critical mass for igniting farmer-to-farmer dissemination and what factor does human population density play in making it happen?
4) Analyze under what circumstances small holder growers would invest in quality sweetpotato planting material, particularly in the context of market led production systems, and what role savings and investment schemes could have in providing the necessary capital.
5) Assess the potential role that private and public tissue culture laboratories could have in mass multiplication of healthy sweetpotato planting material.
6) Assess the potential for improved agronomy and rapid multiplication techniques to improve field multiplication and maintain vine quality, including use of floating fleeces, optimizing vine length etc.
7) Fully document, and demonstrate to farmers etc. the yield and economic benefits and degeneration rates of clean seed under different cropping systems in a range of agro-ecologies.

Challenge 2.2. Inadequate supplies of vines at the onset of the rains

Extended dry periods and droughts prevent or hinder conservation of vines and, in turn, the timely supply of adequate quantities of planting material with the onset of rains.

Current knowledge

72% of respondents to the current CIP Sweetpotato Community of Practice survey questionnaire agreed with the premise that timeliness of vine availability is more important than clean planting material, which probably reflects the importance of the need to find solutions to the problem of vine conservation through dry periods. Lack of adequate amounts of material at the beginning of the rains condemns sweetpotato to being produced on a relatively small scale in areas with one major growing season. The threat of impending climate change also gives impetus to this critical work area.

The needs and opportunities for innovation and impact in this area are well described in the background paper presented by Richard Gibson and will not be repeated here. Gibson observes that…"Although the [above] issues remain, the overwhelming constraint is lack of planting material at the beginning of the rains, leading to late planting and limited areas planted. The latter leads to the crop failing to fulfill its potential to be the first major food crop to be harvested, to fill the 'hungry gap' when granaries are empty and to realize high sales and prices." Dissemination of intensive methods of conserving planting material using domestic waste water is currently recommended as a partial solution. More promising is the potential for burying medium or small roots at the end of the rainy season in small nursery beds. These are then watered for 4 – 6 weeks before the expected arrival of the rains. The roots then sprout prolifically, producing large amounts of planting material from a small area in time for the start of the rains. Preliminary results for this technology in Uganda are given by Gibson and the methodology should be prioritized for further development and validation in a much wider range of agro-ecologies and countries.

Other vine conservation strategies are reviewed by Kapinga *et al*., (2008) and a number, such as pit storage of roots, may also have potential for developing strategies for overcoming preservation of planting material through the dry season and could be systematically compared with the root burial method.

Future areas of work for consideration (not necessarily in order of importance):

1) Fully assess the potential of promising root/tuber based sweetpotato planting material conservation strategies (late planted roots, pit stored roots etc.) through dry seasons and widely disseminate best technologies to other production areas with extended dry periods and drought prone areas in SSA.
2) Assess and research the potential of small scale irrigation equipment for sweetpotato vine conservation and widely demonstrate the potential of such technology in key production areas.
3) Systematically analyze the potential for extending the use of lake shores and other water sources through water harvesting techniques for the conservation of sweetpotato vine material through dry periods.

4) Undertake climate change vulnerability assessments for key sweetpotato production areas in SSA and develop and disseminate adaptation strategies.

Challenge 2.3. Improving the role of sweetpotato in disaster relief and mitigation

Sweetpotato has played, and will continue to play, a critical role in disaster relief and mitigation. How can these distribution efforts be designed to improve their efficiency, increase levels of permanent adoption and exploit potential opportunities for reaching development, as well as relief objectives?

The humanitarian benefits to be derived from sweetpotato are clear. Sweetpotato produces carbohydrate sources faster than other crops and requires comparably little labor. However, low multiplication rates represent a constraint, as lead times to respond to a disaster situation are necessarily short. The principal need is to have vine material of adapted varieties "ready to go" and capacity to rapidly multiply suitable clean vines for distribution to needy farmers or displaced peoples. Even then, if the process must be started from a small amount of clean material, it can take 5-6 months to have sufficient amounts of material multiplied to serve a large number of households. For immediate emergency response efforts, planting material is often sourced from parts of the country not affected by the emergency and is cut and transported, often with limited concern for quality. In such instances, the varieties selected may or may not be adapted to the environment to which they are going.

Sweetpotato is more commonly employed in efforts where populations are being re-settled in post-conflict situation and in efforts to mitigate future agro-climatic or political shocks through improving food and nutrition security. In many cases, these situations provide opportunities for more highly productive varieties to be introduced to a large number of households – in essence a "disaster" situation can be turned into a "development opportunity". There are many challenges in large-scale distribution efforts. Key lessons learned to date include:

1) A large percentage of vines are not planted or are of poor quality when planted if the communities and farmers are not adequately informed of their arrival. If fields are prepared in advance of distribution, a higher percentage of vines will be planted in a timely fashion.
2) Care must be taken to follow standard procedures for selecting healthy planting material of the appropriate material. In many cases, quantity takes such precedence over quality that the condition of the material used is so poor that survival of the material is a problem.

3) Large trucks are often employed for transporting vines. If the vines are packed too tightly in bags or other materials and/or are stacked on top of one another, rotting and loss of material can be significant.
4) Adequate planning is essential, as, ideally, vines should be cut and planted within 2-3 days. Special training of extension personnel, and often farmers, on how to maintain vines while awaiting field preparation is usually required if there are going to be delays in planting due to lack of rainfall or prior notification, etc.
5) In emergency or post-conflict resettlement settings, vine distribution is typically a public sector or donor funded initiative and farmers receive vines for free. In countries subject to chronic drought or flooding, such free distribution schemes often build up a "dependency" mentality whereby farmers living in disaster prone areas await handouts and don't bother trying to conserve their vines, as they expect the NGO or other agency to return if losses occur.

Given their common use and clear contribution to helping vulnerable communities, there is a clear need to improve these systems.

A good example of the use of sweetpotato to assist disaster affected and prone communities was the multiplication and distribution of cassava and sweetpotato to mitigate the effects of drought and flood emergencies in Mozambique in the period 2001-2003. The project was initiated with a specific aim of mitigating the adverse effects of the floods/drought on food crop production in various districts of the country. Its objective was to increase food supplies through farmer production of superior varieties of cassava and sweetpotato. This was achieved through using rapid multiplication techniques and distribution of healthy planting materials of best-bet varieties.

The project targeted 500,000 farming households, each receiving 200 plantable vines of sweetpotato and 100 plantable stems of cassava. Some 65 selected districts of the 128 districts of the country (50.8%) in 9 of the 10 provinces of the country were targeted as operational areas for the multiplication and distribution of healthy improved planting materials of both crops.

The project made impressive progress and provoked awareness of the use of cassava and sweetpotato in disaster mitigation. Twelve implementing institutions were engaged in widespread partnerships with over 120 field level agencies and NGOs. Together, they planned and executed multiplication and distribution operations involving schools, churches and contract farmers using best-bet clones of cassava and sweetpotato planting materials.

The project established a well-coordinated network of fields and other multiplication sites covering over 200 hectares of conventional and rapid multiplication plots of sweetpotato and over 200 hectares of cassava in different districts. The project distributed sweetpotato and cassava planting materials to some 377,735 families across the country. The project also successfully promoted the utilization and processing of both crops by demonstrating the use of improved tools and machines, as well as extension of improved crop production practices. In this decentralized model, the entry point for the NGOs working on the project was generally through communal nurseries rather than distribution of vines direct to farmers. These communal nurseries also became the focus of demonstration sites and thus served a dual purpose. The campaign was principally designed to serve a relatively short term need for rehabilitation of planting material lost through natural disasters, but capacity and expertise developed has remained in demand beyond the life of the project to serve "normal" seed needs, and remains available in the event of any future disaster (Andrade *et al.*, 2004a, 2004b, 2007; SARRNET/UEM 2003).

Useful experience has also been gained in distributing sweetpotato planting material to regions of Northern Uganda affected by conflict. More than 850,000 OFSP vine cuttings have been delivered to Ugandan farmers in the affected districts of Lira and Apac. This represents the amount of vines needed to plant about 30 hectares and is significant given the escalating violence that has forced many farmers to live in protected camps. During lulls in the fighting, farmers moved from behind the defensive perimeter of the camps to attend fields established from this material. The farmers, who normally grow crops like cassava and millet, apparently prefer sweetpotato because it is earlier maturing than traditional crops. Farmers are also aware that sweetpotato is hardy enough to thrive under the rugged conditions of Northern Uganda and requires little weeding. Moreover, for reasons that are not entirely understood, rebel troops usually raid cassava fields and leave sweetpotato unharmed. Efforts were also undertaken to produce vines that displaced people could carry back to their villages when conditions improve (http://www.cipotato.org/vitaa/archive.htm).

Opportunities currently exist to intervene to combat predicted food insecurity in sweetpotato growing regions of Ethiopia following the failure of the short rains. The infrastructure and capacity that was developed in Mozambique is highly relevant for this emerging situation. One issue is that foundation stocks of virus tested material of appropriate locally adapted varieties are only now becoming available and again highlight the need for such provision to be in place to permit a more timely response to disasters as they emerge.

Areas for future work:

1) Fully document existing experiences in order to prepare manuals for future use.
2) Better understand the relationship between emergency vine distribution and longer term issues of dependency and sustainable seed systems.
3) Develop methods to speed up response and preparedness for disaster relief interventions using sweetpotato planting material.

Challenge 2.4. Assuring the quality of sweetpotato planting material for purchasers?

Current knowledge

The Sweetpotato Community of Practice survey questionnaire indicated that respondents ranked viruses as the most important factor lowering farmers yields in East and Central Africa by quite some margin, but not so in Southern or West Africa. The sweetpotato virus disease (SPVD) complex caused by mixed infection of *Sweetpotato feathery mottle virus* (SPFMV) and *Sweetpotato chlorotic stunt virus* (SPCSV) is, by far, the most destructive viral disease of sweetpotatoes in Africa (up to 50% in East Africa), and perhaps worldwide (Carey *et al.*, 1999). In many cases, cultivation practices ensure that sweetpotato plants can be infected all year round. Farmer use of cuttings from their previous crop as planting material and the abundance of weed vegetation, which serves as a continually present reservoir of viruses and vectors, make the control of the disease difficult (Karyeija *et al.*, 1998).

Njeru *et al.*, (2006) reported that although most farmers (73%) in Rwanda were able to identify sweetpotato virus disease (SPVD) as the most damaging disease (also confirmed by laboratory testing) the majority (65%) was not aware of what causes the disease and 53% used no control measures against it. Laboratory testing of over 300 fields in Rwanda by the same author (Njeru *et al.*, 2008) revealed that 83% of symptomatic plants and 31% of asymptomatic plants were virus infected, and with mixed infections common in symptomatic plants but not so in asymptomatic plants. Recent virus surveys in Uganda and Tanzania report varying levels of SPVD infection (Ndunguru and Kapinga 2007; Ndunguru *et al.*, 2008; Kapinga *et al.*, 2008). Between 10-40% infection levels were found in Central Uganda where symptoms were recorded as being from mild to moderate. The majority of farmers practice control measures and improved varieties are widely grown. In Tanzania SPVD levels varied from 94% in the NW (West of the Lake), where there was less knowledge about virus control and more local varieties grown, to 54% in the Eastern part of the lake zone (Mwanza). Limited virus testing using samples originating in this Eastern region reported less diversity of different viruses and that in particular, the mixture of viruses responsible for SPVD in Eastern Africa was not found in this particular area. In general there is a lack of current good and systematic virus survey data, particularly from Western and Southern Africa where little is known about virus incidences or the diversity of viruses present. A comprehensive virus survey has recently commenced in Rwanda, Burundi, Uganda and Congo in a CIP coordinated Belgian funded project (Kreuze, personal communication). Initial findings from this survey from Rwanda back up the earlier study and indicate that 62% of farmers believe that the virus problem is increasing or at least not changing (38%). Farmers not practicing any control measures amounted to 47%, 95% and 65% in Rwanda, Burundi and Congo respectively, although most farmers can recognize the disease but very few are aware of its cause.

Anecdotal evidence and that obtained from questioning key individuals and organizations in the recent fact finding missions certainly support the fact that SPVD is still uncontrolled in many parts of Rwanda, Burundi, Ethiopia and parts of Tanzania. Problems associated with the distribution of virus infected planting material by various agencies were also apparent. Potential control measures for SPVD broadly fall into the use of resistant varieties, obtaining clean planting material, or farmers practicing good husbandry or maintaining the health of their own planting material. The use of resistant varieties is reviewed elsewhere (Breeding Challenge paper) and by Gibson (2008). The production of clean sweetpotato planting material for distribution is mostly achieved by initiating a limited generation multiplication cycle, starting with clean planting material, and maintaining the health of subsequent generations through isolation, good husbandry and negative selection (rogueing). An alternative approach would be to plant virus tested ("indexed") material derived from tissue culture plantlets in a manner similar to the Chinese scheme and practiced in Zimbabwe (see below). Sweetpotato propagation schemes in SSA (with the exception of S. Africa) are not currently subject to official regulatory inspections (certification) as is the case with clonal crops in other parts of the world or indeed for Irish Potato in many countries within SSA.

Rather uniquely in SSA, Smith (2004) and Robertson (2006) reported that the use of tissue-cultured sweetpotatoes by smallholder farmers in Zimbabwe has been shown to improve household food security. Farmers who used tissue cultured sweetpotato varieties, such as Brondal, obtained yields of up to 25 tons per hectare against a national average of 6 tons per hectare. Mutandwa (2008) reported that sweetpotato farmers in Zimbabwe were able to achieve net economic returns of $36 per ha using tissue culture derived planting material (which is replaced every 3 years) whereas growers using unimproved planting material made a loss.

Farmer based maintenance of the health of the sweetpotato planting material through positive and negative selection has also shown to be effective, particularly in Uganda and Tanzania (Kapinga *et al*., 2008; Gibson, 2008) in controlling SPVD. Excellent training material has been produced and the techniques are widely practiced. Much work remains to be done to transfer this knowledge to other areas of Tanzania as well as elsewhere in the region. Gibson (2008) asserts that he believes that virus degeneration in locally adapted varieties in Uganda is self limiting (as distinct from introduced improved varieties) through an as yet unknown mechanism, and that virus indexing schemes are not necessary in this context. We believe that a similar mechanism may operate in indigenous native potato seed systems operating in the Andes of South America (unpublished). Gibson also concludes that farmer based health practices can augment this phenomenon. There is then an apparent contradiction in approaches represented by virus indexing schemes practiced in China and Zimbabwe and those practiced in Uganda for local varieties. The contradiction may partly be explained in that two separate approaches are being taken. One relies on the inherent virus "resistance" of local varieties backed by good on-farm husbandry and the other may be based on the considerable yield gains to be had with virus cleaning of high yielding but virus sensitive varieties, which offsets the need to replace the planting material on a regular basis. The question for the former approach is how to improve productivity from this point and close the yield gap and the question for the virus indexing approach is how to make the system economically sustainable without public subsidy in the long term. Certainly, the yield benefits to be gained from planting virus free material (when compared to badly degenerated material) are considerable and have been documented by CIP in China, SSA, Peru, Philippines and elsewhere.

Sweetpotato propagation schemes in SSA are currently not subject to specific regulatory control by National seed authorities, although they may fall into some broad seed regulations in some countries. Seed production of Irish potato, in contrast, is often subject to specific seed regulations, including disease specific tolerance levels, labeling and rotational requirements etc. It is, however, worth pointing out that certified Irish potato seed often only makes up approximately 1% of total seed needs in many African countries. A typical Irish potato seed certification scheme requires two visual inspections of every seed crop by trained staff, followed up by additional tuber inspections and supplementary laboratory testing. The costs in staff time, travel to site and additional laboratory testing, would be prohibitive to an average smallholder sweetpotato seed producer, and the National authorities are unlikely to have the capacity to carry out such a service on a large scale in the short term. It is unlikely that the economic benefits to be had from adopting a formal seed system could carry the additional costs of the scheme. Such concerns are being recognized in many of the newly emerging policy reviews of Irish potato in, for example, Kenya and Uganda, where the important role of informal seed producers is recognized. Some National seed authorities may however see a role in helping to ensure the quality of primary sweetpotato multiplication sites or foundation seed in the future.

Perhaps of more immediate interest would be in developing community based seed quality schemes to improve the quality of vines produced and hopefully add value to the product if it is sold. Developing an awareness of vine quality through local labeling schemes, perhaps based on new Food and Agriculture Organization (FAO) Quality Declared Seed (QDS) protocols currently being developed by CIP and FAO and other partners, could be used to further enhance impact and adoption. The draft sweetpotato protocol (prepared by the National Agricultural Research Organization [NARO] and CIP) is attached as an Appendix. It is envisaged that the QDS sweetpotato seed protocol would provide an achievable but challenging standard for grower groups, perhaps with initial help from an NGO or extension service. The role of the national seed authority in such a scheme could be to nominate only officially released varieties that can be included, and perhaps to maintain a register of authorized producers. Community based seed schemes operating under the QDS protocol could also obtain its starter material from officially certified foundation seed and thus link formal with informal seed producers.

Areas for future work:

1) Research and resolve the conflicting claims made for the need or utility of virus indexing in the production and multiplication of sweetpotato vine planting material, including an economic analysis.
2) Assess the utility of implementing community based vine quality assurance and labeling schemes particularly for market led production schemes.
3) Implement and widely disseminate appropriate vine multiplication quality standards such as the FAO/CIP Quality Declared Seed standard for use by National programs, NGOs, International bodies etc. in large-scale vine distribution programs.
4) Study the possible advantages and disadvantages of extending seed regulations to clonally propagated crops such as sweetpotato in SSA as proposed by a number of National programs and regulatory authorities.
5) Extend virus surveys to Western and Southern Africa.

Challenge 2.5. Efficient and safe germplasm movement programs?

Current knowledge

Sustainable seed systems for vegetatively propagated crops such as sweetpotato require technical capacity to clean-up varieties (thermotherapy being the most used technique) and to test for viruses (diagnostics) and tissue culture labs for maintaining and propagating virus-free stocks. A critical mass of trained technicians and scientists is also a necessary requirement. Financial sustainability of the laboratories is perhaps best achieved through the creation of rotational funds and public-private sector partnerships.

There remain considerable problems in efficiently moving germplasm and breeding material around the region because of a lack of provision of the above basic requirements. This significantly hampers National and International breeding efforts through introducing long delays (several years in some cases) in moving material across national boundaries. Thus many countries are unable to receive in vitro material, and maintain it in tissue culture, both from genebanks and other breeding programs. This material can often only be maintained in the field or screenhouse where it will inevitably become virus infected – a great pity, since it may have taken two years and considerable cost to clean and test the material for viruses prior to it being shipped.

Equally some countries, possessing little or no phytosanitary infrastructure, could be at risk of introducing exotic pests and diseases into the crop. An internal report, based on survey data and laboratory testing, prepared by Ethiopian Institute of Agricultural Research (EIAR) scientists (Abraham, personal comment) in Ethiopia, concluded that recent SPVD epidemics in the country could have originated from one of a number of sources of historically introduced germplasm (although no previous baseline surveys exist to confirm this hypothesis). The findings also include the first possible report of the West African Strain of *Sweetpotato chlorotic stunt virus* in Eastern Africa. Current concerns over the movement of damaging and epidemic diseases of cassava highlight this risk. CIP recently became the first genebank in the world to gain international quality management accreditation through the ISO17025 standard for the worldwide movement and pathogen testing of germplasm, including sweetpotato. Such accreditation provides donors, recipients of germplasm and other interested parties such as governing bodies, independent and internationally recognized assurance that systems in place are "fit for purpose" and perform to the highest possible standards. It is suggested that the skills required to obtain accreditation could be transferred to key institutions within SSA who could then apply for independent accreditation. Such measures would build confidence in enhanced germplasm exchange schemes as national breeding programs become more active in a wider range of countries. Such activities could be underpinned by further developing and disseminating the latest robust and appropriate technological developments in virus diagnostics (Mumford *et al.*, 2006). CIP is currently developing a suite of real-time polymerase chain reaction (PCR) assays for sweetpotato viruses in collaboration with the Central Science Laboratory (UK) and the Danforth Center.

A survey of sweetpotato tissue culture and virus diagnostic capacity was undertaken as part of this current project and will be presented at the forthcoming seed and breeding workshop to be held in Mombasa. Basically only Kenya (Plant Quarantine Service at Kenya Plant Health Inspectorate Services [PQS KEPHIS]), Uganda (NARO), South Africa (Agricultural Research Council [ARC]) and Tanzania (Mikocheni) routinely carry out all of these tasks under one roof and only PQS routinely carries out full virus indexing for sweetpotato for international distribution. Many other countries have some *in vitro* capacity (often used for more commercial crops) ranging from state of the art (Mozambique) to facilities that require considerable attention and investment. Commercial tissue culture companies can be found in Kenya, Uganda and Burundi although none are currently working with sweetpotato. A number of laboratories in the region are capable of testing for sweetpotato viruses but very few routinely utilize modern molecular diagnostic methods and none perform real-time PCR (outside of the Republic of South Africa [RSA]). Investment would seem to be needed throughout the region in greenhouses, diagnostic and tissue culture infrastructure, and all regions need significant capacity strengthening of staff. These initiatives, along with parallel development of virus diagnostic capacity, will need to be aligned with other current initiatives for other vegatatively propagated crops which require broadly similar capacities and capabilities (Bioearn, Donata, BecANet, CIP Buffet etc.). Initiatives such as, for example, the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) Tissue Culture Business Network, are particularly relevant.

A decentralized system of international, regional, sub regional and national nodes for the reception, cleaning, testing and distribution of sweetpotato germplasm with the highest standards of bio-safety, could be set up using current knowledge and expertise. Models such as the enlargement of the European Union ("Plant Passporting") could be looked at for relevance. Such a capacity could significantly enhance the breeding and seed system effectiveness to the ultimate benefit of farmers throughout the region.

Areas for future work:

1) Build regional and national capacities in *in vitro* multiplication and conservation of sweetpotato germplasm and breeding materials across SSA in conjunction with other initiatives.
2) Develop and widely disseminate appropriate sweetpotato virus diagnostics and develop national capacities across the region in key hubs again in conjunction with other initiatives.
3) Implement a strategy for an efficient de-centralized and regional germplasm distribution network to serve international and national breeding programs based on a regional or sub-regional risk-based approach.
4) Implement internationally recognized quality testing standards for the safe movement of germplasm across the region based on the ISO 17025 accreditation standard and the FAO guidelines for the safe movement of sweetpotato germplasm.

CONCLUSION

The provision of quality planting material for clonal crops such as sweetpotato and Irish potato in SSA is, and remains, a controversial issue. Opinions differ from workers who advocate (and practice) commercializing virus tested tissue culture derived planting material and others who doubt this can be sustainable or is even needed. A key aspect of this debate revolves around the willingness or even the need for smallholder farmers to purchase quality vines following project funding or agency led vine distribution campaigns; thus, the emphasis in the title of this challenge topic focuses on **"sustainable**" seed systems. Much valuable experience has been gained throughout Eastern, Central and Southern Africa in implementing large-scale sweetpotato vine (and new variety) distribution networks. There is clear evidence of a willingness of farmers to pay for vines under specific instances of distributing new improved varieties (including OFSP), when linked to markets and when vine material is scarce. Large-scale public funded vine distribution campaigns have a tendency to create "institutional" markets and also to distort markets, but have been extremely valuable in replacing lost seed and disseminating new improved varieties, many with important pro-poor traits. Perhaps the important point is that future interventions should evolve toward creating in the long-term economically sustainable seed systems, primarily through the involvement of the private sector, including tissue culture laboratories. A clear distinction should also be made between developing seed systems for the needs of farmers increasingly linked to markets (including OFSP growers) and those who may remain largely subsistence farmers. There is also a need to prioritize the balance of resources invested in virus resistance breeding as distinct from virus testing or other plant health management strategies (Gibson *et al*., 2004). Concurrent with that is perhaps the clear need to carry out detailed economic analyses and modeling of the benefits (from a smallholder perspective) of differing approaches comparing subsistence farmers with those linked to markets. A case for continued public funding for capacity to aid efficient dissemination of new sweetpotato varieties with pro-poor traits can also be made in the context of subsistence farmers.

A considerable opportunity also exists in building on the very valuable experience in farm based seed systems (positive and negative selection etc.) from Uganda and parts of Tanzania and extending these programs to elsewhere in the region for the control of Sweet potato virus disease (SPVD). It is apparent that the disease represents a very important continuing constraint in East and Central Africa and efforts to spread good management practice and continued development of virus resistant locally adapted varieties (especially OFSP) remain very important. Much interest also exists amongst vine producers, purchasing agencies and national authorities in improving the quality of vines. A balance needs to be struck between appropriate quality systems and possible seed regulations to reflect the needs of the differing categories of vine producers and to reflect the largely informal nature of the crop. The new FAO QDS guidelines could offer achievable yet challenging standards for community based seed schemes, where the role of National regulatory agencies would simply be to monitor and to oversee the scheme in the broadest sense. There is a case for more oversight on primary foundation or breeders' seed in the longer term. An enhanced sweetpotato *in vitro* multiplication, pathogen diagnostic and quality management capacity at the national and sub-regional level to facilitate the efficient and safe movement of elite breeding material and other germplasm would also represent a sound investment of resources. Opportunities exist to integrate any such investment with other planned initiatives for clonal crops, particularly cassava and bananas/plantain, in the region.

Finally there exists a very significant opportunity to continue the development, evaluation, adaptation and eventual dissemination of dry season vine conservation strategies, such as root nursery beds, throughout SSA. The technology could have an enormous impact on increasing productivity and extending the availability of the crop in drier environments and make a significant contribution to future adaptation to expected climate change.

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ANNEX 2.1. DRAFT FAO/CIP QDS PROTOCOL FOR SWEETPOTATO

INTRODUCTION

Origin

Sweetpotato, *Ipomoea batatas* (L.) Lam., belongs to family Convolvulacea (Morning glory). Sweetpotato originated in or near northwestern South America around 8000-6000 B.C. Guatemala, Colombia, Ecuador, and northern Peru have the greatest diversity in sweetpotato germplasm. Secondary centers of genetic variability are Papua New Guinea, the Philippines and parts of Africa.

Modes of propagation

The sweetpotato can reproduce asexually by: a) colonizing an area by production of storage roots which subsequently sprout to give new plants, b) reproducing vines which may form roots at the nodes, producing daughter plants. The sweetpotato can also reproduce sexually by production of seed, but seed is used only in research for breeding. Sweetpotato is a perennial dicot, but it is cultivated as an annual for vines and storage roots. Sweetpotato is sensitive with a photoperiod of 11.5 hr day length or less promoting flowering, while at 13.5 hr day light, flowering ceases but storage root yield is not affected. Short days with low light intensity promote root development.

Estimated reproductive rate using vine cuttings is 1:15 to 1:20. At optimum conditions, from one tissue culture plantlet it is possible to produce 64 000 cuttings from 800 m^2 field plot in one year.

Pests and diseases

A wide range of pathogenic organisms attack sweetpotato, and although most are widespread, damage levels vary. These organisms include viral, fungal and bacterial diseases, and those caused by nematodes. Globally, at least 20 viruses are known to infect sweetpotato. These viruses occur singly or as mixed infections. *Sweet potato feathery mottle virus* (SPFMV) is the most common virus infecting sweetpotato globally. In mixed infections with *Sweet potato chlorotic stunt virus* (SPCSV), SPFMV is associated with the severe sweetpotato virus disease (SPVD), the most important disease of sweetpotato in Africa. Other viruses include: *Sweet potato mild mottle virus* (SPMMV), *Sweet potato latent virus* (SPLV), *Sweet potato chlorotic flecks virus* (SPCFV), *Sweet potato virus G* (SPVG), *Sweet potato leaf curl viru*s (SPLCV). Whiteflies and aphids act as vector of some viruses.

Bacterial diseases can be economically damaging in some parts of the world. They include bacterial stem, and root rot (*Dickeya dadantii)* occurs worldwide; bacterial wilt (*Pseudomonas solanacearum*), important in southern China; and soil rot (*Streptomyces ipomoea*), is important in parts of USA and Japan. Use recommended control measures such as good crop hygiene, and resistant varieties.

Root-knot nematodes (Meloidogyne species) occur worldwide. The extensive root-knot nematode (RKN) host plant ranges, and their interactions with pathogenic fungi and bacteria in plant disease complexes, rank RKN among the major pathogens in crops. Nematode attack in sweetpotato causes stunting, yellow foliage, abnormal flower production, round to spindle-shaped swellings (galls), necrotic root system, and low yields. More than 50 species of RKNs have been described, but Meldogyne incognita, M. javanica, M. arenaria, and M. hapla Chitwood account for more than 95% in agricultural soils globally.

Worldwide there are at least 270 species of insects and 17 species of mites that feed on sweetpotatoes. Insect pests are categorized into defoliators, virus transmitters, stem borers and root feeders. Sweetpotato weevil, *Cylas* spp. is the chief pest of sweetpotatoes. Worldwide there are three main economically important sweetpotato weevils: *Cylas formicarius* occurs globally*,* while *C. puncticollis* and *C. brunneus* are the main species in Africa. The West Indian sweetpotato weevil, *Euscsepes postfasciatus* occurs in Central and South America, the Caribbean, and the Pacific Islands.

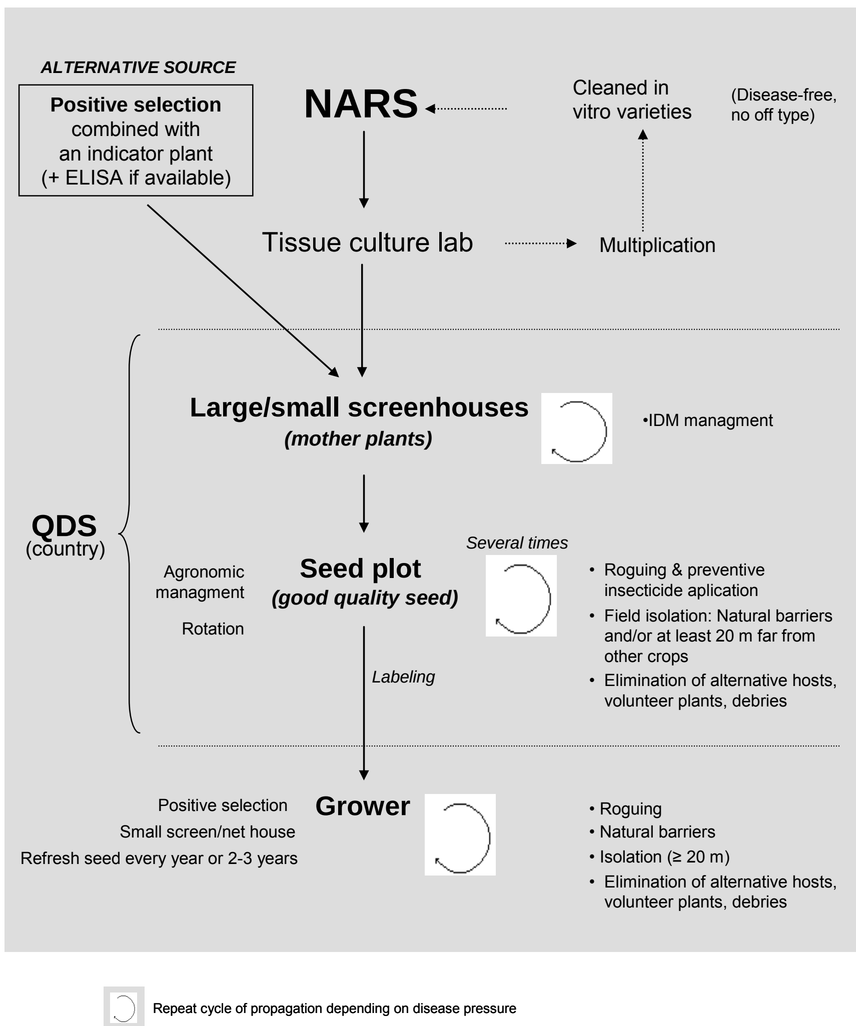
The most damaging stage of weevils is the larval stage. The larvae mainly attack stems and underground parts, although they may also feed on leaves. Adult weevils oviposit in the bases of vines and in exposed roots, while the larvae tunnel through storage roots causing major economic losses. The damage caused by larvae and adults also stimulates the production of terpene phytoalexins, which make the storage roots unhealthy for human consumption. Weevil population and damage is most prevalent during dry seasons, probably because drought increases soil cracking, thus exposing roots to weevils.

PROTOCOL FOR PRODUCTION OF PLANTING MATERIAL

Facilities/equipment

Established protocols specific for region or country or CIP are followed to clean up sweetpotato from different sources, field, screenhouse or tissue culture of all pathogens in tissue culture to produce virus-indexed plantlets for local, regional and international germplasm use (Figures 2.1 and 2.2). Important facilities include well-equipped greenhouses and/or screenhouses, tissue culture laboratories and virus detection equipment and indictor plants for virus indexing. Basic equipment for tissue culture includes: autoclave, lamina flow hood, pH meter, sensitive balances, refrigerators, and heaters. A growth room for in vitro plantlets can be constructed locally. The size of fields for multiplication and increase of stocks of clean plants depends on the demand for clean planting materials and the capacity of the country, organization or agent to meet the demand.

Figure 2.1
Outline of sweetpotato multiplication program.



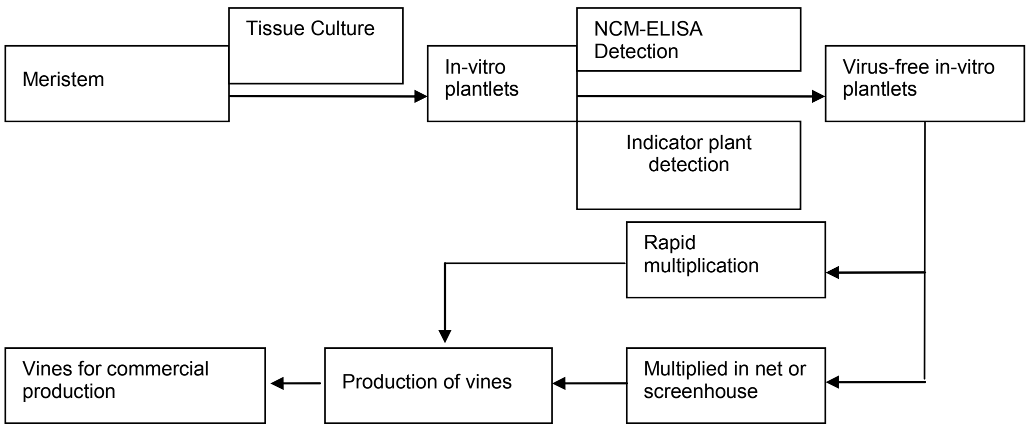


Figure. 2.2 Protocol for virus-free sweetpotato planting material production.

Agronomic practices (including rotations)

Sweetpotato is a perennial but is normally grown as an annual plant. In the tropics it is propagated from vine cuttings, but in temperate regions it may also be grown from rooted sprouts (slips) pulled from bedded storage roots. Apical cuttings, 30-45 cm long are planted by inserting into the soil at an angle. In some parts of East Africa, cuttings may be wilted or left in shade for a few days. In India, the central portion of a cutting is buried in the soil, leaving a node exposed at both ends.

Sprouts are obtained by planting small or medium sized roots close together in nursery beds. The resulting spouts, 22-30 cm long, are removed from the storage roots and planted in the field. Cuttings and sprouts are planted on mounds, or ridges, or on the flat if the soil is deep and well drained. Mounds are used extensively in the tropics especially where the water table is high to improve drainage. Mounds up to 60 cm high, about 90-120 cm apart, are planted with three or more cuttings. Ridging is suitable for mechanical preparation of the ground. Ridges are about 45 cm high and 90-120 cm apart, with cuttings planted at 30 cm intervals.

Sweetpotato is often the lead crop in a rotation cycle, except in very fertile soils. In these soils, planting at the start of the rotation should be avoided, as excessive vegetative growth occurs at the expense of storage root formation.

Seed crop monitoring

A sweetpotato crop for planting material (seed) production, when well established, with good vine growth, is carefully inspected by an experienced breeder or seed inspector or other trained personnel to detect off-type plants within a variety. In addition, all plantings undergo inspection for varietal purity by the appropriate authority some time during the growing season.

Inspection methods

Field inspections before and during harvest are conducted to identify high yielding hills, desirable shape, detection of off-type plants, variety mixtures, serious diseases and pests, coupled with positive selection of roots or vines to serve as the breeder seed for planting the next season's crop. Field inspections are conducted at to coincide with the time when diseases are most conspicuous, such as at months after planting when SPVD is vivid. Inspection of one percent of field taken randomly in four different places of a large field is representative, but for smaller fields a higher percentage can be used.

Harvesting

At harvest, roots are dug out of the soil, and each hill is separately handled and graded. Only those hills with a high yield of well-shaped roots and are free of any defects are selected, and only disease-free vines are cut to serve as breeder seed.

Storage: Proper handling after harvest includes curing of seed roots, proper sanitation, including removal of all old sweetpotato and fumigation of the house before storage of new roots. Dust and debris from the grading and packing area must not come in contact with seed roots or vines. Vines must be stored in well ventilated, shaded places before planting. All storage roots and vines for seed must be transported in net bags or well aerated containers to avoid excess heat damage due to respiration and close packing.

Labeling requirements

Each container of seed roots or vines is appropriately tagged to identify them as foundation, registered, or certified. If the container or bundle of vines is not tagged, the seed is not certified. Label information includes, variety name/code, farm location, seed grower name, harvest date, batch number, weight/batch, number/batch, length, inspector name/code, and quality standards-logo. All labeled seed roots or vines should follow quality standards (Table 2.1).

Table 2.1. Maximum tolerances for disease, insect damage, and internal quality standards for foundation, registered, and certified sweetpotato seed.

Standards	**Foundation (1st generation)**	**Registered (2nd generation)**	**Certified (3rd generation)**	**QDS (4th generation)**
Black rot	None	None	0.1%	0.5%
Root-knot Nematodes	None	0.2%	0.5%	1.0%
Scurf	None	None	0.1%	0.5%
Wireworms	1.0%	2.0%	5.0%	10.0%
Wilt	None	None	0.1%	0.5%
SSR-Pox[1]	None	5.0%	5.0%	10.0%
Sweetpotato viruses				
Mosaic and stunting	None	None	None	1%
Leaf curl	None	None	None	5%
Other (e.g. purpling of old leaves, chlorotic spots, vein clearing)	None	None	None	5%
Other varieties	None	None	None	2%
Storage rot	None	None	None	None
Sweetpotato weevil	None	None	None	None

[1]Seed with pox will be labelled *Sterptomyces* soil rot (pox) below 5%. Other defects are none for foundation, registered and certified seed: other varieties, storage rot.

Multiplication Program Protocol

Breeder seed of all varieties officially released in a country is produced and maintained by the sweetpotato breeder. Breeder seed is the highest quality available of the variety. The breeder seed is carefully maintained until the next multiplication cycle is repeated. Guidelines for production of foundation seed, registered, and certified seed are basically the same. The guidelines relate to land requirements, inspections, and standards for fields, seeds and plants. Sweetpotatoes grown for certification are handled much the same way as the commercial crop except for the following: plants showing any mutations and symptoms are discarded, a 4-year rotation is followed, only vine cuttings may be used for production of foundation seed, and during the growing season fields that are to be certified must have at least one field inspection by the relevant official.

Materials for rapid multiplication

Fertilizer, NPK 17-17-17 at the rate of 42 gm^{-2} is applied after planting. Urea is applied at the rate of 13 gm^{-2} after each harvest of cuttings, followed by light watering. Manure at 2.5 kgm^{-1} is applied as farmyard manure before planting. The manure should be well decomposed.

Insecticides: all cuttings should be dipped in carbofuran (0.05% ai) solution for 20 min before planting. This will kill all stages of the weevil and provide some residual protection for the young plants. Before planting, apply carbofuran at the rate of about 5 gm^{-2}. Mix thoroughly with soil. To control aphids and white flies, and mites, apply weekly acricide or Ambush or available alternative pesticides on market following recommended dosage.

Fungicides: Apply Benlate (4 g in 10 l of water) or other available fungicide on market following recommended dosage when symptoms appear.

Varieties: Identify appropriate varieties for rapid multiplication.

Cuttings: three node cuttings are taken from vines whose leaves were previously removed. Apical or top cuttings are planted separately.

Preparation of nursery beds

The beds are raised, 10 m long, 1.2 m wide and 20 cm height. Fertilizer (17-17-17), manure (2.5 kgm^{-2} and insecticide (carboduran) are applied and mixed thoroughly with soil before planting.

Preparation of planting material: Cuttings are taken from vigorous mother plants of about 3 months. Leaves are removed from the vines. Prepare three node cuttings from all parts of the vine. Apical cuttings with three nodes are planted separately. Deep the cuttings in a solution of carbofuran and water for 20 minutes before planting.

Planting

Density: 50 cuttings m^{-2} (0.2 m between rows x 0.10 m intra-row). The cuttings are planted upright with two nodes below the soil surface.

Cultural practice

Irrigate 2-3 times a day, early morning and late afternoon with a horse pipe or watering can. **Weed** periodically to maintain the nursery beds clean. **Rouge** all diseased plants.

Where there is excessive sunlight and hit, use mats or other locally available material to shade the nursery beds. Remove the mats when the first leaves start developing. Avoid keeping the mats for more than 2 weeks to prevent etiolation.

Cutting (Harvesting) vines: Cut apical cuttings (25 cm long) 5 cm above the soil level leaving some nodes on the stems to enable further production of cuttings from the axillary buds. The procedure of cutting above the soil surface ensures a 98% chance of selecting weevil-free plants.

Data to be collected in rapid multiplication beds includes, % sprouting or establishment (2 weeks after planting), harvesting (cutting) dates of apical cuttings, number of apical cuttings harvested, % rooting success (survival in the open field), and reaction of cuttings in the open field related to the yield.

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CHALLENGE THEME PAPER 3: NUTRITIONAL IMPACT WITH ORANGE-FLESHED SWEETPOTATO (OFSP)

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Overall Challenge: How can we get provitamin A rich orange-fleshed sweetpotato (OFSP) into the diet of the most vulnerable groups?

BACKGROUND

In contrast to Asia, malnutrition among young children is on the rise in Sub-Saharan Africa. A key millennium development goal (MDG) called for the reduction of underweight prevalence by 50% by the year 2015. Overall, in Africa, prevalence is expected to increase from 24% in 1990 to 27% in 2015. High rates of HIV/AIDS prevalence exacerbate malnutrition. Hence in East Africa, where the HIV/AIDS effect is strong, underweight prevalence is predicted to be 25% higher in 2015 than in1990 (The World Bank, 2006).

Vitamin A is an essential micronutrient for human health. Vitamin A deficiency (VAD) is widespread among young children in the developing world; globally, 127 million children under six years of age are estimated to be affected (West, 2002). Sub-Saharan Africa (SSA) and India have the highest estimated prevalence rates of sub-clinical vitamin A deficiency (Figure 3.1). VAD can limit growth, weaken immunity, cause xeropthalmia leading to blindness, and increase mortality (Sommer and West, 1996).

There are two types of vitamin A available in foods: preformed retinol (vitamin A itself) typically found in animal foods such as eggs, liver, and milk; and provitamin A carotenoids found in plant foods such as dark green leafy vegetables, yellow and orange vegetables and fruits, and orange-fleshed sweetpotato (McLaren and Frigg, 2001). Β-carotene is the major provitamin A carotenoid, and the dominant carotenoid in orange-fleshed sweetpotato.

Poor households typically cannot afford to consume the highly bioavailable animal foods on a regular basis. High rates of deficiency in the major micronutrients (vitamin A, iron [Fe], and zinc [Zn]) are common among poor populations that consume plant-based diets (Hess *et al.*, 2005). Many plant sources of vitamin A are seasonal, and after provitamin A carotenoids are absorbed into the body, they must be converted into retinol for the body to be able to make use of them. Rates of conversion vary among carotenoid containing plant foods (up to five fold) and also depend on what else is consumed at the same time (for example, fat increases absorption) and the health status of the individual (e.g. more deficient individuals absorb and/or convert at higher rates than replete individuals). Heat processing may also increase conversion rates compared to the raw product, depending on the plant matrix (Hess *et al.*, 2005). Current guidelines recommend that provitamin A activity be expressed in Retinol Activity Equivalents (RAE). The RAE definition is based on the assumption that 16.7% of the ingested beta-carotene is absorbed and 50% is converted to retinol. This results in an average conversion factor of 12 units of beta-carotene to form 1 RAE. Many dark green leafy vegetables are probably less bioavailable than this, while palm oil is far superior (2:1 conversion factor). In contrast, the conversion factor for preformed retinol from animal sources is 1:1 and for other provitamin A carotenoids 24:1 (Institute of Medicine, 2001).

During the past five years, further evidence has been obtained regarding the potential impact of OFSP on young child vitamin A status. A South African study demonstrated that OFSP is bioavailable and efficacious in improving vitamin A status in children (Jaarsveld *et al*,. 2005) and significant improvements in vitamin A intake and serum retinol concentrations (a proxy for vitamin A status) were obtained from an action-research study of an OFSP-based integrated agriculture-nutrition-market intervention in a very resource poor setting in Central Mozambique (Low *et al.*, 2007b). The latter study emphasized the importance of having all three components (agriculture, nutrition and market interventions) to ensure improvement in young child vitamin A intakes and sustained adoption of the new material. A third study (Haskell *et al.,* 2004) using the isotopic tracer deuterated retinol to estimate total vitamin A stores in 14 Bangladeshi men determined a conversion factor of 13:1 for orange-fleshed sweetpotato when it was cooked pureed with a small amount of oil.

Orange-fleshed sweetpotato as a staple food has an advantage over most vegetables in that it can supply significant amounts of vitamin A *and* energy simultaneously -- thus helping to address both VAD and undernutrition. OFSP is an example of a *biofortified* crop in which the micronutrient status of staple foods is enhanced through plant breeding to the point where impact on micronutrient status can be achieved (Bouis, 2002). Since the poorest households typically obtained over 60% of their energy needs from food staples, this strategy is particularly suited to poor rural households that cannot access purchased fortified food products but could grow OFSP.

The intensity of the orange color reflects the amount of beta-carotene present in the sweetpotato. In most of SSA, white-fleshed varieties dominate and contain no beta-carotene. On a fresh weight basis (fwb), light orange varieties contain at least 250 RAE/100 gms (30 µg/g), medium-intensity varieties at least 458 RAE/100 gms (55 µg/g) and dark-orange -varieties at least 833 RAE/100 gms (100 µg/g). To put things into perspective, the recommended daily intake for healthy two and five year old children is 400 RAE and 500 RAE, respectively (Institute of Medicine, 2001). Depending upon the color intensity of the OFSP variety used and taking losses during cooking into account (approximately 20% through boiling), 1/4 to 1 cup of boiled and mashed sweetpotato meets the intake requirements of a young child.

Sweetpotato leaves are also consumed in many countries in SSA, with the notable exceptions of Kenya and Uganda where they are principally considered to be animal feed. The leaves also contain significant amounts of beta-carotene, but bioavailability is certain to be much lower than for the OFSP roots and to our knowledge, no formal study has been done to determine the conversion rate of beta-carotene from sweetpotato leaves into retinol.

Because of the urgent need to address widespread VAD in SSA, the development and use of beta-carotene-rich OFSP roots deserves special consideration in any sweetpotato initiative. Compelling evidence is available of the potential contribution of OFSP to improved nutrition. To evaluate potential health and economic impact, economists estimate the number of vitamin A deficiency (VAD)-related Disability-Adjusted Life Years (DALYs) that could potentially be saved through the use of biofortified sweetpotato. Results indicate that just by replacing white-fleshed with orange-fleshed varieties the VAD burden could be reduced by 15 to 22% in 17 SSA countries where sweetpotato is widely grown (Stein *et al.*, 2005; Fuglie and Yanggen *in press*). *Ex-ante* analysis determined that if OFSPs were adopted by one-in-six Ugandan households within 10 years of becoming available, the effort would achieve an estimated internal rate of return between 16 and 30 percent and yield a net present value between $23 million and $67 million (Fuglie and Yanggen *in press*).

The focus of this theme is on the narrower nutritional objectives associated with OFSP for humans. OFSP varieties with adequate agronomic performance are already available in several SSA countries; therefore it is the first biofortified crop in use at farmer level and serves as a model for the adoption of biofortified crop with a visible trait. Further breeding work is needed to improve agronomic and organoleptic qualities to ensure sustained adoption and is discussed in Challenge Theme Paper 1 on Breeding. OFSP, either in fresh or processed form, can be branded as a health improving product. When marketed to urban consumers, there are additional income benefits for rural producers that could induce a potentially complementary impact on nutrition through increased spending on other health enhancing services and products. The marketing aspects of OFSP promotion are addressed in Challenge Theme paper 4 on Value chain.

Challenge 3.1. Increase the bioavailability of micronutrients in OFSP and retention during processing and storage

Orange-fleshed sweetpotato roots and leaves contain a diverse array of vitamins and minerals with potential nutritional benefits. The ultimate benefit depends on the total amount of micronutrients ingested and whether the micronutrients are retained during processing and storage and are absorbed and utilized by the body after being consumed.

Nutrient content of roots and leaves

OFSP roots are a rich source of provitamin A and can meet easily the intake needs of young children in their commonly served form, boiled or steamed, as noted above. True retention (TR) of beta-carotene varies from 70-92%, depending on cooking time (longer cooking periods lowering TR) and whether the pot was covered with a lid (covering increases TR) (Jaarsveld *et al.* 2006). Dominant varieties of maize and cassava, in comparison, have no vitamin A (Table 3.1), although biofortification efforts are underway to improve beta-carotene contents in these crops. Although sweetpotato leaves contain ample amounts of beta-carotene, the amount of vitamin A available per 100 grams is estimated to be much lower (51 ug/100 gms) due to its presumed lower bioavailability, as no efficacy study has been done using sweetpotato leaves. Sweetpotato roots also are a good source of vitamin C and have moderate amounts of several B vitamins and vitamin E (Table 3.1). Protein levels in sweetpotato and cassava leaves are higher than in their respective roots, but the amount of leaves consumed by humans limits their total contribution.

Sweetpotato leaves are widely consumed in several SSA countries, yet varietal specific information on nutritional benefit is limited in SSA compared to Asia, as is data on the average amount consumed and the seasonality of consumption. The promotion of their consumption exists in a few initiatives, mostly through home or school gardens. Part of the difficulty in comparing sweetpotato leaves from different varieties for human consumption is that young leaves are typically harvested piecemeal during the growing season. Hence, by the time roots are evaluated at the end of the growing season, the leaves from some varieties lack the desired palatability as fiber has accumulated. Hence, incorporation of regular assessment of organoleptic qualities of sweetpotato leaves has logistic and cost implications. Specific varieties for use as a vegetable only do exist, but these are only being evaluated on a small-scale in Kenya and Tanzania.

Table 3.1. Nutrient composition of orange-fleshed sweetpotato, cassava and maize.

Nutrient	Units/ 100 gms	Orange-fleshed Sweetpotato		Cassava		Maize
		Raw Roots	Leaves	Raw roots	Leaves	White flour
Vitamin A	Ug	300-1300	51-230	1	115	0
Iron	Mg	0.32-0.88	1.01	0.27	7.6	2.4
Zinc	Mg	0.18-0.57	0.29	0.34	0.40	1.70
Thiamin (B1)	Mg	0.08	0.16	0.09	Na	0.25
Riboflavin (B2)	Mg	0.06	0.34	0.05	Na	0.08
Niacin (B3)	Mg	0.56	1.13	0.85	2.40	1.90
Vitamin B6	Mg	0.21	0.19	0.09	Na	0.37
Vitamin E	Mg	0.26	na	0.19	Na	0.42
Vitamin C	Mg	22.7	11.0	20.6	310	0
Protein	G	1.6	4.0	1.4	7.0	6.9
Fiber	Mg	3.0	2.0	1.8	4.0	9.6
Phytate	Mg	10	42	54	42	792

As noted in the Theme paper on breeding, there is a positive correlation in the sweetpotato germplasm between beta-carotene, iron, and zinc. If included as a selection criterion in breeding programs, average levels of iron and zinc in OFSP could be expected to double within the next five years. The range of iron and zinc values found to date in OFSP germplasm is provided in Table 3.1. Iron and zinc deficiency are the other two widespread micronutrient deficiencies in the world, with their deficiencies associated with increased susceptibility to infection, impaired growth, anorexia, and impaired cognitive function. Iron deficient anemia is estimated to affect over 1 billion people worldwide (Hess *et al*., 2005). Clearly, if the three micronutrients could be enhanced simultaneously that would be highly desirable

However, a main constraint inhibiting the contribution of iron and zinc contributing to improved nutritional status is the low rates of absorption associated with plant sources of iron and zinc. Similar to the situation found in vitamin A, flesh foods are rich sources of bioavailable heme iron and zinc, whereas many plant sources contain high levels of phytate and in some, polyphenols, which inhibit the absorption of iron and zinc —even when they are present in relatively large amounts. Levels of phytates are particularly high in unrefined cereals, nuts, and legumes. Phytate levels are higher in sweetpotato leaves than roots. One study from the Philippines found that only 5% of the iron from sweetpotato leaves was absorbed (Ortaliza *et al.,* 1974). The negative effect of phytates on zinc uptake can be mitigated by increasing amount of dietary proteins consumed (WHO, 2002). The phytate level in sweetpotato roots, however, is quite low compared to that found in maize (Table 3.1). Moreover, sweetpotato has considerable amounts of vitamin C, which enhances non-heme iron absorption (Nestel and Nalubola, 2003). However, the effect of phytate comes from the amount in the entire meal. Hence, if sweetpotato is consumed along with maize, for instance, the inhibitory effect on absorption would still be there. As sweetpotato is consumed in some areas as a stand-alone breakfast food, in these instances phytate inhibition would be minimal.

In addition, many studies have demonstrated a positive effect that vitamin A supplements or vitamin A fortified foods have had on hemoglobin concentrations in children and pregnant and lactating women (Semba and Bloem, 2002). Evidence of interactive effects between vitamin A and zinc is much less clear (Hess *et al.*, 2005). Since OFSP is naturally biofortified with provitamin A, one might expect that the effects on iron status through increased OFSP consumption might be positive.

Requirements for several nutrients in terms of averages for assessing populations (EARs) and recommend intakes for individuals (that have an additional safety margin built in to assure adequate nutrient status) are provided in Table 3.2 for two key target groups: children 1-3 years of age and non-pregnant women 19-30 years of age as a reference. The target level set by HarvestPlus to consider a staple food crop biofortified in a specific nutrient is 40% of the daily EAR requirement for a non-pregnant adult woman. With this definition and assuming that 200 grams of sweetpotato is consumed, 100 grams of sweetpotato would have to provide 1.6 mg fwb of zinc and 1.7 mg fwb of iron. While the levels of iron and zinc content achievable via conventional breeding will not be able to attain "biofortified" status for adult women, it is possible that a significant contribution towards improved intake of young children 1-3 years of age could be made. Given their lower requirements, only 0.56 mg and 0.63 mg of zinc and iron in sweetpotato roots would meet 40% of their requirements, if the bioavailability of these micronutrients is confirmed.

Quality traits as a function of the environment

Like many other sweetpotato traits, the quality traits have been found to be influenced by the environments. For example, the average dry matter content varies widely depending on cultivars, environments and cultivation practices, from 13.8 to 48.3% (Bradbury and Holloway, 1988). Existing study findings on stability of β-carotene contradict each other. While some studies (Manrique and Hermann, 2000; Gruneberg *et al.*, 2005) found extremely low environment interaction effects, Kosambo *et al.* (1998) and Ndirigue (2005) report significant effects on levels of β-carotene. On the other hand Manrique and Hermann (2000) observed increased concentrations of ß-carotene at high altitudes among the studied clones. Similar observations in just one variety have been made by Dr. Mulokozi (personal communication). Thus ß-carotene levels of popular sweetpotato varieties in the region are not clearly known, due to large estimate variations in different environments. Knowledge on the influence of environment on ß-carotene is of great importance in guiding recommendations by the nutritionists on intakes to meet daily requirements of vitamin A by sweetpotato as well as in evaluating the stability of β-carotene in sweetpotato cultivars or breeding clones under different environmental conditions. Lack of stability in beta-carotene content would complicate commercialized processed product development as processors would have to deal with an inconsistent product.

Table 3.2. Estimated average requirements (EARs) for group level analysis and individual level requirements of essential nutrients.

Nutrient		**Estimated Average Requirements (EAR) for Groups**		**Recommended Intakes for Individuals**	
	Units/ day	Child 1-3 years	Female 19-30 years	Child 1-3 years	Female 19-30 years
Vitamin A	ug	210	500	300	700
Iron	mg	3	8.1	7	18
Zinc	mg	2.5	6.8	3	8
Thiamin (B1)	mg	0.4	0.9	0.5	1.1
Riboflavin (B2)	mg	0.4	0.9	0.5	1.1
Niacin (B3)	mg	5	11	6	14
Vitamin B6	mg	0.4	1.1	0.5	1.4
Vitamin E	mg	5	12	6	15
Vitamin C	mg	13	60	15	75
Protein	g	11	38	13	46

Source: Institute of Medicine (2001), except for zinc. Zinc figures from International Zinc Nutrition Consultation Group

The influence of the varied time of harvesting on the ß-carotene levels in sweetpotato is also not fully understood. Most farming communities harvest sweetpotato piecemeal allowing households to get food early before total crop maturity, and also minimize food wastage through ground storage of an otherwise perishable crop. However, the nutritional content of the root is reported to change with time during the crop growth (Woolfe, 1992). For example, the level starch accumulates with time. Also the protein root content levels are reported to vary with date to harvest. A declining trend was observed for leaf ß-carotene content in sweetpotato cultivars with increasing time of harvest. Kosambo *et al.* (1998) found significant effect of storage root age on carotenoid content. Twelve weeks after planting, the yield and the amount of pro-vitamin A present in the roots evaluated were high enough to provide adequate dietary pro-vitamin A and means there would be some nutritional benefit if piecemeal harvesting began at that time. More recent studies by the Tanzanian Food and Nutrition Center (TFNC) also found significant effect of maturity on β-carotene content of sweetpotato roots (Personal communication, Generose Mulokozi). Varieties harvested at 7-8 months had significantly higher β-carotene content than varieties harvested at 4-5 months. Apart from appropriate date of harvesting recommendations for root yields, there is need to determine the appropriate date of harvesting to maximize the availability of pro-vitamin A carotenoids in sweetpotato roots.

In addressing micronutrient deficiencies the potential for exploiting soil-crop nutrition-human nutrition interactions should not be overlooked. For example, a plant that is zinc deficient will suffer from reduced yields. Moreover, the low concentration of zinc in its tissue reduces its nutritional value as a human food. Zinc fertilizers do exist, and the possibility of enhancing the micronutrient content of the human diet through improved crop health is unexploited territory in SSA (Alloway 2004). It is also possible to consider the use of foliar sprays. Applications of foliar sprays containing minerals were found to enhance the concentrations of some minerals and trace elements in the same variety in the same field (Paterson and Speights 1971). The Zn containing spray significantly increased the leaf Zn content, but when Fe was applied, the calcium and boron content was lowered.

Retention of Beta-carotene during processing

Wheatley and Loechl (2008) review the major studies undertaken during the past two decades concerning OFSP products and retention of beta-carotene during processing and storage (pp. 12-23). During this time, there has been considerable improvement and greater standardization of procedures used to assess beta-carotene content (Rodriguez-Amaya and Kimura, 2004). Research in this area is constrained by the high cost of doing beta-carotene assessment using HPLC and other nutrient analysis. The review concludes that:

1) OFSP varieties have beta-carotene contents high enough to contribute significantly (after cooking/processing) to the daily recommended intake of young children.
2) Medium-to-dark orange fleshed varieties should be preferred for processing over lighter orange-fleshed materials (having less than 50 μg beta-carotene per gram fresh root weight).
3) Some food products containing OFSP such as bread, mandazi, and chapati are of good quality and acceptable to consumers, including children.
4) Bakers/processors can reap some advantages from the use of OFSP raw materials, but in some areas their commercial uptake may be hampered by cost disadvantages and supply problems.

5) Storage of dried roots should be for less than 4 months, when dramatic carotenoid losses were shown; losses may be lower with fresh roots when stored for short periods.

More research is clearly required to:

1) Understand losses in beta-carotene after different time periods of storage (1 week, 1 month, 2 months).
2) Develop and test low-cost methods on how to reduce degradation of beta-carotene during storage of fresh and dried roots, particularly at the household level.
3) Develop and implement standardized protocols for the collection of relevant data on the profitability and beta-carotene content of products.

Future areas of work for consideration:

1) Understanding the bioavailability of iron and zinc in sweetpotato roots with high beta-carotene contents and improved iron and zinc contents.
2) Understanding the bioavailability of vitamin A in sweetpotato leaves.
3) Understanding the influence of maturity and other varietal characteristics on the rates of micronutrient accumulation in roots.
4) Understanding the relationship between soil fertility and beta-carotene and other relevant micronutrients.
5) Understanding the potential for micronutrient enhancement in sweetpotato roots through the use of micronutrient enhanced fertilizers.
6) Research on methods for improving micronutrient retention during storage and processing and the influence of varietal type on retention.
7) Development of lower cost methods for assessing micronutrient content in OFSP-based processed products.

Challenge 3.2. Maximizing the nutritional impact of OFSP

Vitamin A deficiency (VAD) is not just the result of inadequate vitamin A intake. Maximizing the nutritional impact of an OFSP is complex and requires choices to be made regarding target groups and the design and intensity of the non-agricultural components of the intervention.

Undernutrition is not just the result of inadequate food intake, but is also caused by: the quality of the food being consumed, poor access to health services, poor sanitation, and in the case of young children, inappropriate feeding and care practices. In the same vein, VAD can have multiple causes: inadequate vitamin A intake because the sources of vitamin A are lacking in the diet or the source of vitamin A is not adequately bioavailable, inadequate absorption of vitamin A because the lining of the intestine may be damaged by parasites or diarrhea, or increased use of vitamin as the body fights off diseases such as measles and malaria.

Children under five years of age and pregnant and lactating women are at greatest risk of VAD. In recent years, attention has particularly focused on the young child due to studies in the 1980's that proved that large-scale vitamin A supplementation led to significant (on average 23%) child mortality reduction (McLaren and Frigg, 2001). Moreover, a recent reassessment of the nutrition situation concluded that the best opportunity for addressing malnutrition is the period prior to conception until two years of age (World Bank, 2006). However, there are many reasons that other target groups might be considered for an OFSP-based intervention. These are summarized in Table 3.3 along with consideration of what might be the potential challenges working with a given target group. For example, investing in reaching school children, the future parents of the world, may be an effective means for reaching large numbers of households through a centralized location *if* children prove to be effective transmitters of technologies from school to household. Moreover, influencing preferences and changing behaviors regarding diet and heath practices is complex and young children are under the strong influence of their parents and other adult caretakers (Nicklas *et al.,* 2001). In addition, experience to date indicates that adult preferences in varietal selection (taste in particular) often differ from young child preferences, but adults determine what varieties are grown and how much are grown.

The three most common strategies for combating VAD are distribution of vitamin A supplements, food fortification, and food-based approaches that aim to increase access to and intake of vitamin A-rich foods. Clearly, an OFSP-based intervention falls in the latter category. Food-based approaches can be seen as complementary to the other strategies and particularly suited for rural areas where access to fortified foods is limited by availability or purchasing power. A food based strategy has the advantage of bringing in more nutrients, both macro- and micro-, than just vitamin A, and may be more sustainable.

Table 3.3. Description of reasons for potentially targeting different groups with ofsp-based interventions, alternative sources of vitamin a to which the target group may have access and the challenges of working with that group

Target Group	Reason for Targeting	Alternative Sources of Vitamin A	Challenges of Working with this Group
Children 6-12 months	High risk of VAD and mortality	Age group most likely to still be breast fed and to receive vitamin A capsules (attend for immunizations)	Requires working with mothers on special dietary requirements and care practices for this age group
Children 12-24 months	Very high risk of VAD and mortality, especially among children no longer breastfeeding	May have access to vitamin A capsules in many countries; some have breast milk	Requires working with caretakers on special dietary requirements and care practices for this age group
Children 25-59 months	High risk of VAD and mortality	May have access to vitamin A capsules in many countries	Child typically eating what family eats and shares with others
School children	Opportunity to influence lifetime food preferences; Mothers and fathers of the future; Central location for demonstration –lowering operational costs; ? Potential for knowledge transmission to other household members; ? Potential for sustained integration into curriculum (large-scale impact)	May have access to school feeding programs that could included fortified foods	Bureaucratic resistance; requires teacher and/or parental community involvement; maintenance of gardens/fields when school not is session; age-specific training approach & materials
Adolescents	Higher vitamin A during adolescent growth; Opportunity to educate and improve status, esp. among girls, prior to parenthood	Only through growing or purchasing vitamin A rich foods	Reaching school drop-outs; age-specific training approach & materials; requires parental cooperation/consent
Pregnant Women	Greater vitamin A requirements than normal; Concentration of vitamin A in breast milk depends on woman's vitamin A status	In some countries, may have access to vitamin A capsule immediately after birth of child	Identifying candidate women at early stage & special dietary needs
Fathers	Often determine or influence what is grown and what is sold (varies by culture/household) & care practices	Through growing or purchasing vitamin A rich foods	May perceive nutrition as woman's area
Elders	Often influence household dietary and young child care practices	Through growing or purchasing vitamin A rich foods	Difficult changing beliefs; Physical ability to participate; Age-specific approach for training activities and materials
Food Insecure Rural Households	Have household members at high risk of VAD and undernutrition; Diet diversification enhances health of all members	Through growing or purchasing vitamin A rich foods; young children may have access to vitamin A supplements	Vine maintenance in drought-prone areas; Requires cost-effective approach for assuring adoption and appropriate use; Competition with other crops/activities
Urban slum dwellers	Have household members at high risk of VAD and undernutrition;	Through growing or purchasing vitamin A rich foods; may have greater access to fortified foods than rural dwellers; young children may have access to supplements	Land/water for cultivation may be limiting; Cooperation and/or adequate time availability from potential beneficiaries; support from municipalities
Displaced populations	Often suffering from multiple nutritional problems, including VAD; Food insecure, hence anxious for productive technologies	Food aid may be fortified with micronutrients	Multiplication rate of sweetpotato requires lead time for large-scale response; Limited contact time per beneficiary; High rates of dis-adoption likely; hard to monitor uptake if mobile population
HIV/AIDs affected persons	High risk of VAD and mortality; Require easy to manage technologies; Often food and income insecure	May have access to micronutrient supplements or fortified food supplements	Identifying candidate beneficiaries; Capacity of individuals to do physical labor—often requires working at community level; complex as links to health service provision essential

The design of integrated interventions can be complex as it requires a multi-disciplinary approach. The example of the Towards Sustainable Nutrition Improvement project (TSNI) can serve as a case in point (Low *et al.,* 2007a). In this model, OFSP is not a "magic bullet" but an easily exploitable resource to enable resource-poor households to provide adequate nutrition to their most vulnerable household members. OFSP provides an entry point for change agents to empower poor caregivers to change behaviors concerning dietary practices. There are three components: 1) *Agriculture*: consisting of the introduction of a new source of vitamin A and energy, biofortified OFSP; 2) Demand Creation and Empowerment through improved knowledge of *Nutrition*: At the village level, principal caregivers, both women and men, are encouraged and enabled to improve infant and young child feeding practices, hygiene practices, and diversify the household diet. Demand creation efforts focus on building awareness among the broader community to create: a) demand for the new OFSP cultivars and its derivatives, b) demand for other vitamin A-rich foods, and c) a supportive environment to accelerate behavior change at the household level; and 3) *Market Development*: This component aims to link farmers to traders and to inform consumers about where they can purchase OFSP. Farmers able to commercialize their crop are more likely to permanently adopt the crop and expand the area under production. This action research study demonstrated significant increases in vitamin A intake and a 15% reduction in prevalence of low serum retinol (a proxy for vitamin A status) in young children in spite of the poor health environment (Low *et al.*, 2007b). A follow-up study, the Reaching End Users, is currently investigating whether a variant of this model, in which an explicit attempt was made to lower the cost of the intervention, can be cost-effectively scaled-out. The design is explained in greater detail in Challenge 3.4.

The TSNI approach was an integrated package and further study is needed as to which components of this package are essential for adoption and impact on young child vitamin A intake. Many small-scale interventions are currently underway in SSA that utilize OFSP (Field team visits, May-June 2008), but most are just integrating OFSP into larger agricultural initiatives with limited focus on understanding which components are critical to uptake and proper utilization. One question is whether OFSP will "passively" end up in the young child diet and have a significant impact on the group most at risk of VAD when interventions are generally targeted at rural households without a specific intervention to change young child feeding and care practices.

There are also questions as to whether linking an agricultural-nutrition intervention more explicitly to a health intervention would substantially increase impact on VAD status. A clinical trial in Indonesia (Jalal *et al.*, 1998) utilizing sweetpotato-based weaning foods demonstrated that the greatest rise in serum retinol occurred when meals contained added beta-carotene sources and added fat and the children were de-wormed. The potential of this type of OFSP-based agriculture-nutrition-health intervention has not yet been tested at the community level in SSA.

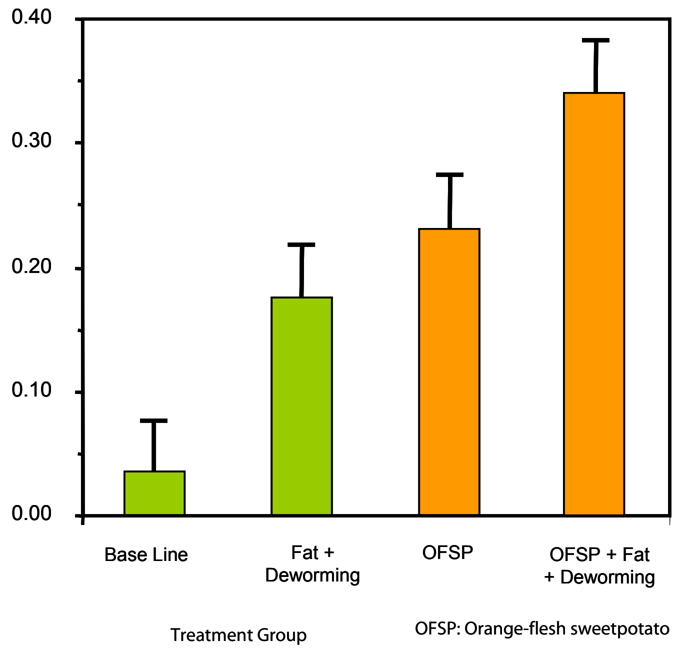

Figure 3.1
Change in serum retinol (vitamin A status indicator) (Jalal *et al.*,1998).

Clearly, reaching the most at risk group of VAD (children under 2 years of age) requires addressing a broad range of child feeding and care practices and is a more complex intervention than just aiming at rural households. Assuring behavior change regarding OFSP use in the household is more complex than just creating awareness that OFSP is good for health. Increasing vitamin A intake is only part of the solution; health interventions are essential to improve the absorption of vitamin A in the body. The challenge is to find which entry points in reaching vulnerable households and specific target groups have the best chance for sustained adoption and widespread impact in short, medium, and longer-term interventions.

Future areas of work for consideration:

1) Investigating the use of OFSP linked to a health intervention that will decrease vitamin A loss (for example, de-worming or targeting pregnant women receiving pre-natal care) and enhance the impact of an integrated OFSP-based intervention;
2) Understanding how to better evaluate young child and school-age children preferences compared to adult preferences;
3) Understanding whether OFSP reaches the group most at risk of vitamin A deficiency (children under five) when targeting households for food security or commercialization interventions;
4) Understanding whether school children are effective entry points for knowledge and technology transmission to other household members.

Challenge 3.3. Maximize the role of OFSP in mitigating the situation of persons living with HIV/AIDS (PLWH)

The high prevalence of HIV/AIDS, particularly in Eastern and Southern Africa, exacerbates the malnutrition situation and could affect the design and outcome of any potential OFSP intervention. Adequate nutrition is essential for the success of expensive anti-retroviral treatment regimes.

Current knowledge

SSA continues to be the region most affected by the deadly HIV pandemic: 68% of adults and 90% of children infected with HIV are in SSA. In 2007, a staggering 22.7 millions adults and children were living with AIDS with 1.6 million deaths attributed to the disease that year in SSA. Unlike other continents, the majority (61%) of those living with AIDS in SSA are women. The highest prevalence rates in SSA are in Southern Africa (35% of all cases in SSA and 32% of new infections), followed by Eastern Africa, where data indicate that prevalence is stabilizing or declining (UNAIDS and The World Health Organization, 2007). HIV/AIDS and malnutrition have long been know to co-exist, often resulting in the "slimming disease" so characteristic of early AIDS patients. A complex set of underlying primary malnutrition, primary effects of AIDS virus infection, secondary effects of AIDS and finally AIDS complications can all lead to a vicious cycle, as illustrated in the figure and updated in recent reviews for the HIV stage (Faintuch *et al.*, 2006) and highly active anti-retroviral therapy (HAART) stages (Drain *et al.*, 2007). Decreased appetite and taste for food are among the important factors not indicated in the figure (Berti, 2008). Several studies have shown that malnutrition is a common problem among people undergoing HAART in resource-poor settings, and that wasting is one of the best predictors of risk of mortality (Paton *et al.*, 2006; Zachariah *et al.*, 2006)

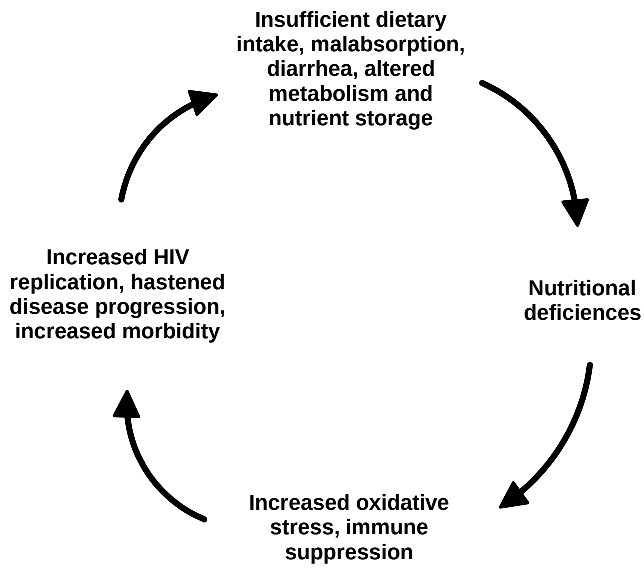

Figure 3.2
Vicious cycle of micronutrient deficiencies and human immunodeficiency virus (HIV) pathogenesis.

Source: Semba and Tang, 1999.

Of particular relevance for OFSP is that energy requirements increase with HIV infection (approximately 10%) and further with active AIDS (20-30%) (Berti, 2008), to which OFSP could potentially respond, and that HIV infection appears to impair absorption of Vitamin A (Kelly *et al.*, 2001), requiring greater intakes of Vitamin A for equivalent serum levels.

HIV thus leads to the establishment of an increasingly vicious cycle, with food insecurity (reduced access and increased need) heightening susceptibility to HIV exposure and infection, and HIV in turn heightening vulnerability to food insecurity. At the same time, food intake is an increasingly recognized factor for HAART tolerance and adherence (The World Bank, 2007). While not all wasting among PLWH is caused by lack of food, qualitative and quantitative studies of the needs of people being treated in resource-poor settings often list food as one of their greatest needs (Au *et al.*, 2006; Mshana *et al.*, 2006) The goal of nutrition support for PLWH in need of anti-retroviral therapy (ART) is to stabilize nutritional status prior to and during treatment, help people regain strength, and contribute to improving nutritional status during treatment. In places where food insecurity prevents people from accessing or adhering to treatment regimes, food supports can play an important role in increasing uptake and adherence to treatment (Megazzini *et al.*, 2006).

Most attempts to assess the impacts on the agricultural sectors of hard-hit African countries have been based on micro-level studies in areas known to have high HIV prevalence. Many experiences on the adaptation of agricultural-based interventions to particular vulnerabilities that households affected by HIV/AIDS experience have been summarized in both NGO and UN documents e.g. FAO (2003). This has resulted in a set of commonly cited statements that build on the logic that loss of adult labor due to AIDS causes severe labor constraints in rural households, resulting in less land being cultivated and a shift away from labor intensive and higher value cash crops to less labor intensive, lower value crops, particularly cassava and sweetpotato which have more flexible planting and harvest periods than do grain crops. Labor loss occurs not only as a result of sickness, loss of muscle mass, reduced physical capacity, and premature adult death, but also as a result of its reallocation to nurse the ill, while working capital is siphoned off to pay mounting medical bills. Empirical evidence calls for a more nuanced approach to addressing this issue. Some evidence finds that the primary constraints on rural productivity and livelihoods may be land and cash more than labor. A study in western Kenya, for example, found a variety of impacts on rural agricultural households struggling with the illness or death of an adult. Total household expenditure for death-affected households was US$462 per year, compared with US$199 for illness affected households and just US$21 for non-affected households. Illness-affected and death-affected households spent 56 percent and 61 percent, respectively, of the amount spent on agricultural inputs by non-affected households (Gillespie and Kadiyala, 2005) .

A set of five SSA country studies based on nationally representative agricultural surveys to which a module to capture the effect of prime-age adult illness and death was added concluded that land/labor ratios of many affected households are similar to those of non-affected households, implying that agricultural labor might not be the household's principal production constraint. "Affected" households were not homogeneous: Households with a prime-age female death were more likely to attract a new prime-age adult member and were richer than households with a prime-age male death (Mather *et al.,* 2005). Households losing the head of the household were much more affected negatively than households losing a prime-age adult that was not a head or the spouse of a head. When they compared the *ex post* percentage area overall cultivated to roots and tubers in Mozambique, Rwanda and Zambia, the mean average differences between affected and non-affected households were not significant (Mather *et al.,* 2005). However, in the case of Rwanda, there was a significant increase in production of sweetpotatoes and a decline in beer banana processing (a labor intensive activity) among households with a chronically-ill prime age adult (Donovan and Bailey 2005). Interpretation of data from Southern Africa in terms of whether crop shifts are due to the pandemic is complicated by the acknowledged growth in roots and tuber projects in this region during the past decade due to policy changes to promote these crops for drought-mitigation and food security and changes in output/input price ratios for grain crops relative to roots and tubers (Mather *et al.,* 2005). Clearly, assessing impact of the pandemic on agriculture at the macro-level is a methodologically challenging issue.

As more PLWH are placed on HAART, and AIDS becomes a chronic disease, policy makers are increasingly looking at ways of improving food intake and nutritional status in resource-poor settings that are more sustainable over the longer term than either nutritional supplements or food supply programs (Food and Nutrition Technical Assistance (FANTA) Project and World Food Programme (WFP) (2007). Although vegetable gardens, small animal production, traditional herb cultivation and other activities are increasingly commonplace in community programs, with reported benefits for participants, little more rigorous evidence is available on the impact of agriculture-based programs on HIV progression or AIDS complications. There are clear gender issues that need to be monitored. If ARVs permit more adults to work and they can earn cash from OFSP, perhaps fewer women and girls will be pressed into service as health care providers. If OFSP helps to ease the food security burden on women in HIV/AIDS affected households that too has positive implications.

In some countries, OFSP is already recognized as an excellent source of vitamin A. For example, a recent newspaper article in Kenya stated "The sweetpotato, for instance, is specially recommended for its richness in vitamin A, which is a requirement for HIV/AIDS victims." (Kariuki, 2008). In terms of widespread adoption, the question arises as to whether being seen as a recommended food for HIV/AIDS affected individuals will negatively affect uptake by non-affected individuals due to the stigma still associated with the disease. Ethical challenges also have arisen – extension personnel in Mozambique have reported instances of local leaders and village promoters directly or indirectly implying that eating OFSP will help prevent AIDS infection (Low, personal communication). A similar situation is found in the Lake Zone of Tanzania, an area of high HIV/AIDS prevalence, where OFSP is called "medicinal sweetpotato" (Field visits 2008). Clearly, HIV/AIDS-affected households can benefit from foods that improve food security and nutrition. The extent to which OFSP can meaningfully contribute to those affected households, and whether the best way of reaching them is through programs specifically targeted at HIV/AIDS affected households or just targeting poor rural and peri-urban households in general warrants further investigation.

Future areas of work for consideration:

1) Impacts of HIV/AIDS taste perception and preferences for OFSP varieties, including their digestibility compared to other food sources, among children and women of reproductive age;
2) Advantages and disadvantages of OFSP production versus other agricultural activities in HIV/AIDS-affected households, and ways that the advantages could be increased;
3) Impacts of OFSP production and consumption on energy and Vitamin A intakes of producing households, and of consumption in consuming households;
4) Impact of OFSP on the intra-household division of labor in HIV/AIDS-affected households and the status of young women;
5) Impacts of community involvement in OFSP production and marketing on livelihoods and food security for HIV/AIDS affected households;
6) Impacts of greater OFSP consumption on nutritional status and progression among PLWH, particularly children and women of reproductive age;
7) How the promotion of OFSP as a crop for HIV/AIDS affected households affects its image and acceptability among non-affected households.

Challenge 3.4. Identifying cost-effective models of scaling out integrated OFSP programs

There are few well-tested extension strategies that combine the provision of new varieties, crop management, and changing nutritionally related behavior in the household. Appropriate cost-effective models that can be scaled-out to reach significant numbers of beneficiaries are required and depend on the perceived role of sweetpotato in the diet.

The challenge of technology dissemination and uptake is a field of research in and of itself. In SSA, there have been attempts to transfer models from other parts of the world to SSA countries with mixed success. There are relatively few interventions that have attempted combining provision of new varieties, crop management, and changing nutritionally related behavior in the household. Even fewer have collected and analyzed relevant cost and benefit data for assessing whether the intervention is cost-effective. This dearth of information has hampered investment in food-based initiatives compared to other approaches to combating micronutrient malnutrition as supplementation and food fortification programs have more readily definable benefits and costs structures than do integrated agriculture-nutrition initiatives.

An intervention utilizing sweetpotato is intrinsically linked to how its role is perceived. There are at least seven ways in which sweetpotato is perceived in SSA, varying between and even within different countries:

1) **As a principal staple essential for food security**. Sweetpotato is a daily part of the diet with per capita consumption exceeding 70 kgs/capita per year;
2) **As a secondary or co-staple.** Sweetpotato is eaten 2-4 times a week when it is in season. Per capita consumption varies depending on whether there are 1-2 growing seasons, ranging from 10-40 kgs/capita/year;
3) **As a famine food or disaster-related food.** Sweetpotato often survives when maize fails, hence its reputation as a famine food. Early maturing varieties can be moved in quickly and provide food within 3-4 months in disaster relief efforts providing that planting material can be sourced;
4) **As a "vegetable"**. Sweetpotato is considered as a horticultural crop grown in community, school or home gardens and eaten in small amounts as a complement to the staple food as a vegetable, such as carrots or pumpkin would be;
5) **As a bread substitute or snack food.** Boiled or steamed sweetpotato roots are used principally as breakfast food in lieu of bread or eaten by itself as a snack, particularly by children, during the day;
6) **As a woman's crop.** In most SSA countries, non-commercial sweetpotato production is under the control of women. Projects seeking to target women as producers, potential income earners, and caregivers of young children recognize sweetpotato as an entry point;
7) **As a health food**. Beta-carotene-rich orange-fleshed varieties introduce the new role of sweetpotato as a health food. Interventions wanting to improve the incomes of the poor, and particularly of women, seek to improve marketing opportunities for sweetpotato, either as fresh roots or processed products. The challenges involved with promoting OFSP commercially as a branded product are addressed in the Value Chains Theme paper.

The promotion of OFSP as a nutritious food implies that some kind of nutrition component is required. In her review of 30 agriculture interventions and their impact on nutritional status, Berti *et al.* (2004) found that projects that invested in different kinds of capital (physical, natural, financial, human and social) were more likely to have an impact on nutritional status. The inclusion of nutrition education, taking gender into account, was a particularly critical human capital investment but not might be sufficient to ensure impact on nutritional status.

Field visits in 2008 revealed that many initiatives are underway on a small to medium scale that include OFSP as a component. This reflects the great demand for technologies to address widespread VAD and technologies that target vulnerable groups. In some initiatives, OFSP is the focus of the agriculture intervention; in others it is one crop among several being promoted. Some are just distributing the vines or have OFSP as one of many crops being introduced (agriculture only intervention); others combine agriculture with nutritional awareness campaigns, emphasizing that OFSP is good for health or contains vitamin A; fewer have more intensive nutrition interventions that entail community level programs to change household dietary practices and/or feeding and care practices of young children; some have active market development components; and a handful have associated finance components providing linked savings or credit schemes to their interventions. Yanggen and Nagujja (2006) summarize strategies used in Uganda by a variety of actors.

Table 3.4 provides a summary of 59 existing projects utilizing OFSP in 15 countries as noted during 2008 field visits conducted in May and June. It is not a definitive list by any means, especially for Uganda and Kenya, but provides insights into the types of development efforts (some of which have explicit research components) that are promoting OFSP. By far, the dominant intervention strategy is to promote OFSP alongside other crops (73% of cases) for the benefit of rural households and promote general awareness of the nutritional value of the crop, but do not engage in more intensive nutrition education or market development. Most initiatives at this stage are small in scale, with only 20% of the projects targeting more than 10, 000 direct beneficiary households.

Scaling-out of any intervention is always a challenge, but in the case of OFSP the integrated nature of the intervention provides an additional challenge as nutrition/health interventions have typically been treated institutionally as separate initiatives from agricultural interventions. Moreover, marketing and finance components require an additional set of skills. The key question is whether such scaling-out a fully integrated approach can be done cost-effectively. A major study, known as the Reaching End Users project, is currently underway in Uganda and Mozambique to scale-out an OFSP-focused intervention in agriculture, nutrition, and market development. The intervention was designed to use village-level promoters to supplement extension personnel as a means for reaching a larger number of households. In addition, communities were divided into those that would receive a more intensive intervention (more direct contacts for message transmission for a longer period of time) than other communities. In Uganda, national NGOs are implementing the intervention with significant backstopping from a team with disciplinary expertise in each area and there is one extension agent responsible for all aspects of agriculture, nutrition and marketing. In Mozambique, international NGOs are implementing the intervention, and separate extensionists are assigned for agriculture and nutrition, supervised by separate higher level personnel. There is one higher level agronomist coordinating market development who engages principally with the agriculture extensionists and promoters. Results from this study (due in 2010) will provide insights as to what is the intensity of contact that is needed and what it will cost to succeed in integrating OFSP into the household farming system *and* integrating into the young child diet. The study also will provide insights into developing markets for OFSP in two very different settings —in Mozambique, sweetpotato markets are underdeveloped and transport costs very high; in Uganda, there is a strong, existing marketing system for sweetpotato in which white-fleshed, red-skinned roots predominate and OFSP has to "break into" this competitive market.

Another major initiative reaching large number of households is also in Mozambique. A CIP scientist stationed within the National Institute of Agrarian Research (IIAM) is breeding new, more drought resistant, OFSP varieties in collaboration with Mozambican counterparts and also backstops the multiplication of primary planting material to serve eight provinces in the country and trains partner organizations on multiplication, production techniques and agro-processing. Multiplication plots are maintained by project staff in several provinces and links are made with a wide range of partners (93 district level public sector extension offices and 77 NGOs and CBOs) who purchase the material for further multiplication and/or distribution. In this approach, each partner integrates OFSP into its own programs and in most cases OFSP is not the major focus of the particular programs but part of broader agricultural initiatives, some of which have nutrition components (Andrade *et al.*, 2007). OFSP vines are also used for disaster relief in response to localized droughts and floods. In 2006, after a year of severe drought, a nationally representative survey reported 164,000 households growing OFSP. While small adoption studies have been conducted by the project, no comparative assessment of the performance of different models using OFSP has been done.

In Asia, Helen Keller International (HKI) has taken home gardening (without an OFSP component) integrated with livestock production successfully to scale in Bangladesh, Cambodia, Nepal and the Philippines, indicating that it is possible to go to scale with a garden approach when there is substantial government commitment (Talukder *et al.*, 2000; Bushamuka *et al.*, 2005; Helen Keller International, 2006) In SSA, Faber *et al.* (2006) documented an approach using orange-fleshed sweetpotato as one of many vegetables in community gardens linked to young child growth monitoring programs in South Africa The design of the program aims to ensure a source of vitamin A-rich foods year round as vegetables are often beyond the financial reach of poor households. A nutrition education component is an essential feature in the South African setting as traditionally vegetable consumption was not high in these communities. The South African government has recently incorporated the vegetable garden concept, with OFSP included, into its national school nutrition program. The food production component of the program has the goal of imparting practical skills to students on food production and natural resource management while the goal of the nutrition education component is to empower the children to make healthy lifestyle choices. As of April 2007, 6390 schools country-wide had established gardens. The program works in collaboration with the National Research Program (ARC) and FAO (Maduna, 2008). The major challenges revolve around the management of the gardens themselves. The program is in its initial stages and will generate important lessons regarding public sector support of school garden initiatives.

Clearly there are many potential delivery mechanisms for OFSP. The degree of complexity of the intervention will determine the level of expertise required for implementation and this, in part, drives the kinds of partnerships needed, especially when interventions are scaled to reach a large number of beneficiaries. This undoubtedly will vary by country due to differences in agro-ecological settings and the human and financial capital available to implement, and the level of development of the target populations.

Table 3.4. Summary of type of on-going development projects utilizing OFSP in SSA in 2008.

	Number of projects using OFSP	Scope of the Intervention: Number of projects targeting small, medium, and large Numbers of direct beneficiary Households (HHs)			Model used for the intervention: Number of projects/organizations using different approaches to OFSP introduction (Ag=Agriculture; NutAw=Nutrtion-Awareness only; NutInt (Nutrtion-Awareness + Behavioral Change Component; Mar=Marketing; Fin=Finance (Credit/Savings)									
		Small (<2000 HHs)	Medium (<2000-10,000 HHs)	Large (<10,000 HHs)	Emergency or resettlement: Ag only	Emergency or resettlement: Ag + NutAw	OFSP promotion Ag only	OFSP promotion Ag + NutAw	OFSP promotion Ag + NutInt	OFSP promotion Ag + NutAw + Mar	OFSP promotion Ag +NutInt + Mar	OFSP promotion Ag + Mar	OFSP promotion Ag + NutAw + Fin	OFSP promotion Ag +NutAw + Mar + Fin
Countries														
East and Central Africa														
Kenya	6	3	3	0	0	0	3	0	1	2	0	0	0	0
Uganda	7	1	4	2	2	0	1	1	0	2	1	0	0	0
Ethiopia	2	1	1	0	0	0	2	0	0	0	0	0	0	0
Tanzania	5	4	1	0	0	0	1	0	0	0	1	1	1	1
Rwanda	3	3	0	0	0	0	1	1	0	1	0	0	0	0
Burundi	2	1	0	1	0	0	1	1	0	0	0	0	0	0
Southern AFrica														
Mozambique	15	5	5	5	1	0	2	11	0	1	0	0	0	1
Malawi	2	0	2	0	0	0	0	2	0	0	0	0	0	0
Zambia	5	2	2	1	0	0	3	0	1	0	1	0	0	0
South Africa	4	2	1	1	0	0	2	1	0	0	0	0	0	0
Madagascar	4	3	1	0	0	0	2	1	1	0	0	0	0	0
Angola	0													
Zimbabawe	1	0	1	0	1	0	0	0	0	0	0	0	0	0
West Africa														
Ghana	1	0	0	1	0	0	0	1	0	0	0	0	0	0
Nigeria	0													
Burkina Faso	1	1	0	0	0	0	0	1	0	0	0	0	0	0
Mali	1	0	0	1	0	0	0	0	0	1	0	0	0	0
Niger	0													
Total	**59**	**26**	**21**	**12**	**4**	**0**	**18**	**20**	**3**	**7**	**3**	**1**	**1**	**2**

Table 3.4. Summary of type of on-going development projects utilizing OFSP in SSA in 2008 (continued).

	OFSP focus of intervention		Partnership diversity: Number of projects with involvement of category of organization: CG=CGIAR center; NARS=National Research Pgm; Ext=Public sector extension; CBOs: community-based organizations								
Countries	**OFSP: Only crop promoted**	**OFSP: one of several crops promoted**	**CG**	**NARS**	**International NGOs**	**Local NGOs**	**CBO**	**Public Sector Ag Ext**	**Public Sector Nutrition / Health Ext**	**Private Sector**	**Univ of other advanced research institutes**
East and Central Africa											
Kenya	3	3	2	4	0	4	2	0	1	1	3
Uganda	5	2	2	3	4	4	5	1	0	0	2
Ethiopia	0	2	0	0	2	0	1	1	0	0	0
Tanzania	1	4	0	2	4	4	2	1	1	0	1
Rwanda	0	3	0	3	2	2	3	0	2	0	0
Burundi	1	1	0	1	1	0	1	1	0	0	0
Southern AFrica											
Mozambique	3	12	2	3	12	2	2	7	3	0	1
Malawi	0	2	2	2	2	2	1	2	1	0	0
Zambia	0	5	0	4	3	1	3	3	1	1	0
South Africa	2	2	0	4	0	0	2	2	2	1	1
Madagascar	0	4	0	4	1	0	1	3	0	0	0
Angola											
Zimbabawe	0	1	0	0	1	0	0	1	0	0	0
West Africa											
Ghana	0	1	0	1	0	1	1	1	0	0	1
Nigeria											
Burkina Faso	1	0	0	0	1	0	0	1	0	0	0
Mali	0	1	0	1	1	0	1	0	0	0	0
Niger											
Total	**16**	**43**	**8**	**32**	**34**	**20**	**25**	**24**	**11**	**3**	**9**

Table 3.4. Summary of type of on-going development projects utilizing OFSP in SSA in 2008 (continued).

	Chidren < 6yrs of age	School going children	Women of Reproductive Age	Pregnant Women	HIV affected communities	Refugees or Recently Resettled Populations	Rural Households in General (all members)	Urban Consumers
Countries								
East and Central Africa								
Kenya	1	0	0	0	0	0	5	1
Uganda	1	1	2	0	0	4	3	0
Ethiopia	0	0	0	0	0	0	2	0
Tanzania	0	0	0	0	3	0	2	0
Rwanda	0	0	1	1	1	0	2	1
Burundi	0	0	0	0	0	1	2	0
Southern Africa								
Mozambique	1	1	4	1	2	0	14	0
Malawi	0	0	0	0	0	0	2	0
Zambia	0	0	0	0	1	0	4	0
South Africa	1	1	1	0	0	0	3	0
Madagascar	0	0	0	0	0	0	4	0
Angola								
Zimbabawe	0	0	0	0	0	1	1	0
West Africa								
Ghana	0	0	0	0	0	0	1	0
Nigeria								
Burkina Faso	1	0	1	0	0	0	0	0
Mali	1	0	0	0	0	0	1	0
Niger								
TOTAL	**6**	**3**	**9**	**2**	**7**	**6**	**46**	**2**

Future areas of work for consideration:

1) More in-depth understanding of adoption rates and nutritional impact achieved in programs where OFSP is one of many crops introduced and/or has distinct role in the food system that has yet to be investigated;
2) *Ex-ante* studies of the potential scalability of different delivery systems for OFSP, identify potential bottlenecks and synergies with other components of the intervention;
3) Development of monitoring and evaluation systems that could be realistically implemented in projects going to scale with the perspective of establishing norms to ensure the collection of baseline data essential for evaluating progress and ultimate impact.

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CHALLENGE THEME PAPER 4: SWEETPOTATO VALUE CHAINS

Graham Thiele, John Lynam, Berga Lemaga, and Jan Low

Overall Challenge: How do we improve the value chain for sweetpotato given its bulky nature, undiversified use, and image as a poor man's food?

BACKGROUND

Sweetpotato roots are bulky and perishable unless cured. This limits the distance over which sweetpotato can be economically transported. Production areas capable of generating surpluses tend to be relatively localized but dispersed, which leads to a lack of market integration and limits market size. Moreover, production is highly seasonal in most countries leading to marked variation in the quantity, and quality, of roots in markets and associated price swings. There is little commercial processing into chips or flour, which could be stored for year round consumption for use in ugali, bread and cakes, or processing into fermented and dried products like fufu. Sweetpotato consumption tends to decline as incomes rise, a change often linked with urbanization, partly because it is perceived as a "poor man's food" but mostly because of the change in relative prices of root crops compared to grains in urban areas due to transport cost differentials.

Addressing this challenge means improving the sweetpotato value chain, understood as including all the actors from input suppliers (appropriate varieties, vines) to farmers, traders and consumers (Figure 4.1). More broadly the value chain also includes a) the institutions or regulatory framework which structures the way in which transactions occur in the chain and b) the service providers, including research and development organizations, who help to improve its functioning. A value chain approach means more than looking at markets. It includes changes in seed and production systems to improve the value added in market, implying strong linkages with crop management. Quality is often a key factor determining entry into urban markets and root quality starts with appropriate crop management techniques. It seems likely that significant changes in crop management will only occur where farmer investment and intensification are justified by improved market prospects.

This Challenge essay also includes post harvest processing or storage. This can lengthen the period for which sweetpotato can be marketed but may also be relevant for subsistence oriented households to increase the period over which sweetpotato can be consumed, particularly where there is a marked dry season.

As we will discuss later, because of its novel attributes and potential for improving nutrition, orange-fleshed sweetpotato (OFSP) presents particularly interesting prospects for market development.

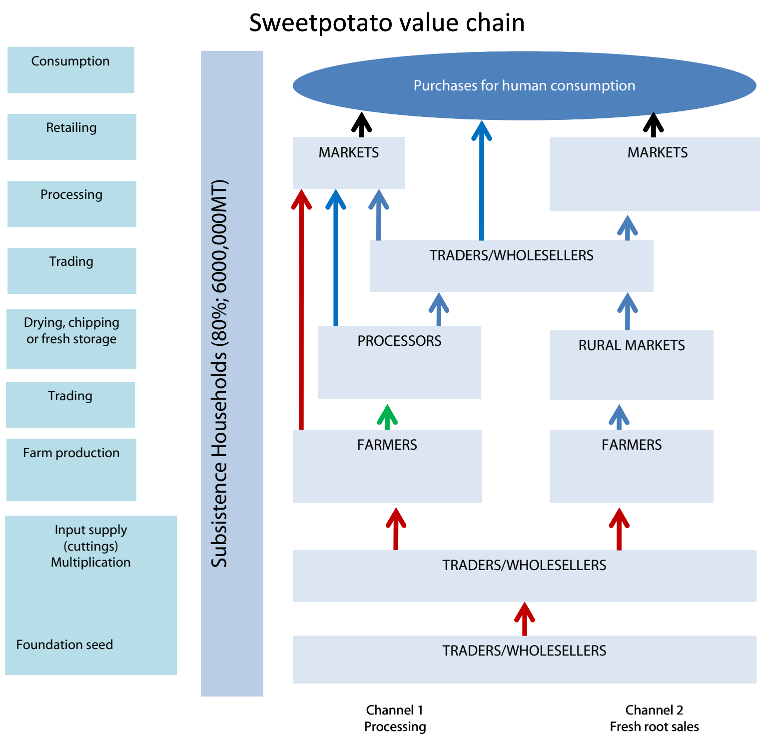


Figure 4.1
Sweetpotato value chain.

Improving the sweetpotato value chain should lead to a linked set of impacts on the livelihoods of the poor including:

1) Increased income of those selling sweetpotato with particular advantages for women who often take the lead in managing this crop.
2) Reduced expenditure on food of those purchasing sweetpotato roots or processed products; and
3) Enhanced nutrition for those producing and purchasing sweetpotato (especially OFSP).

Since sweetpotato is grown extensively by poorer rural households and in many parts of Sub-Saharan Africa (SSA) is managed by women, market chain development of the crop naturally "targets" poor rural women and their households. Sweetpotato market chain development will require a gender-sensitive approach to monitor intra-household control of resources dedicated to or coming from sweetpotato production and commercialization. From such understanding strategies for assuring gender equity can be devised.

PRINCIPAL CHALLENGES

Challenge 4.1. Limitations of size for sweetpotato markets

Current knowledge

Sweetpotatoes are principally grown in food systems in SSA dominated by root crops and bananas/plantains and secondarily grown in maize-based systems. Sweetpotatoes are a strategic and flexible part of these food systems. Early maturing varieties of around three months are first to come into production to end the "hunger season" and these are often improved materials. Due to their flexible planting times and range of maturity periods farmers can manage the supply period if not constrained by an extended dry period. This helps ensure continuity of staple food supply, both for home consumption and market, so that producers can take advantage of generally higher staple food prices early in the growing season. In the root crop belt of West Africa sweetpotatoes complement the supply periods of cassava and yams, the two principal crops in those food economies. The interacting roles and development potential of the different root crops in West Africa are compared in Table 4.1.

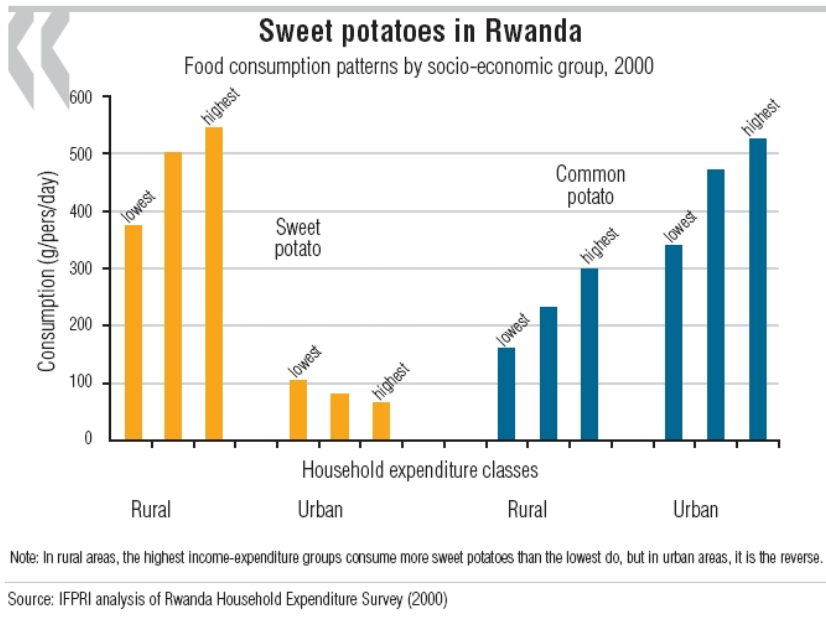
Table 4.1. Comparison of different root crops in the food economies of Coastal West Africa.

	Cassava	Yam	Orange-fleshed Sweetpotato	White-fleshed Sweetpotato
Importance	Very high	High	Low	Medium
Productivity	Very high	High	Low	Can it compete with cassava?
Preference	Mass Consumption Gari	Mixed processed and fresh, festive food	Niche crop Fresh, Potential	Niche, fits in system in seasonal way
Producers	Commercial	Mixed	Village level	Village level
Research issue	Industrial quality	More commercial system	Quality, Taste, Dry matter to develop market	Productivity, Market chain in competition with cassava, yam
Seed system	Relatively simple	More difficult	Dependent on vines and water	Dependent on vines and water throughout year
Uptake/Upscaling	Market-led	Local	Institutional, school feeding, relief programs, and local procurement for institutional programs	Move from village niche to market system
Link to Goal	Income, the pathway out of poverty for producers	Limited growth of preferred food fighting change in consumption habits	Develop consumption, make it preferred good, raise productivity, create vine system	Income, eventual industrial use

In countries with two rainy seasons (for example, Rwanda, Burundi and Uganda) sweetpotato is available 11 months of the year and is a primary staple. Elsewhere in SSA, where there is only one main growing season, sweetpotato is available 4-8 months of the year and it is a secondary staple (Low and van Jaarsveld, 2008). Marketable surpluses are seasonal and come from more specialized production zones. It is not economically feasible to transport sweetpotato from distant locations or from areas with poor road infrastructure (Hall *et al*., 1998). Farmers in less favored locations often report that marketing sweetpotato is difficult; either markets are too distant using local transport or farmers are forced to be price takers of a sole trader serving the area. The risks of oversupply are greater in rural locations distant from significant urban populations, as reported in Rwanda and elsewhere, so that when harvests are heavy no market exists for extra production (S. Karitanyi, personal comment 2008).

Discontinuous supply from relatively specialized production zones, high transaction costs (see Challenge Paper 5) and the bulky and perishable nature of the root leads to relatively high marketing costs, increasing prices to urban consumers. In some rural areas in Eastern and Central Africa, sweetpotato is heavily consumed (annual per capita consumption of over 80 kg). In most other rural areas, it is a secondary staple consumed 2-4 times per week when in season. Boiled and steamed roots often serve as a breakfast food. With the exception of some cities such as Kampala (Uganda), sweetpotato plays a more limited role in urban diets, often as a breakfast or snack food. Anecdotal reports suggest that it is perceived as an inferior good or "poor man's food" (Wheatley and Loechl, 2008; GTZ, 1998). Some consumers report not liking to eat much sweetpotato as it can cause flatulence (due to undigested and dietary fiber). The degree to which cooking controls the flatulence varies by cultivar (Tsou and Yang, 1984) and improved techniques are needed to evaluate this negative varietal characteristic. Whilst many observers agree that sweetpotato has become more important in urban markets, with its use as a bread substitute being particularly important, this has not been clearly documented. In general, there is a dearth of precise information about the consumption of sweetpotato. One study from Rwanda (Figure 4.2) shows how consumption of sweetpotatoes is substantially lower in urban areas and falls with increasing income, confirming that here it is an inferior good in urban areas (DeWalt, 2007).

Figure 4.2
Food consumption patterns of potato and sweetpotato by socio-economic group in Rwanda



The dispersed and seasonal nature of sweetpotato production, high costs of marketing (lack of processing opportunities), competition with other staples, the periodicity in the diet and limited consumption in towns, lead to low volume or "thin" urban markets in those SSA countries where it is a secondary staple. This limits the adoption of productivity enhancing technology as additional supply leads to sharp price falls. This expectation may choke off production increases or technology adoption. The multiple causes of thin markets means that there is no single critical entry point into sweetpotato value chains that would release a transformation of production and consumption. Any such transformation would have to take place across the value chain.

The promotion of orange-fleshed sweetpotato (OFSP) or diversified use into processed products (this strategy is discussed in Challenge Paper 3) could potentially drive such a transformation of the value chain. Both strategies rely on the development and marketing of a new product. An alternative or complementary strategy would be to extend the supply period through the year (this strategy is discussed in Challenge Paper 2), either through storage or extension of the production period.

A market transformation strategy based on the introduction and promotion of OFSP will need to be adapted to the very different market contexts for sweetpotatoes across Africa. Three relatively broad contexts are characterized in Table 4.2. In both West and East Africa, OFSP will have to break into markets with strong existing preferences, for example, for highly preferred high dry matter, white or yellow-fleshed varieties, in most of these two regions. In the Southern African context, the challenge is to build market demand where sweetpotato is consumed seasonally as a secondary staple and there are no strong preferences at present, as is the case in Mozambique and particularly in countries emerging from conflict. Experience from pilot projects in Mozambique suggests that the second context will be less problematic for market penetration of OFSP (Low *et al.*, 2005).

Table 4.2. Comparison of market contexts for introduction of OFSP in different African sub-Regions.

	West Africa	**East Africa**	**Southern Africa**
Consumer Preferences	High Dry Matter Poundability	High Dry Matter	No Strong Preference
Sweetpotato (SP) Market Penetration: ▪ **Local Market** ▪ **Urban Market**	High Low	High Medium	Medium Low
Continuity of Supply	Different Root Staples	Varies in Different Production Regions	Seasonal

Many projects and research and development organizations have enthusiastically promoted OFSP in communities in SSA, and especially in Mozambique, Uganda, Tanzania, Kenya and Rwanda. This has led to considerable adoption in pilot communities and increased consumption of OFSP amongst the rural families involved, and in Mozambique, health impacts have been demonstrated (Low *et al.*, 2007). As of 2008 very limited quantities of OFSP were reaching urban markets in Uganda, Tanzania, and Rwanda; more in Kenya. Some market traders had seen OFSP roots in these countries but few were apparently aware of any nutritional benefits and often they would mix them with white and yellow roots so that they could be sold. There was no evidence of any price premium for OFSP in this group of countries, and sometimes OFSP incurred a price penalty when traded. The exception was Mozambique where in the Gurue market in 2007, OFSP was selling in separate piles at about a 20% premium over white fleshed sweetpotato (Thiele visit report) and in areas of Zambézia with very limited purchasing power OFSP sold faster (Low *et al.*, 2005). Here radio campaigns and work with market traders had successfully shifted consumer perceptions generating this premium. This provides proof under these market conditions that demand creation can effectively differentiate OFSP from white fleshed sweetpotato and generate a price premium.

As a new product in urban markets, OFSP has unique visual and health attributes for consumers which offer potential for brand identification. This could be reinforced by supplying markets with higher quality roots and possibly grading. Introducing OFSP varieties alone has limited potential for success. Rather, introduction must be associated with adjustments through the value chain, driven by awareness and demand creation associated with improved health status for consumers. If demand can be created for a high quality product, there is potential for a price premium emerging compared to white fleshed sweetpotato, further motivating farmer adoption of OFSP varieties.

Demand creation should look for particular market entry points. It could start with nutritional education in school feeding programs or with changing product perceptions at the high end of the market, through promotion in supermarkets which are rapidly expanding in cities in SSA. The latter option is being tested in Kenya and Tanzania, combined with supplies of indigenous African vegetables, both of which focus on improved nutrition. This promotion as a vegetable among high-income consumers has the potential to spill over into urban markets supplied through the traditional wholesale markets. In Mozambique, painted market stalls, signs on buildings, decorated cloth for women, radio programs, community theater, and training traders to market OFSP are employed to create awareness of OFSP's nutritional qualities and build demand for purchase.

Demand creation should be based on an understanding of the role of sweetpotato in food systems. In Central and East Africa there is often a cultural perception that sweetpotato is a "sweet" food most appropriate for women and children. This creates a natural link to some of the most vulnerable groups for a nutrition intervention around OFSP but is a possible barrier for wider market penetration. Similarly, adults prefer high starch content varieties, while children prefer the softer, lower starch roots.

Areas for future work (not necessarily in order of importance):

1) Study urban and rural markets to understand volumes, preferences and market structure for SP and OFSP.
2) Identify specific market opportunities where increased production could be absorbed e.g. OFSP in school feeding programs.
3) Analyze role of SP and other staples in urban diet and cultural perceptions of different foodstuffs in order to change product image and consumer behavior.

4) Develop campaigns for urban consumers to shift perceptions and develop new product concept of OFSP as a healthy, visually attractive and "modern" foodstuff.
5) Develop and test strategies for market penetration of OFSP in different market contexts.

Challenge 4.2. Perishability and availability

Current knowledge

In most places in SSA there is a marked dry season and sweetpotato is only produced part of the year. Roots are perishable, and unless cured or placed in stores, will likely not be marketable 1-2 weeks after harvest. Market traders in Nairobi and Kampala reported selling consignments within 3 to 4 days after arrival before rotting occurs (Omosa, 1997; Hall *et al.*, 1998).

Roots can be stored in the ground for an additional period but they are attacked by weevils when soil is dry and cracked. This leads to a marked seasonality of supply with substantial price variability and deterioration in quality as the dry season progresses. Seasonality of supply creates a barrier to increasing per capita consumption and income earning possibilities both for fresh sales and for processing. There are some places, such as Rwanda, where production occurs in wetlands outside the rainy season and seasonality of supply is less marked.

Farmers have developed "In ground storage and piecemeal harvesting" technology to maintain the supply of fresh sweetpotato for as long as possible (Hall *et al.*, 1998). In Uganda this involved:
Staggered planting, so that crop will not all mature simultaneously.
Menu of varieties with different characteristics including maturation time to make fresh sweetpotato available over a longer period and provide roots with different post harvest characteristics e.g. yield, in ground storability and taste.
In ground storage of roots after maturity, for up to six months.
Piecemeal harvest of roots needed for immediate use.

Piecemeal harvesting is an indigenous practice which may reduce weevil losses as more superficial and potentially damaged roots are harvested first (Smit, 1997). Some work has been done on integrated pest management (IPM) to extend the cropping season and lengthen the period of in ground storage (see Challenge Paper 5 on Crop Management).

Farmers in areas with marked dry seasons in Uganda and Tanzania sun dry sweetpotato to extend the period when it may be consumed. In Uganda, roots are sliced (*amokeke*) or crushed (*inginyo*) before drying (Hall *et al.*, 1998). *Amokeke* is reconstituted whole as a breakfast food and *inginyo* used for flour to produce atapa, a starchy staple. In Tanzania roots are sliced fresh (*vichembe*) or after boiling (*matoborwa*) before drying. These products can be stored for six months in Uganda, and perhaps longer in Tanzania. Attack by insects limits storage period. Artisanally dried products are mostly used for home consumption with limited commercialization, probably because they are not competitive with dried cassava chips. Slicing and drying by hand is labor intensive for processing large quantities when fresh storage would be preferable, but is an option for dealing with small quantities at a time.

If farmers could store fresh roots they could benefit from higher prices at the end of the harvest season. In practice there is little use of pits, clamps (mounds of sweetpotato sealed with earth to maintain humidity and keep out pests) or other types of stores in SSA; Malawi is an exception, although these are used in other parts of the world (Hall and Devereau, 2000). Research by the Natural Resources Institute (NRI) on low cost storage using pits and clamps with thatched roofs showed that storage up to 4 months is possible. Stored roots are fit for home consumption but sell with a price penalty or may not be marketable because they lack the "just from the garden look" which consumers expect in fresh products (Hall and Devereau, 2000). Low cost storage was validated by NRI in Tanzania. Adoption of stores for commercial use depends upon the expected price difference between the time of harvest and the moment of sale and this is variable across and within countries. A much higher price out of season was encouraging adoption of storage in Tanzania in 2004 (RIU, 2007). A cost benefit analysis of stores for home consumption in Uganda showed much higher rates of return than for any other sweetpotato enterprise (Wheatley and Loechl, 2008).

Sweetpotato roots respire during storage, but this can be reduced by curing. Curing sweetpotato roots at about 29ºC with high humidity for four-seven days prior to storing at 12-14ºC is used commercially in the United States to heal wounds, protect against disease, reduce shrinkage and extend storage (Kemble 2004). High ambient temperatures may mean that this type of curing is not applicable in SSA (Hall and Devereau, 2000). NRI has tested pre-harvest curing by removing sweetpotato foliage 14 days before harvesting, which reduced post harvest losses by up to 40% (RIU 2007). Breeding is possible to improve storability as shelf life is a varietal characteristic, but it appears that cultivars that lose weight rapidly rot more (Rees *et al.*, 1998).

Areas for future work:

1) Work on improving in ground storage together with IPM to extend availability of white/yellow fleshed SP and OFSP in areas with reasonable market access and sufficient levels of productivity to be competitive in urban markets (linked with Challenge Paper 5)

2) Participatory research and economic analysis of curing and low cost storage in market related pilots (linked with understanding seasonality of supply and price premium associated with out of season production).
3) Varietal development to offer most diverse set of harvesting periods with broad array of post harvest characteristics (linked with Challenge Paper 1).

Challenge 4.3. Processed sweetpotato products are mostly unknown in Sub-Saharan Africa

Current knowledge

Sweetpotato is a bulky and perishable root. If it could be converted into processed products this could increase consumption by allowing it to be transported further and stored longer. An increase in the size of the market would also create new income earning possibilities and add value for farmers. Processed sweetpotato products targeted at higher income groups and promoted with brand identification would help break the image of sweetpotato as a poor person's crop.

But, as far as could be judged from field visits and a review of the literature, neither locally nor improved processed sweetpotato products of white/yellow or orange fleshed sweetpotato are of any real commercial importance on a large-scale at the moment. Many pilot initiatives selling sweetpotato processed products exist, particularly in Uganda, Kenya, and Mozambique, on a limited scale. OFSP flour is being marketed in supermarkets in Nairobi.

The past year has seen marked rises in the prices of internationally traded grains, which are likely to be sustained, although probably at somewhat lower levels than present. Wheat and maize prices for grain and flour have increased in many SSA countries as a result. Sweetpotato is not traded internationally and surveys in many markets suggest that its price has not increased so sharply. This makes sweetpotato relatively more competitive compared to wheat, assuming this compensates for other cost disadvantages in the supply chain.

In countries with two rainy seasons (Rwanda, Burundi and Uganda) sweetpotato is available most of the year. In most other SSA countries it is not available during much of the dry season, limiting the period of consumption. This gap has stimulated research on the consumer acceptability, nutritional value and the enterprise viability of a variety of processed sweetpotato products, which are discussed below.

Sweetpotato can be chipped and dried. At the village level, women slice the sweetpotato into thin round chips by hand. Commercially oriented operations require an investment in chippers, with manual, bicycle driven and motorized versions available, and drying racks. Analysis of a pilot initiative in Uganda indicated that chipping with white SP varieties was not financially viable (Wheatley and Loechl, 2008). Dried chips can be milled to make sweetpotato flour. This adds more value for farmers, and reduces volume for transportation, and was financially viable in a pilot trial. But it is difficult for farmers to maintain quality (a) because they cannot determine moisture content and may mill chips which are not properly dried and (b) it may contain impurities as farmers use public mills (Wheatley and Loechl, 2008).

The largest flour market is for staples such as ugali. White fleshed sweetpotato flour would have to compete on price and quality with cassava and maize flour in this market. Since fresh sweetpotato tends to sell at a higher price than cassava this could be difficult. In addition, in East Africa sweetpotato flour was less acceptable for some staples; for example, consumers did not prefer sweetpotato ugali because of its sweet taste (Omosa, 1997 reported in Wheatley and Loechl, 2008). In East Africa, it appears that the clearest market for sweetpotato flour would be as a substitute for wheat flour in the production of the snack foods, chapattis (flat unleavened bread) and mandazi (doughnuts) and porridge, where sweetness is not an issue. In Kenya, a processor chain began in 2005 that consists of one contact farmer, one miller and a distributor (Touchstone) which supplies the OFSP flour to Uchumi supermarkets and other markets in Nairobi. The contact farmer buys OFSP (preferring medium-sized roots of the Ejumula variety) from other farmers, from which he makes chips. He then delivers the chips to the miller who makes OFSP flour and packs and delivers it to the distributor, who is based in Nairobi. The flour is packed in half kilogram bags (Kaguongo, 2007). In 2007, farmers were complaining that the price being offered was too low compared to the price for fresh roots and often supply the contact farmer with roots of secondary quality, selling first quality roots on the local market. The OFSP flour marketed in Nairobi is targeted at higher income consumers for these purposes and is located in the specialty flour section in supermarkets.

Owori and Hagenimana (2001) reported several factors that might limit adoption of sweetpotato as a raw material: sweetpotato flour is of a lower quality than wheat flour, and bakers, who are used to managing and storing dried ingredients, reported that washing, peeling and boiling sweetpotato required too much labor time. The seasonality of supply of fresh roots could be a further problem for bakeries, although less so in countries such as Rwanda where there is more dry season production. Experience with other composite flours in Africa suggests that flour mixing is not viable at the mill level but rather at the bakery. However, organizing value chains for sweet potato flour are organizationally complex when compared to mills located in urban areas grinding imported wheat.

In tests with consumers, boiled and mashed sweetpotato gave products with the highest consumer acceptability, and snack sellers reported that they could sell these for the same price as those made solely from wheat flour (Hagenimana and Owori, 1997 reported in Wheatley and Loechl, 2008). Bread made with fresh mashed sweetpotato was preferred by consumers to bread made only from wheat flour. Sweetpotato as flour or mashed lowered costs and increased the net revenue of snack food sellers and bakers. Mandazi made with mashed sweetpotato absorbs considerably less oil (an expensive ingredient) than those made with wheat flour alone (Hagenimana *et al.*, 1998).

OFSP either mashed or as flour potentially offers a new set of attributes which could make sweetpotato based processed products more competitive. Improved nutritional characteristics because of beta-carotene and an attractive orange color mean that sweetpotato could command a price premium and break out of direct price competition with alternative flours. Links have been created with millers and OFSP has been supplied to make sweetpotato flour in Nairobi and a composite flour for porridge in Kampala (Wheatley and Loechl, 2008; Horton, 2008).

Consumer research has shown that some food products containing OFSP such as golden bread are of good quality and acceptable to consumers, especially children. Studies of flours and other processed products indicate that provided high beta-carotene varieties are used and chips are stored for less than four months, Vitamin A levels remain sufficiently high after processing for these products to make a significant contribution to Vitamin A deficiency (Bechoff *et al.*, 2008a; Bechoff *et al.*, 2008b).

Consumer taste tests in a market in Mozambique showed a strong preference for golden bread made with boiled and mashed sweetpotato (38% of weight of wheat flour) over conventional white bread because of heavier texture, superior taste and attractive golden colour. A 110g bun would provide 45% of the Vitamin A requirement of a three year old child. Profits when baking golden bread increased by 54 to 92% because sweetpotato had a much lower cost than expensive imported flour. At rural locations where wheat flour is at least 1.5 times more expensive per kg than fresh sweetpotato, the cost advantage of OFSP is higher. For rural bakers, boiling and mashing sweetpotatoes was not seen as a problem but urban bakers with larger volumes might need specialized equipment (Low and van Jaarsveld, 2008). The major constraint is assuring sustained supply of roots to bakers. Research is on-going in Mozambique to improve the bread value chain. In addition, there could be concerns on the part of bakers on meeting quality standards (G. Sina, personal comment 2008).

OFSP has also been used for making niche products including juice and sweetpotato crisps. OFSP juice requires the addition of citric acid, it is readily accepted by consumers and a snack shop in Mozambique sells it on a commercial basis. OFSP crisps have been piloted by a commercial company in Kampala (Horton, 2008). These products are targeted at higher income groups and can serve a similar function of changing the image of OFSP and stimulating wider consumption. Lessons could be learned from similar programs such as CIP's through Papa Andina Initiative which promoted native potatoes in the Andes building on unique attributes of attractive visual appearance and Andean origin. Here, promoting niche products, with low volumes, such as chocolates made with dried potato, helped shift consumer perceptions of native potatoes as a poor man's food. Promotion of the use of niche products like OFSP juice could have a similar function in SSA.

Sweetpotato is sometimes mentioned as a source of starch. But this is unlikely to be a commercially viable venture in SSA because sweetpotato starch here lacks any compelling functional advantage over alternative sources and raw material costs are relatively high (Wheatley and Loechl, 2008).

Areas for future work:

1) Develop a strategy for increasing consumer demand for sweetpotato and especially OFSP building on its unique attributes. This requires the development of general product concept for OFSP based processed foods relevant for the particular country setting and target group.
2) Develop approach for scaling up golden bread production which addresses hidden costs of shifting from use of dry ingredients to fresh roots and quality concerns.

Challenge 4.4. Limited coordination among actors in sweetpotato value chain

Current knowledge:

Sweetpotato is usually transported relatively short distances because of its bulky and perishable nature. This leads to the emergence of geographically distinct supply chains, with particular arrangements of market chain actors, distinct varietal preferences and sets of linked service providers. For example, the Dar es Salaam market preferences are for white skinned varieties whereas in Mwanza the preference is for red skin.

The value chain begins with vine producers. Specialized vine producers are not common in SSA, and farmers ordinarily produce their own vines. Farmers supplying urban markets are often located in areas with some specialization in sweetpotato, although they continue to be relatively diversified. Commercial cultivation of sweetpotato with larger plots intended primarily for sale is exceptional. In Uganda, larger farmers are found on main roads in Soroti and Kumi serving Kampala and other major provincial cities. (Hall *et al.*, 1998). South Nyanza district in Western Kenya has large scale production to address year-round demand in Nairobi and a peak demand period for Ramadan in the coastal areas.

Private brokers or middlemen often purchase sweetpotato in production areas with a more commercial orientation. They agree prices, amounts and time of harvest with producers and may harvest and bag to ensure quality. They assemble truck loads from numerous small farmers located in what are usually diversified, smallholder systems. This leads to high transaction costs. Transport costs along poor roads may take up a large percentage of the margin between farm gate and wholesale price. One study in Uganda found that brokers made a profit of 5% of the farm gate price (Hall *et al.*, 1998).

A study in Uganda found that packing, handling and filling of sacks used to transport roots to urban markets can be rough, contributing to physical damage. Forcing roots into overfilled sacks with an extension so that a 100kg sack can hold 120kg further increased the probability of scuffing and cuts. The use of overfilled bags in Uganda was linked to taxes, market dues and handling charges being made on a per bag basis. Despite this treatment the study concluded that contrary to popular belief physical losses in the marketing chain were low (Hall *et al.*, 1998).

Larger cities in East and Central Africa sometimes have larger markets assuming a wholesale function, where whole bags are sold to retailers who operate in the same market or elsewhere. Trade in wholesale markets in Dar es Salaam is controlled by commission agents, who broker transactions between assemblers and retailers and charge a flat rate per bag (RIU 2007 and G. Ndunguru personal comment). This structure often limits farmers' access to urban markets.

In general there are no regulatory systems which enforce grades by size and quality standards in sweetpotato value chains. Sweetpotato is usually bought and sold on the basis of volume, rather than weights. Rwanda is an exception here, where scales are found and used in urban markets and prices were quoted by weight. In most urban markets sweetpotatoes are sold in heaps. A study in Mwanza (Tanzania) described how heaps of 5-7 roots were sold at fixed prices but that in any sale additional roots, making up 10-20% of total weight would be provided as a "top up". Heaps were sorted into small, medium and large roots which sold at different prices. Medium sized roots received a relatively higher price per unit weight, and the preferred Sinia variety sold at a price premium of 14% above Polista. Cut and damaged roots were valued by traders at 93% of the price of good roots, and weevil infested roots were valued at 64% (Ndunguru *et al.*, 1998). Weevil damage may affect a majority of roots marketed in some areas when the crop is harvested in the dry season (G. Thiele, personal observation Mwaloni market, Mwanza). In Kigali, retail market varieties with different skin colour were mixed in the same heap but roots were sold by kg (G. Thiele, personal observation).

Collective action by farmers has been promoted as a means of reducing transactions costs in assembly for getting to a cost-effective volume (namely a lorry load), and of attaining bargaining power in market transactions. Thin and seasonal markets limit the potential gains to collective action, particularly when supplying local markets. In areas of commercial production for urban markets, such as exist in Uganda, either local traders organize the assembly and transport or traders based in urban markets come to the production areas, often doing the harvesting. Traders based in production areas have an advantage in organizing collective action around assembly but must rely on brokers in urban markets to break down the lorry load. Traders based in urban markets have better market intelligence and networks of retailers but are less efficient in assembly. Achieving increased efficiencies through the whole fresh root marketing chain thus appears limited to improving the efficiency of trader/broker collection practices unless there are major structural changes in urban wholesale markets allowing farmer access at lower transaction costs.

A number of different models have been tested for intervening in sweetpotato value chains:

Model 1: Proactive market creation and creation of OFSP traders group

The Towards Sustainable Nutrition Improvement (TSNI project) used a pro-active market creation model to introduce OFSP products to the market which was thin and undeveloped in Central Mozambique. It helped farmers sell to local traders, who sell to other rural consumers or local small businesses which use OFSP as a raw material (bakers, etc.). Local traders were helped to acquire OFSP booths, painted a distinctive orange color to create brand awareness, and placed in accessible locations. Quality grades were introduced and only first and second quality OFSP were purchased, with first quality roots receiving a higher price (Low *et al.*, 2005). This type of intervention requires careful identification and training of appropriate traders and good site location, which restricts its scalability.

Model 2: Direct linkages of producer groups with urban markets

The NGO Farm Concern organized OFSP producer groups to establish partnerships which take over assembly and sell roots directly to wholesale traders, supermarkets and millers in Nairobi using the Commercial Village concept (Kaguongo 2007). Producers contracted the services of truckers for transport. They were able to capture more marketing margin and displace the assemblers on whom they had depended before.

Model 3: Developing local processing enterprises

Farm Concern helped OFSP farmers sell to a small local enterprise making SP dried chips, the miller produces flour as a service to the enterprise (fee per kg), the enterprise packages the flour, and sells to a registered market development firm that identifies outlets (Touchstone), and sub-contracts a distributor to deliver the product to large-scale supermarkets, private millers who make nutritious porridges and flours and other outlets.

Model 4: Direct linkages of producer groups with institutional markets (schools, tertiary institutions and hospitals)

The Sweetpotato Coalition project in Central Uganda linked 37 sweetpotato farmer groups with 20 local institutional markets. Farmers responded positively and sold sweetpotatoes but some were disappointed by a lack of timely payments. Rural-based pilot processing centers where used to market dried chips to millers and to process and sell sweetpotato snacks and juice in local markets (Wheatley and Loechl, 2008).

Model 5: Build trust between farmers and other market chain actors and stimulate innovation and product development to add more value

CIP and PRAPACE applied the Participatory Market Chain Approach (PMCA) with the sweetpotato value chain in Uganda (Bernet *et al.*, 2006). The PMCA is a short shock treatment which improves market chain coordination. It gets market chain actors talking to each, builds trust and sets in motion the development of market oriented innovations. The PMCA engaged farmers, market traders, representatives of marketing bodies, processors and exporters. It led to the exploration of four innovations:

Development of an orange-fleshed sweetpotato crisp product.
Construction of the kiosk for marketing sweetpotato products in the Kalerwe market.
Development of two brands of porridge mix employing sweetpotato flour as a main ingredient.
Establishment of a 'Sweetpotato Marketing Chain Club' to continue to promote innovations after completion of the PMCA exercise.

The sweetpotato crisp product was developed and is being marketed by TomCris Enterprises. The Njukunju Group is now developing another competing product. The kiosk was constructed and used for the first time at the Final Event for Phase 3 of the PMCA. The two brands of porridge developed by the SOSSPA and Kasawo enterprises have been tested in focus groups. Attractive packaging has been developed for these two products. The sweetpotato club has been established but has not yet begun to function as a stakeholder platform.

Different value chain models may be appropriate under different circumstances and elements of the models described here could be combined. In part the choice will depend on the objective, particularly the search for improved efficiencies in existing market chains, the introduction of OFSP with its associated branding, or the development of value chains for processed products. Because current markets are relatively thin, careful value chain facilitation to ensure that supply and demand grow together will be needed. If either gets seriously misaligned there will be frustration on the part of farmers who are left with produce they cannot sell or on the part of retailers who cannot meet demand from customers. However, as markets get established and the value chain consolidates, issues shift to maintenance of quality standards within the marketing chain and the introduction of new varieties, seed systems and integrated crop management techniques. A dynamic should build for the continual search for improved efficiencies, productivity, or quality within the value chain.

All these models report positive short term outcomes but there has been no serious analysis of longer term outcomes or of their relative merits. Preliminary analysis suggests that different models have different limitations. Projects which follow model 2 for example rely on collective action at farm level in assembly, in maintaining grades and standards and in contracting directly with supermarkets. This allows both a price premium and permits farmers to capture most of the market margin. However, at a project level, coordination functions and credit support in the market chain are often assumed by an NGO, instead of the supermarket or a farmer group. As promotion of OFSP deepens and demand expands, the question is whether the OFSP value chain will become self-organizing, for example, through contracting between supermarkets and an expanding array of farmer groups and whether OFSP will increase in wholesale markets.

The introduction of small-scale processing under model 3 also provides an organizational locus for farmer collective action. The viability of processing will depend on organizing root supplies during as long a supply period as possible, while at the same time competing with fresh market demands. Initially farmer groups will have to commit to continuously supplying the processing enterprise with roots in exchange for having a floor under fresh market prices. Farmer collective action will be essential to ensure quality parameters and timely delivery in the establishment of markets for fresh roots and processing products.

Pilot experiences indicate that factors critical to the development of value chains include:

1) Ability to establish a constant supply of sweetpotato roots through piecemeal harvesting, varietal selection (different maturation periods), exploitation of different agro-ecological zones, storage capability, trader and farmer group coordination.
2) Surplus production exists at the household level.
3) Fresh root price on the market competitive with other staples.
4) For products substituting wheat flour, fresh root price versus wheat flour price.
5) Assembly and transportation costs not prohibitive between production and processing centers.
6) Economically viable products acceptable to consumers can be identified.
7) Purchasing power of target consumer groups within range of proposed product.
8) Sufficiently prompt payments can be made to farmers for their roots.

Areas for future work:

1) Systematically gather information about prices and analyze how farmers and other value chain actors access price information.
2) Test alternative models for facilitated value chain development drawing on prior project experiences.
3) Promote and analyze different options for studying collective action among farmers to improve reliability and quality of supply of roots.
4) Explore options for stimulating innovation in the value chain using a lower cost version of PMCA in the context of particular market opportunities.
5) Test different schemes for managing supply and vertical integration including potential for contract farming (drawing on experiences with cassava).

6) Develop and test different schemes for demand creation which engage all actors in value chain.

Challenge 4.5. Potential of sweetpotato as an animal feed

Current knowledge

Sweetpotato at present plays a limited role in livestock production in SSA. However, on farm research in SSA has demonstrated that sweetpotato forage varieties which produce abundant vines can be used as a high value feed for dairy cow, dairy goat, and large scale pig production, and dual-purpose feed varieties can be used as smallholder pig feed. In Asia, forage and dual-purpose sweetpotato varieties for pig production have been adopted by many farmers increasing feed availability and decreasing feed cost, although here sweetpotatoes are predominantly an animal feed and do not compete with food uses. Technologies developed for silage of sweetpotato vines and roots in Asia have further improved the nutritional value of vines and roots, increased growth rate, and decreased production cost (Peters 2008). Feeding strategy simulation models (LIFE-SIM) have been developed for pigs, dairy cows and goats to analyze their bioeconomic response to feeding strategies in different production systems (León-Velarde *et al*., 2006; León-Velarde *et al*., 2007).

The clearest opportunity for sweetpotato as an animal feed in SSA exists in East Africa and the Central African Highlands:
Smallholder dairy cow systems have grown significantly in most parts of the region, particularly in the highland areas.
Dairy goat production, after years of research, has increased dramatically in Kenya.
Smallholder pig production is beginning to intensify, where there is either contracting or good access to markets.

The opportunity is based on the partial replacement of voluminous Napier grass used as feed mainly for dairy cows and goats, but also pigs, with a more productive and nutritional substitute. It takes 0.6-0.7 hectares (ha) to support one cow each year, based on average Napier grass production of 35 ton/ha. CIP-SSA sweetpotato breeders estimate that, in East Africa, advanced forage varieties should easily yield 35 ton/ha of vines per season (i.e., 70 ton/ha/year where two crops are possible), and up to 60 ton/ha per season (120 ton/ha/yr) under more favorable conditions and management. This replacement would be highly profitable for dairy cow and goat producers and for the larger contracting pig farmers who combine commercial feed and vines because of cost reduction and land saving.

The advanced dual-purpose varieties, with high biomass yield from both roots and vines, selected specifically for feed production, have the potential to contribute to the growth and economic efficiency of smallholder pig production, which relies on sweetpotato roots and vines as the main bulk of pig feed. The extent of its impact will depend on the increase in total biomass of the improved varieties compared to the current varieties that are fed to pigs.

Comparing the relative merits of dairy cow, dairy goat, and pig production, we see that pure and cross-breed cows provide the most steady daily income as they are milked for 9–12 months, but require a massive amount of feed and a great deal of skilled care. Pure breed goats, due to the high prices of goat milk, yield very high income for the small amount of feed needed daily. As with most pure exotic breeds, pure breed goats also require care, investment, and skills to keep them alive and productive. Smallholder local pig production, fed on sweetpotato roots and vines-based diet, can yield comparable profits to pure breed dairy cows and goats. The forage sweetpotato could be adopted by dairy cow, dairy goat, and larger contracting pig farmers; while the dual-purpose varieties would contribute to the smallholder pig production. The potential would be greatest in areas where sweetpotato grows for most months of the year and there is a large concentration of cows, goats, and pigs, namely those East and Central African highlands with access to urban markets (Peters, 2008).

The use of sweetpotato in commercial feed ration depends on global maize price trends. The potential of substituting maize with sweetpotato in commercial production will be determined only when the long term price differential becomes clear between maize, on the one hand, and sweetpotato, cassava, and soybean meal, on the other.

Areas for future work:

1) Evaluate yields of forage and dual purpose sweetpotato varieties in multiple locations.
2) Carry out post harvest trials on cutting, silage, and feeding in order to enhance the role of sweetpotato in various livestock feeding systems. Cutting allows vines to be mixed with other feeds in order to balance the feed, and reduces feed waste. Cutting is needed for silage. Silage can be made with various additives (e.g. chicken manure), and the appropriate additive depends on the availability and cost.
3) Feeding trials are needed to determine the replacement rate of sweetpotato vines for Napier grass for dairy production, looking at returns to labor as well as returns to land.
4) Trials of sweetpotato silage are needed to estimate economic and growth efficiency of silage use.

5) Use minimum data trade off analysis to understand effects on profitability of different feed based enterprises across the whole farm.
6) Carry out collaborative trials with factories on commercial feeds including sweetpotato either on station or with contracting farmers.
7) Analyze long term shifts in prices of raw materials for commercial feed and carry out economic analyses of different feed compositions using linear programming and LIFE-SIM simulation models to understand under what relative prices sweetpotato would be competitive with maize and cassava.

CONCLUSION

Despite its bulky nature and undifferentiated use there are real prospects for improving sweetpotato's value chain. Facilitated market development will be needed to increase the efficiency of existing chains and develop new chains with careful balancing of the growth of supply and demand creation. Much of this work is linked to OFSP. Its unique set of market attributes creates new hope of breaking the perception of sweetpotato as a poor man's food and increasing processing and marketing of sweetpotato. This should generate a series of potentially favorable impacts on the livelihoods of the poor who produce and consume the crop.

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CHALLENGE THEME PAPER 5: INTEGRATED CROP MANAGEMENT

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Overall Challenge: Yields of sweetpotatoes are low in Africa and improved crop management will be critical to increases in productivity and yet there is virtually a research vacuum on integrated crop management (ICM) and most farmers have few incentives to intensify crop management.

So the question is: how can quality information related to sweetpotato ICM be generated and how could this information be made available to farmers through appropriate means so that improved crop management can contribute to increased productivity and take advantage of emerging market opportunities?

BACKGROUND

Sweetpotato has several advantages within the context of African cropping systems: i) it produces food in a relatively short time, ii) it gives reliable yields in sub-optimal growth conditions, iii) it requires lower labor inputs (appropriate for vulnerable households) than other staples, vi) it serves as an alternative food source for urban populations, facing increasing prices of cereals and v) it provides a potential option to reduce vitamin A deficiency.

In Sub-Saharan Africa sweetpotato is grown in a few regions as a principal staple food crop but in most countries it is grown as a food security crop. In eastern and southern Africa, the crop is generally cultivated in areas with frequent drought stress where cereal crops produce only marginal yields and farmers seek to exploit their agro-biodiversity to buffer stress events. Sweetpotato produces stable and reliable yields under often marginal growth conditions in a relatively short period of time to serve as a back-up for the main staples or to bridge the time until their harvest. In a few countries in the region, where there is a bimodal rainfall pattern, for example, Kenya, Rwanda and Uganda, sweetpotato makes an important contribution to household food security and is also gaining importance as a cash crop sold as fresh roots on urban markets. Sweetpotato value-added products are on the increase with prospects of reducing post harvest losses and improving household incomes. In West Africa, sweetpotato is found in the moist savannah zone where it is part of more diverse root and tuber cropping systems.

Average root yields are low, ranging between 3 to 6 t/ha (tons per hectare) if water supply is a limiting factor or up to 10 to12 t/ha where natural soil fertility and rainfall are adequate. The potential yield of sweetpotato can be up to 40 to 50 t/ha, or possibly a bit less for high dry matter indigenous land races. As with most other crops in Africa, there is a very large yield gap between what farmers achieve and what is normally attained on the experimental stations. Figure 5.1 presents a preliminary yield gap analysis for Sub-Saharan Africa which shows how present yields could be increased from 6 to 20 t/ha if constraints were managed properly. This analysis is, in fact, conservative given experiments with improved materials in eastern and southern Africa, where an average of 24 t/ha are obtained.

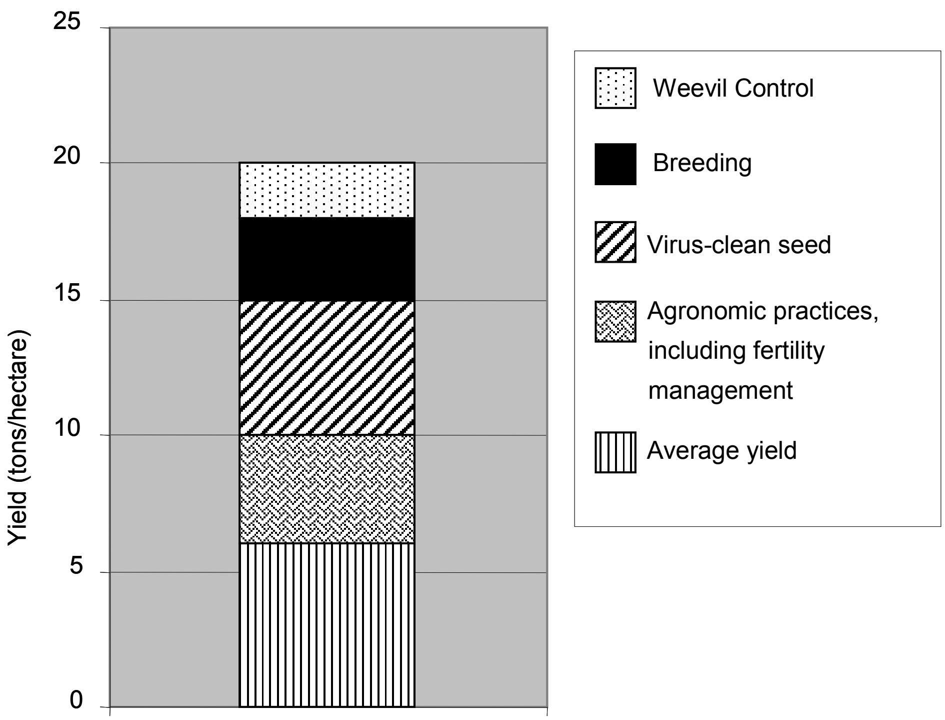

Figure 5.1
Sweetpotato yield gap: Rainfed conditions.

The main constraints to sweetpotato productivity in Africa and, at the same time, opportunities for gains in yield can be summarized as follows:

1) Inappropriate agronomic practices (e.g. planting techniques and spacing, site selection, soil fertility management). Improved management can contribute substantially to increased yields (more than 100% increase). However, facilitating farmer access to fertilizers would not be an easy task, so the estimation of yield gains through better management of local sources of nutrients and other practices is conservatively estimated at 60%.
2) The lack of virus-clean planting material. Most of the local landraces and introduced materials are degenerated because of sweetpotato virus disease. Experts and scientific references indicate that a yield gain of 30% to 50% could be obtained through healthy planting material.
3) Limited yield potential of local land races. Genetic gains in terms of yield are expected to be about 30-40 % compared to healthy local cultivars. Breeding is also the pathway for introducing quality traits (higher micronutrient content, dry matter content, etc.) that do not contribute towards improving yields but are essential for achieving other goals, such as consumer acceptance and improved nutritional status.
4) Sweetpotato weevil. The weevil is an important constraint to sweetpotato in Africa; however, most of the effect occurs when sweetpotato roots are already formed and the principal effect is to reduce the percentage of marketable roots. Published work in Cuba indicates, however, that about 10-20% increase in yield could be expected through a better control of sweetpotato weevil. Improved control could contribute to avoiding losses of yields already formed and increase the value of the roots for potential markets.

Another important area is the quality of the harvested roots with respect to their shape, color, damage etc. Quality is affected by biotic factors such as weevils and diseases, by the genetic background of the varieties, by soil type/structure (compactness) and also by erratic nature of rainfall or availability of moisture. These are causes for outgrowths or secondary growths and cracking.

The quality of the planting material and the genetic background of the varieties, which should have resistance to the main constraints, are the starting points, and a key component of integrated crop management (ICM) strategies. Farmers usually do not manage single problems or constraints; they manage crops under their site-specific conditions. Therefore, developing and making available information about ICM components, using a holistic approach to increase the productivity and quality of field crops, is the most appropriate approach to developing a strategy to overcome these yield-limiting and quality-reducing factors.

In the African context, the ICM approach has often been oriented to the management of one specific crop (the main crop in the system), and in most cases to the management of a few major constraints to productivity of that specific crop. A better concept, however, lies in integrating the management of different factors that influence yields of sweetpotato, but in relationship to the management of other individual crops and livestock activities. This seeks to benefit from the interactions among them and make use of synergies in order to improve, for example, pest control or soil fertility while eventually increasing farm productivity as a whole. The justification for not focusing exclusively on sweetpotato integrated management is that in much of Africa it is a secondary crop and, unless there is farmer motivation to improve yields by, for example, linking farmers to the market, they may not be interested in adopting sweetpotato ICM.

However, options often exist for improving cropping practices in sweetpotato by taking advantage of nutrient applications and improved crop management on other crops in the farming system. In other words, although the main goal is to increase sweetpotato productivity, the entry points for ICM should not only look at sweetpotato management, but also at the management of the cropping system that farmers manage in order to maximize synergies.

Sweetpotato ICM should prioritize the use of low-external input practices for the management of most constraints, particularly in a time of rising prices of purchased inputs. Moreover, ICM is often more knowledge intensive than input-based technologies such as improved varieties or agro-chemicals. Hence, this technology also requires a capacity building and/or strengthening component in order to support local institutions and farmers to fine tune their ICM strategies. Facilitating farmer access to information and knowledge about innovative crop management practices becomes essential for the adaptation of ICM strategies to local conditions.

PRINCIPAL CHALLENGES

The principal challenges of sweetpotato ICM lie in developing or adapting the right combination of technologies for specific agro-ecological and socioeconomic contexts. This is obviously made more feasible when farmers have access to the market where sales provide the returns on farmer investments in labor and knowledge intensive technologies. However, a critical aspect of many ICM-related interventions and innovations is the relative long-term character and payback period of many interventions. For example, there may not be immediate improvement in crop yields or effect on control of pests, but there is an immediate use of resources (time, labor). Hence, the ICM strategy should include a mixture of technologies aimed at both immediate and long-term improvements.

Improving sweetpotato productivity and quality through ICM can be seen as a mixture of scientific, biological, technical and human challenges that require a set of interrelated approaches addressing specific constraints and groups of constraints. Integrating scientific and farmers' knowledge would assist in the design of crop management options and enable farmers to adapt and fine-tune ICM to their specific conditions. This would also allow farmers to be prepared to take advantage of emerging demands or to face changing conditions, such as those created by improved links with the market.

Developing and disseminating suitable ICM technologies is also constrained by inadequate institutional capacity and resources, as many national agricultural research systems (NARS) have very few staff working on ICM for root and tuber crops (and even less so for sweetpotato). They have often no long-term strategy or concept on how to develop sweetpotato-related technologies and create awareness among farmers on the need to employ them. This is variously attributed to lack of staff and staff turnover, lack of resources and other institutional priorities. Moreover, there is need for a strong linkage between research and extension and development organizations. Because knowledge and labor intensive technologies are often the backbone of any ICM strategy, there is need for innovative capacity building and training methodologies based on solid agronomic expertise combined with participatory methods to incorporate farmer local knowledge on ICM development, adaptation and innovation.

Challenge 5.1. Improving crop management practices dependent on farmers' objectives

Farmers manage cropping systems and leaf/root production for different end objectives, including home gardens, integrated crop-livestock systems, relay and intercropping systems, and commercial systems.

Current Knowledge

The short maturity, quick ground cover, relative high productivity, and adaptation to more marginal soil conditions of sweetpotatoes allow farmers significant flexibility in how they incorporate the crop into their farming system. The crop can take advantage of residual moisture and fertility following rice in the inland valley systems of West Africa. It provides a perfect establishment crop in a sweetpotato-cassava relay cropping system in savanna ecologies, and, as such, is the first food to be produced after the “hungry” season. Most farmers cultivate sweetpotato in home gardens or in small field areas ranging from 0.1 ha to 0.5 ha; larger plots are rare and often associated with production for market. Sweetpotato is generally considered a low-input crop, but often grown as a no-input crop. For example, no organic and/or inorganic fertilizers or pesticides are applied and apart from an initial weeding and hilling-up little major field work is being invested in the crop. Moreover, the crop is often planted on the remaining (often exhausted) land after the main field activities for the key crops have been concluded. Fortunately, there are exceptions to this in Uganda and western Kenya, where the crop has a more commercial orientation.

In regions with increasing demographic pressure or in conditions when market access opens new opportunities for revenue generation, land can become a limiting factor to subsistence or commercial sweetpotato production. In these circumstances an intensification of the cropping system might become an important response. In this respect inter- and relay cropping systems which increase output per area and/or per unit input, are suitable options. Sweetpotato is an appropriate crop for these systems because it is flexible in terms of planting dates, robust in its handling but also competitive and has a number of other characteristics which might benefit the associated crop(s), such as protection against soil erosion, weed control etc. There are, however, some caveats. Although these systems often show promising results in experimental settings, their successful management depends on several factors. First, they increase the use of resources and especially if soil water or nutrients are limiting factors, higher plant densities might not be manageable and result in crop failure. Second, sweetpotato is a highly competitive plant, which can suppress the development of other crops, hence time of planting, plant densities, types and growth forms of crops characterize the aptness of crop associations.

Further intensification will lead to greater use of external resources such as fertilizer, water or mechanization for crop management and might only be feasible and cost efficient for commercial crop production. In these high-input systems sweetpotato will be grown as a single crop to optimize resource use to the demand of the crop. However, the purpose of production might range from leaves for vegetable use, vines for the production of planting material or fodder (in zero grazing systems) to tubers for the fresh market or for processed products.

With the notable exception of South Africa, in Sub-Saharan Africa (SSA) there is little experience with sweetpotato as an irrigated and inorganically fertilized crop and research would have to provide expertise and guidance to make these systems cost efficient and the products meet the required standards for commercialization. This type of research would be rather site specific to be adapted to the locally available resources.

We are interested in how ICM relates to cropping systems. There are basically four different groups of technologies which are used in sweetpotato:
Integrated technologies, which are not crop specific, but are knowledge and labor intensive (soil fertility management, management of drought stress, etc.).
Specific sweetpotato technologies based on external inputs (irrigation, inorganic fertilizer, planting material brought from outside of the farm, etc.).
Specific sweetpotato technologies based on internal inputs (weevil control, irrigation, planting densities, planting materials produced within the farm, etc.).
Varieties (as a specific group according to the importance within the project).

These groups could be further subdivided according to costs in time, labor and information. Generally, cost-intensive technologies are less labor intensive and vice versa, which would suit different cropping systems.

Traditional and new varieties would have to be tested for their nutrient and fertilizer use efficiency (in favorable and marginal conditions) not only for the major nutrients nitrogen, phosphorus, potassium (NPK) but also for their micronutrient requirements, because in many marginal soils these nutrients might also limit crop production, and for their adaptation to the different cropping systems.

Areas of future work for consideration:

1) Characterize and describe the main sweetpotato cropping systems and their needs and potentiality according to the farmers' end objectives (home consumption, market or both);
2) Define and test prototype ICM strategies according to each cropping system, the main constraints and farmers' end objectives (more details in the other challenges of this paper);
3) Define the appropriate agro-ecological conditions for intensified/commercially oriented systems and adapt and fine-tune their management with the participation of farmers

according to the cropping systems, and assess the modified cropping systems in terms of gains in sustainable land use, risks and cost-benefit;

4) Understand the effectiveness of different management practices under on-farm conditions and different cropping systems. Determine if they can be applied singly or if they must be integrated —for example, does soil fertility investment pay without appropriate weevil control?
5) Determine capacity building needs to help local institutions and farmers to conduct adaptive, participatory research and training for fine-tuning ICM alternatives according to local systems and end objectives.

Challenge 5.2. Extending the supply period to meet demands for sweetpotato products

Current Knowledge

The flexibility that comes from sweetpotato's short maturation is unfortunately not matched either by its ability to be stored for extended periods in the ground (as with cassava) or to survive under extended drought or dry season conditions. Thus, to fully develop the market and utilization potential of the crop, including the nutritional benefits from orange-fleshed sweetpotato (OFSP), would require a significant extension of its supply period. Where the growing season is very long, as in Rwanda, or there are extensive wetland or valley bottom areas, as in Uganda, sweetpotato has developed as a principal crop in the food economy, in major part due to the extended supply period.

There are a range of options that can be utilized to extend supply. One important component is the use of varieties with different characteristics. In commercial production areas of Uganda farmers manage a suite of varieties of different maturities and also stagger planting dates. Drought resistance and weevil tolerance are also important traits in extending supply and storage in the ground into the dry season. Other options could also be employed by the farmer in combination with varieties and planting time. These include: 1) exploiting different micro-ecologies, 2) post-harvest storage (see the discussion in the Challenge Paper 4: Value chain), 3) relay or rotational cropping with other crops, and 4) managing vine availability to ensure early planting. In order to achieve the objectives of this challenge, activities would have to link up and be coordinated/integrated with activities related to the seed systems and market chain development themes, and to the ICM challenges included in this paper on integrated pest management (IPM) (5), on cropping systems development (1) and drought management (3).

One crucial aspect of extending the sweetpotato supply period is the timely provision of planting material. The conservation of planting material at farm level during the dry season and the availability of sufficient planting material (with the respective quality characteristics if possible) at planting time are two major constraints to sweetpotato production. This is particularly true for extending the supply period, especially in drought prone and low potential areas. To overcome these problems there is need for adapted or new technologies to improve planting material storage or maintenance conditions. These include, for example, maintaining plants in the field (under irrigated conditions or in specific micro-ecologies) for rapid vine multiplication as well as IPM technologies for weevil control. In this area research in sweetpotato agronomy and physiology could make an important contribution linking to the expertise and experiences generated within the seed system theme (more details in Gibson, 2008).

A second step would be to vary planting dates, varieties and cropping systems. All these farm specific options depend on the availability of resources (land, labor and inputs), the capacity of the farmer to use them efficiently and the incentives to do so. Options would consist in staggered planting, intercropping 'major' crops with sweetpotato and using areas with sufficient moisture supply for off-season production. These operations can compete with or complement other farm activities and food production strategies. Therefore, exploiting the synergies between crops, for example sweetpotato – cassava systems, would improve productivity, stabilize food supply during the year, and provide a system attractive to subsistence farmers.

A third possibility to extend sweetpotato supply is post-harvest conservation and processing and transforming of sweetpotato into new products. There exists a variety of traditional and new technologies ranging from processing at farm level to industrial production (Agona *et al.*, 1998; Owori, 2003). Acceptance and use of these products has been rather limited. Apparently the processing of sweetpotato into chips or flour is not very attractive to farmers as prices are lower than for the fresh product (information from country visit, Malawi). Hence, research would have to exploit options for extended storage of fresh storage roots –farmers claim, for example, that traditional varieties can be stored much longer than improved ones, which rot within 14 days after harvest (Rees *et al.*, 2003)– developing appropriate varieties, methods and physical structures (Van Oirschot *et al.*, 2000). Experience for processing exists for Africa but also for South East Asia, where technologies might be transferred to Africa.

Areas of future work for consideration:

1) Introduction and assessment of sweetpotato varieties with different maturities, which can fit into different cropping systems.
2) Identification of micro-ecologies with sufficient moisture supply and close enough to markets where sweetpotato could be produced for extended periods.
3) Design and assessment of intercropping options and crop rotations that could extend the supply period.
4) Development of alternatives for conserving planting materials and for having planting material on a timely manner, particularly in drought prone areas.
5) Assessment of farmer organizational arrangements that could coordinate sequential sweetpotato planting and harvesting.
6) Development of post-harvest practices that could reduce sweetpotato weevil and disease damage and could extend the storage period for the provision of quality roots for the market.

Challenge 5.3. Managing the crop under moisture constraints

Sweetpotato is a marginal crop in unimodal rainfall areas with long dry seasons and expanding the potential production range of the crop, and its ability to target Vitamin-A-deficient populations, will require managing the crop under moisture constraints, including access to receding river banks, dambos, and inland valley systems.

Current Knowledge

Drought management is an important factor for increasing sweetpotato productivity, given that sweetpotato yields can be severely affected by limited water availability. As vitamin A deficiency (VAD) is much more of a problem in regions with a long dry season and more erratic rainfall, this problem must be overcome to maximize the potential contribution of OFSP to reducing VAD in drought-prone environments. Drought management refers to a range of technologies which are well known but might need some adaptation to sweetpotato cropping systems. They consist of soil preparation and water harvesting technologies which increase water collection and water retention capacity of the soil and are applicable to crops in general. Moreover, sweetpotato is often grown in the dry season in lowland areas with high soil moisture and cropping systems must balance water logging with drought mitigation. Given the increase in climatic variability due to global warming, more specific research will be needed in sweetpotato physiology, as well as new management options to increase drought tolerance and water use efficiency and yield, and also to explore technological options to keep planting material viable during long dry periods.

There are two different approaches to the management of moisture constraints: (i) using the genetic diversity of the sweetpotato plant to identify genetic traits, their expression in plant physiological processes and select cultivars best adapted and most productive under these conditions; (ii) using, adapting and developing technological solutions which either provide alternative sources of moisture or conserve available moisture to increase its use efficiency.

Varietal improvement, focusing on drought resistance (acceptance, tolerance, escape) and on water use efficiency, is complex and has had limited success in the past. The best cultivars are selected on the basis of mechanisms that define the plant's ability to withstand drought conditions (Saxena and O'Toole, 2002). The better a cultivar is adapted to drought conditions, the less intensive needs to be a technological (agronomic) intervention, i.e. drought resistant cultivars can be used in low-input agriculture while with decreasing drought resistance farmers have to invest more resources in 'moisture providing or conserving' technologies to successfully produce a crop.

ICM should provide technological solutions to limited moisture supply (during drought spells, at the end of the rainy season) and to changing moisture conditions. An integrated approach would be especially beneficial in this respect. As Sivanappan says:

There are always strong links between soil conservation and water conservation measures. Many actions are directed primarily to one or the other, but most contain an element of both. Reduction of surface runoff can be achieved by constructing suitable structures or by changes in land management. Further, this reduction of surface runoff will increase infiltration and help in water conservation. Soil and water conservation can be approached through agronomic and engineering procedures. Agronomic measures include open and tied ridges, contour farming, off season tillage, deep tillage, mulching and providing vegetative barriers on the contour (Sivanappan, 2005).

These measures not only improve soil moisture availability but also reduce erosion and improve soil fertility.

Periodically changing water tables in flood plains or inland valley swamps offer opportunities for cropping system diversification and the production of different sweetpotato products such as leaves, vines and storage roots, staggering planting times and varying crop management. This often requires more sophisticated crop and farm management to synchronize field operations and product marketing. These areas have a high development potential but in some regions (West Africa) there are often increased disease burdens associated with working these areas.

Areas of future work for consideration:

1) Increasing genetic diversity of sweetpotato by introducing and selecting cultivars best adapted and productive under drought conditions.
2) Development and adaptation of technological solutions which either provide alternative sources of moisture or conserve available moisture to increase its use efficiency for both the crop and for keeping sources of planting material alive and ready to provide cuttings when rain starts.
3) Study sweetpotato physiology in relation to water availability, so that the effects of water management practices can be better understood.

Challenge 5.4. Improving soil fertility management

There are limited suitable options for improving soil fertility management (which is essential to increase crop and farm productivity) in a crop like sweetpotato that is considered a low-input and subsistence crop and where there are few incentives to use labor and resource-intensive technologies.

Current Knowledge

African farming systems are in general highly nutrient constrained. Apart from the volcanic soils of East Africa, the soils are geologically old and highly weathered. At the same time fertilizer markets on the continent are underdeveloped and where they do exist, fertilizer prices are high by world standards given costs associated with inadequate transport infrastructure, and fertilizer availability is often limited to nitrogenous fertilizers and diammoniumphosphate (DAP). Furthermore, African farmers have limited access to organic manure and in many regions there are very few traditional technologies for the preparation of organic fertilizers based on internal or external resources. Farmers grow higher value, commercial crops on their better soils and concentrate the application of their limited organic and inorganic nutrients on these plots, resulting over time in a mosaic of plots with different nutrient and soil organic matter status. Sweetpotato is often grown on land with poor soil fertility, because farmers know that the crop can still produce an acceptable yield under those conditions, but yields are significantly lower than their actual potential. Even when farmers produce for the market, they rarely apply farmyard manure or other organic fertilizers. Generally sweetpotato production is not an attractive entry point for improved soil fertility management but rather the crop could take advantage of residual fertility from increased nutrient applications in other parts of the farming system through rotational systems, incorporation of vines and crop residues, and potential exploitation of legumes within the cropping system (Fischler and Wortmann, 1999).

Integrated soil fertility management (ISFM) would help the farmer not only to improve soil fertility but also many other agronomic aspects of crop production, such as water retention capacity in the soil and pest and disease control, all of which would contribute to increased crop yields. To establish soil fertility technologies with farmers, they have to be based on available and affordable resources. For example, in a first step, a nutrient inventory of these resources could be produced and their potential studied to be transformed into plant (and soil) available nutrients. In a second more innovative step, methods and technologies would be developed to prepare and treat different kinds of organic fertilizers to improve their efficacy and their effect on crop growth. They range from simple structures for composting to the production and application of beneficial microorganisms to improve aerobic or anaerobic decomposition processes.
Simultaneously known technologies, such as rotations, legumes etc., need to be adapted to local conditions to show the benefits of an integrated approach.

Inorganic fertilizers are out of the reach of most African farmers, even more so with increasing energy prices. Their use could probably only be justified to speed up the growth of vines for planting material. For tuber production other conditions such as water supply or pest control should be in place to optimize resource use efficiency. Research could contribute to the development and evaluation of inorganic fertilizer based cropping systems (see Challenge 5.1). However, it is important to assess if the entry point for improved soil fertility management based, for example, on chemical fertilizers should be sweetpotato or other important crops in the system, so that those farmers who can access this input could make the best use of it. Combinations of chemical and organic fertilizers would also be possible (Alleman, no date).

Developing appropriate and adapted technologies for adequate integrated soil fertility management is only part of the challenge. Other important parts of the challenge are i) how to facilitate farmers' access to appropriate information so that they can improve their decision-making about the usefulness of these methods and technologies, ii) how to generate opportunities (i.e. by linking sweetpotato production with the market) to motivate and encourage them to use technologies for improving soil fertility not only for selected high value crops but for the entire farm in order to improve yields and, even more importantly, to improve yield stability. Hence, approaches to include sweetpotato in ISFM would have to be linked to other challenges in the project, such as the activities related to the production and use of orange-fleshed sweetpotato varieties (OFSP), those related to the market chain development, and the development of innovative capacity building and training methods.

Areas of future work for consideration:

1) Use appropriate methods to elaborate inventories of potential sources of organic and inorganic fertilizers to be used as part of ISFM, according to the variability of cropping systems explained in Challenge 1.
2) Develop methods and technologies to prepare and treat different kinds of organic fertilizers and improve their efficacy and their effect on crop growth and yield. Technologies could range from simple composting methods to the use of beneficial microorganisms to accelerate soil fertility processes, and also if possible, assess feasibility of chemical fertilizers in mixtures with organic sources.
3) Develop or adapt rotational strategies oriented to maintain or enhance soil fertility in the different cropping systems that include sweetpotato and according to farmers' end objectives.
4) Study the influence of soil fertility on parameters that could be demanded by the market, such as root shape, size and quality, also in terms of micronutrient and vitamin A contents.
5) Develop or adapt suitable participatory methods to facilitate farmer involvement in research and training processes oriented to ISFM according to their end objectives (i.e. market or OFSP production and use).

Challenge 5.5. Controlling the sweetpotato weevil

There are limited options to control sweetpotato weevil (the most important pest constraint on yields and root quality in SSA) given that plant breeding has generated only low levels of tolerance; control has to be based on improved cultural practices, but the application of these practices depends on effective returns, usually only possible under improved market conditions.

Current Knowledge

Weevils and viruses are the two most important biotic yield constraints on sweetpotatoes, although severity varies significantly by agro-ecology. Weevils, however, even in small populations, can affect the quality of the storage roots, rendering them commercially less valuable (Ndunguru *et al.*, 1998). They become a problem towards the end of the season when soils are drying up and storage roots are left in the soil for too long. In some areas where weevils are endemic, damage is also recorded during the growth season and production losses reach up to 60-100% (Chalfant *et al.*, 1990; Lenné, 1991; Jansson and Raman, 1991; Mullen, 1984; Smit, 1997). In a recent research priority-setting survey carried out by Fuglie (2007), management of weevils was the highest ranked need in relation to improved sweetpotato crop management. Traditional strategies to avoid weevil damage include early planting and harvest, rotation, submerging the fields at the beginning of the planting season, appropriate and timely hilling-up, and the use of varieties with storage root development deep in the soil. Pesticides are rarely used.

Some research results have shown that late planting is associated with higher levels of damage by sweetpotato weevil (Odongo *et al.*, 1995; Jeremiah *et al.*, 1996, 1998), and that some cultural practices such as appropriate hilling-up, intercropping and crop rotation could also contribute to reducing weevil damage (Muhanna and Kiozya, 1996; Nsibande, 1999; Odongo *et al.*, 2003). The use of pheromone traps to control the weevil has shown mixed results with Downham *et al.*, (2001) indicating that it is possible to reduce damage using this technology but Smit *et al.*, (2001) indicating that no significant difference were found. There would be two points to address regarding this technology: first, find ways to improve its effectiveness (see below) and, secondly, find ways to make the pheromones available at affordable prices.

There have been mixed results regarding tolerance of sweetpotato cultivars to the weevil damage. For example, Stathers *et al.* (2003) found that cultivars with high foliage weight showed lower levels of damage, and Mbilinyi *et al.* (1996) and Jeremiah *et al.* (1996) also found difference in weevil damage across cultivars, but Odongo *et al.*, (1995) found no differences. These mixed results would suggest that continuing screening for tolerance in cultivars may generate interesting results in the future.

The complete complex of the three weevil species found in Africa needs special attention in the vine nurseries, which cover small plots between the growth seasons, where a food shortage for insects exists and a feeding concentration takes place. Pest management in these plots is especially important considering the high economic value of vines and the need for healthy and pest-free planting material to avoid early crop infestation.

There exists a substantial body of scientific investigations on sweetpotato weevil in Africa, but NARS have not yet developed a consistent IPM program, which reduces weevil damage and controls the pest. However, there are reports from successful programs in Central America (Cisneros and Alcazar, 2001), which used sex pheromones in combination with biological control agents such as the entomopathogenic fungus, *Beauveria bassiana*, produced by cottage industry, and predatory ant colonies in sweetpotato fields and other compatible cultural practices such as the use of pest-free planting material, crop rotation, and others (Lagnaoui *et al.*, 2000). In all these cases a suitable combination of technology development, appropriate training methods and institutional support was present. Although the conditions in African small-holder agriculture might be more complex and a direct transfer of technology not possible, this example shows that IPM can provide sustainable solutions, improving yield in quantity and quality and production efficiency.

A way forward could be the development of an attract-and-kill or "attracticide" strategy, which consists of an insecticide-pheromone co-formulation: the males are attracted by the pheromone and killed through contact with the insecticide (Kroschel and Zegarra, 2007). This strategy is consistent with the aims of IPM because only the target pest is affected, avoiding deleterious effects on beneficial and other non-target organisms. Other areas of research comprise improving the understanding of biotic and abiotic factors affecting the population dynamics of weevils and the development of predictive models, the adaptation of appropriate pest management technologies by farmers, for example, planting early in the season, which is associated with the timely availability of planting material and can help to reduce damage, and capacity strengthening with NARS and other stakeholders in IPM. Other regional important pests should be also considered within an IPM strategy. A more detailed discussion of IPM issues and opportunities is provided in Annex 5.1.

Areas of future work for consideration:

1) Identify, improve, test and provide training about cultural practices that have influence on weevil damage, such as planting dates, which are in turn associated with the availability of planting material;
2) Study innovative control methods based on previous knowledge about pheromone use, for example, develop and assess "attract-and-kill" strategies, particularly for systems where farmers would have to respond to market standards;
3) Develop, adapt or scale-up and out appropriate methods to improve farmer knowledge about biology and behavior of the insects and about the available control practices in a suitable and cost-effective way;
4) Explore the possibility of finding tolerance of sweetpotato cultivars to the damage caused by the weevil;
5) Develop a better understanding of the biotic and abiotic factors that affect the population dynamics of the sweetpotato complex, which could be used for predictive models for better targeting research and development efforts. This effort should be

conducted in close coordination with NARS so that a capacity building process could also take place.

Challenge 5.6. Scaling up and scaling out integrated crop management recommendations

Because sweetpotato ICM recommendations will vary, depending first on market conditions and secondly on cropping systems, the challenge is how to improve the understanding of farmers' driving forces for adoption and developing and scaling-up and out innovative capacity building approaches oriented to farmers, which should be integrated with efforts for new variety assessment and dissemination, and as a part of market development programs or integrated with nutritional education in OFSP promotion.

Current Knowledge

Improved ICM practices in sweetpotatoes are knowledge intensive, usually require increased labor application, and vary depending on the cropping system. Moreover, sweetpotato producers tend to be geographically distributed and not all farmers in a production region grow the crop. Developing and scaling-up and out cost-effective capacity building methods for sweetpotato growers and understanding farmers' decision-making for adoption of ICM are thus a significant challenge. Because of the limited human and financial resources existing in most countries, this challenge should address attempts to maximize the very limited capacities that will be devoted to capacity building for improved sweetpotato ICM through integration into other "change" programs to be included in the project. This would certainly include market development and OFSP promotion programs. Such programs would provide an environment suitable for innovation which would facilitate farmers' decision-making to invest in improved ICM. Nevertheless, there are a range of unknowns in the development of cost-effective programs with the ability to reach an appropriate scale. For example, are farmer field schools (FFS) an appropriate method for this purpose? Are there alternatives to FFS for dealing with knowledge-intensive management practices? The issue of gender in capacity-building methods is critically important in sweetpotato, as it is often considered a woman's crop and integration of nutritional awareness with improved crop management would be a women's role in the household and processing activities.

Farmers are probably more diverse in their attitudes, customs and preferences than the crops they grow or the cropping systems they manage. Therefore to engage farmers in research activities and/or interest them in new technologies depends on a variety of factors, which in their majority cannot be 'controlled' or managed by research or development projects. Apart from creating incentives, considering farmers' preferences and opinions about technological options should be an integral part of the research strategy to improve researchers' and development practitioners' understanding of the driving forces behind technology adoption. For example, there is a consensus that agricultural research has a much higher rate of return (success) in high potential areas or high input systems than in low potential areas or low input systems. In addition, there is an increasing trend to income diversification, especially of subsistence farmers, resulting in a growing portion of the household income coming from non-farm activities. This in turn affects farmers' willingness to adopt new technologies (especially labor and knowledge intensive technologies).

In a first step, a socio-economic analysis of the farming households would indicate with which group of farmers the work should be conducted, either full-time or part-time farmers in the diverse cropping systems indicated in Challenge 5.1 of this paper. Also, it is important to understand if farmers are net food purchasers or surplus food producers. If their activities are subsistence or market-oriented, what kind of resource base is available to the farmers? In addition, whether they have a specific interest in the sweetpotato crop would be extremely important as a starting point for research and capacity-building efforts towards developing and disseminating sweetpotato ICM.

As outlined by the project objectives, commercial opportunities are seen as a major incentive to increase sweetpotato production and for the adoption of more efficient technologies. However, ICM technology development needs to start before the market chain development can actually generate a demand; therefore, there should also be a strategy to work with subsistence farmers.

Areas of future work for consideration:

1) Develop, adapt and assess participatory research and capacity-building methods suitable for ICM development and dissemination in relation to other challenges included in the project (market development and OFSP production and use). ICM should not be seen as an isolated area of work, but as one that responds to demands according to the cropping system and farmers' end objectives.
2) Develop a better understanding of the typology of farmers who grow sweetpotato in different cropping systems and according to different end objectives, and about their perceptions and the driving forces for innovation related to ICM when having to respond to market or home consumption demands.

Challenge 5.7. Increasing user access to information and improved technologies

In general terms, there are limited investments by NARS and NGOs in sweetpotato research and extension. These organizations usually dedicate their attention to other staple and cash crops. Therefore the development of information and improved technologies (crop management and varieties) for sweetpotato proceeds at a very slow pace and possible productivity gains or other benefits are not realized.

Current Knowledge

The two main actors in agricultural research and development at country level are usually NARS and nongovernmental organizations (NGOs). Given limited resources, research on sweetpotato has been restricted to small grant funded work. During the country visits there was no root and tuber crop program which had major staff time dedicated to on-going ICM research activities for sweetpotato. Breeding has been seen as key to increasing production and overcoming other constraints; hence resources have been invested in this area rather than in the development of crop production technologies.

Apart from the main actors, there are several other stakeholders in the agricultural sector that actively influence directly or indirectly success or failure of research and development activities. A stakeholder analysis could help identify the actors and their interests, constraints, resources and willingness to contribute to the objectives of the project activities within a pilot site or specific country. Using an innovation system's approach (Hall *et al.*, 2004), would help to understand the different stakeholders related to sweetpotato ICM and identify entry points for research and capacity building at institutional level. Their early involvement would be important to the development and advance of project activities.

In addition, NARS, because of their specific role in research and development of SSA countries, would need extra attention to strengthen their capacities, internal structures and institutional memory.

Areas of future work for consideration:

1) Within an agricultural innovation system perspective at the regional, national and local levels, develop an understanding of the drivers of increased performance of public institutions and NGOs in meeting farmers' needs for ICM.
2) Develop suitable capacity building methods oriented to research/development institutions that could use existing resource capabilities and better utilize external

resources in order to develop ICM options that could respond to farmer or system demands.

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ANNEX 5.1. SWEETPOTATO INTEGRATED PEST MANAGEMENT (IPM) IN AFRICA: FURTHER CONSIDERATIONS

Jürgen Kroschel

INTRODUCTION

Sweetpotato (*Ipomoea batatas* (L.) Poir.) is cultivated in over 100 developing countries and ranks among the five most important food crops in over 50 of those countries. One of the most widely grown root crops in SSA, it is particularly important in countries surrounding the Great Lakes in Eastern and Central Africa, in Angola, Madagascar, Malawi and Mozambique in Southern Africa, and in Nigeria in West Africa. In Asia, sweetpotato is the most important root and tuber crop, with China being the largest producer worldwide. In Africa, it is grown predominantly in small plots by poorer farmers, and hence known as the "poor man's food". Increasing sweetpotato production and use is recognized for its role in improving incomes and food security among the rural poor.

Among the major constraints in sweetpotato production are biotic constraints by insect pests (Kapinga and Carey, 2003). For East Africa, e.g. a complex of pests has been described (Skoglund and Smit, 1994):

- stem and root feeders (sweetpotato weevils, *Cylas puncticollis* and *C. brunneus*, and rough weevil, *Blosyrus obliguatus*, all Coleoptera: Curculionidae);
- defoliators (clear wing moth, *Synantedon dasyceles* (Lepidoptera: Sesiidae), striped sweet potato weevils, *Alcidodes dentipes* and *A. erronneus*, long-horned beetle, *Peloropus batatae* (all Coleoptera: Curculionidae), sweetpotato butterfly, *Acraea acerata* (Lepidoptera: Nymphalidae), sweetpotato hornworm, *Agrius convolvuli* (Lepidoptera: Sphingidae), tortoise beetles, *Aspidomorpha* spp., *Laccoptera* spp. (Coleoptera: Chrysomelidae); and
- virus transmitters *Aphis gossypii* (Homoptera: Aphididae) and *Bemisia tabaci* (Homoptera: Aleyrodidae).

The complete pest complex needs special attention in the vine nurseries, which cover only small plots between the growing seasons and during the drought periods, where a food shortage for insects exists and a feeding concentration takes place. Pest management in these plots is especially important considering the high economic value of vines and the need for healthy pest free planting material to avoid early crop infestation. During the cultivation periods widespread infestations by sweetpotato weevils (*Cylas* spp.) are most serious, followed by regional and local yield reductions caused by rough weevils (*Blosyrus obliguatus*) and the sweetpotato butterfly (*Acraea acerata*).

Sweetpotato weevils (Cylas sp.) are the most serious insect pests of sweetpotato in Central America, Africa and Asia; production losses often reach 60-100% (Chalfant *et al*., 1990; Lenné 1991; Jansson and Rama,n 1991; Mullen, 1984; Smit, 1997). In a recent research priority-setting survey carried out by Fuglie (2007), management of weevils was the highest ranked need in relation to improved sweetpotato crop management. Even small weevil populations can reduce sweetpotato root quality. In response to weevil feeding, sweetpotato storage roots produce bitter tasting and toxic sesquiterpenes that render them unfit for human consumption. Studies by Ndunguru *et al*. (1998) have shown that consumers will pay only reduced prices for roots damaged by Cylas spp.

In certain areas of East Africa, serious damages of the surface of roots caused by larvae of the rough weevil *B. obliguatus* have gained economic importance. It reduces the marketability and when extensively damaged, roots have to be peeled thickly. The sweetpotato butterfly *A. acerata* can be a serious constraint to sweetpotato production in parts of Uganda, Rwanda, Burundi, eastern Zaire and Southern Ethiopia (Lenné, 1991; Ndamage *et al*., 1992; Girma, 1994). In Southern Ethiopia, frequent outbreaks have occurred in the last decades with tuber yield losses between 31 to 53% in unsprayed control plots. Mostly at the beginning of the dry season, a severe attack can result in extensive defoliation. However, it has been shown that single defoliation at different growth stages does not affect the yield but repeated defoliation is common. This means that farmers also have to learn not to overrate the importance of this pest and to apply control methods only according to the current infestation.

Whereas the two species C. puncticollis and C. brunneus are reported only from Africa, a third species, C. formicarius, is found globally (Wolfe, 1991). Most research has been carried out for C. formicarius, which is the main sweetpotato pest in Central America and Asia. Owing to lack of both funding and entomological capacity, African national research programs have not been able to develop an IPM program to reduce major losses caused by sweetpotato weevils and other regional pests, although the development and implementation of successful IPM programs for sweetpotato weevil management have been reported from Central America. In Africa, the uses of cultural practices such as hilling up or crop rotation are the only tools and recommendations to farmers, but which are not nearly sufficient enough to control this pest effectively.

Management of sweetpotato weevil

Sweetpotato weevil IPM in Cuba – a success story

CIP scientists and national collaborators in Cuba have clearly demonstrated that IPM can successfully control *C. formicarius* (Cisneros and Alcazar, 2001). Site-specific IPM strategies successfully developed and adopted included the use of sex pheromone, which had been made commercially available, for mass trapping of male weevils in combination with biological control agents such as the entomopathogenic fungus, *Beauveria bassiana*, produced by cottage industry, and the setting up of predatory ant colonies in sweetpotato fields, and other compatible cultural practices, like the use of insect-free planting material, crop rotation, and others (Lagnaoui *et al*., 2000). Pheromone-impregnated rubber septa, suspended in traps 10 cm above the foliage, were distributed at distances of 25 x 25 m. The weevils were killed either by mass trapping in simple water traps placed below the septa or by insecticides or *B. bassiana* applied on the ground around the septa that achieved higher efficacy. Through this collaborative IPM project, covering a six-year period (1993-1999), it proved possible to reduce national mean damage caused by sweetpotato weevils from 45% to 6%, for a production area of 45,000 ha. After 10 years, this project was terminated successfully. The IPM components are still in place today.

Use of sex pheromones

Building on the generally good experience and successful use of sex pheromones in *C. formicarius* IPM, a research collaborative program was initiated in 1997 by the International Potato Center (CIP) and the Natural Resources Institute, UK, to identify the pheromone chemical structure of the two species of African sweetpotato weevil *Cylas puncticollis* and *C. brunneus*. Although sex pheromones were identified and synthesized (Downham *et al*., 1999), the synthetic pheromones were found to be sufficiently attractive for monitoring weevils but not appropriate for mass trapping or mating disruption. Due to their low efficiency they have not been further researched and used. Recently, the pheromone structure and efficacy of all three *Cylas* species were revisited in a comparative study. Each of the three species scrutinized were shown to produce a distinct bouquet of volatile compounds accompanying the specific major sex pheromone component, which acted obviously as synergists to the major component (Vasquez *et al*., in prep.). However, also as a single-component, the major sex-pheromone components were revealed to be sufficiently attractive to efficiently lure males in linear olfactometer studies. The two African weevils each required a 10-times higher concentration of the major component for the same level of attractiveness as the synthetic lure for *C. formicarius* to be reached, but nevertheless demonstrating the component's potential use for sweetpotato IPM in Africa. In this context, it is especially noteworthy that this research also resulted in new, cheap and efficient synthesis protocols of the sex pheromones for the three weevil species that could substantially contribute to large-scale production, commercialization and use of the pheromones in Africa.

Opportunities for sweetpotato IPM in Africa

The sweetpotato IPM program developed for the sweetpotato weevil *C. formicarius* in Cuba has several components which could be adapted in an IPM research program for its successful use in Africa. The search for sources of resistance to sweetpotato weevils in the crop's germplasm has not yielded reliable results. Hence no conventional resistance breeding has been possible to date. Instead, the recent results on the sex pheromone structures and synthesis give good prospects for the development of effective lures for the sweetpotato weevil management. Under this project, the synthesis of the sex pheromones of the two African sweetpotato weevils should be scaled up in collaboration with advanced labs using newly-developed protocols, to produce semi-commercial amounts for larger field evaluation and applications. For practical and economic reasons, the numbers of pheromone traps employed per unit of agricultural area has often limited the use and adoption of mass trapping devices in pest management. In order to develop more rational use of sex pheromones, the attract-and-kill or attracticide strategy has already received attention and been successfully used in controlling different insect pests including the potato tuber moth *Phthorimaea operculella* (Zeller) (Kroschel and Zegarra, 2007). This strategy consists of an insecticide-pheromone co-formulation: the male moths are attracted by the pheromone and killed through contact with the insecticide. This strategy is consistent with the aims of IPM because only the target pest is affected, avoiding deleterious effects on beneficial and other non-target organisms.

For this challenging African wide sweetpotato project a systematic and fully ecological-based approach to pest management in sweetpotato should be considered to develop and disseminate site-specific IPM technologies for the main sweetpotato pests based on the following strategic results:

- Sweetpotato production systems and regional occurrence and distribution of sweetpotato pests assessed and understood.
- Abiotic factors influencing population dynamics of sweetpotato pests determined and models developed and validated to predict seasonal occurrences.
- Natural occurrence and influence of biotic factors on pest population determined and use of biocontrol agents evaluated.
- Potential use of sex pheromones in attractants and biocontrol products for IPM in sweetpotato assessed.

- Utilization of appropriate pest management technologies by farmers enhanced using participatory methods; and
- Capacity of national agricultural research systems (NARS) in IPM technology development and transfer strengthened.

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CHALLENGE THEME PAPER 6: PARTNERSHIP, GOVERNANCE AND STRATEGIC COMMUNICATION

Howard Elliott

BACKGROUND

The challenges to the Workshop are twofold: 1) How do we incorporate the lessons from partnership experiences in the development, governance and implementation of this multi-level, multi-disciplinary, multi-challenge and multi-region program to unleash the potential of sweetpotato in Africa? 2) How does the Program address the goals of enhancing incomes and reducing malnutrition through choice of varieties, attention to research challenges, and choice of target populations? This paper starts from the premise that the nature of the partnerships, governance and strategic communication will follow from these choices.

The development of a program to unleash the potential of sweetpotato in Africa is following an approach similar to that which was used by the Science Council to develop system priorities: expert synthesis of the potential gains from research, consultation of the scientific community to establish global priorities, regional consultation (electronically and through regional fora) and finally a synthesis by the Science Council discussed with a mixed expert and stakeholder audience to come up with "system priorities". This paper deals with partnerships, governance and strategic communications that will be necessary to implement the research and research into use objectives of the Program.

The author is led by the subject matter to propose an agricultural innovation systems approach. It requires that the expert-participants define the strategy at the Program level and identify the goals by regions, target population, production system, and themes. It is assumed that research is a primary driver of the system but the Workshop must define what systems are to be developed. It is an assumption that the Program for Sweetpotato in Africa creates synergy by working in three sub-regions.

The main text of the paper defines "partnerships", calls for an expression of alignment of the Workshop around shared partnership principles. It then provides in Annexes some "partnership tools" that can be used to elicit details about partners' readiness and precise contribution (or "value proposition").

Partnerships evolve and roles of participants change over the life cycle of a project or program. The paper and Annexes provide some analyses of common patterns and challenge participants to analyze these patterns as they relate to a sweetpotato project.

The Workshop is challenged to make recommendations for governance of the Program. Experiences with SWEPs, Challenge Programs and Regional Programs for Collective Action providing some lessons. Nevertheless, key judgments have to be made about the composition of any governance mechanism: the relationship between the convening Center and Program Steering Committee (PSC); the presence or exclusion of institutional representatives from the PSC; and the advantages and disadvantages of fully independent or disinterested PSC members and their time commitment to governance functions.

The paper finally argues that strategic communication is a critical function that facilitates governance, ensures equal power relations and keeps all partners on the same message. The Workshop is challenged to identify the priority to be attached to this function and the priority targets for its messages.

INTRODUCTION

The Challenges

How do we incorporate the lessons from partnership experiences in the development, governance and implementation of this multi-level, multi-disciplinary, multi-challenge and multi-region program to unleash the potential of sweetpotato in Africa? How does the Program address the goals of enhancing incomes and reducing malnutrition through choice of varieties, attention to research challenges, and choice of target populations? The nature of the partnerships, governance and strategic communication will follow from these choices.

This paper is about building partnerships with observations on the governance and strategic communications that have been critical factors in successful partnerships. Good governance and good communications can help avoid problems among partners. Moreover, good strategic communication can reduce pressures for costly political processes and face-to-face meetings.

Partnerships are essential to innovation with partners increasingly connected over significant distances. Successful partnerships of this type depend on shared goals, effective governance of the collaboration and the specific institutional arrangements that are designed. This paper reviews experiences in the Consultative Group on International Agricultural Research (CGIAR) and partner organizations for lessons that can be used in the Sweetpotato project.

The Project is following an approach that independently recognized an idea expressed by the CGIAR (draft 2008) Change Management Working Group on Partnerships:

> Key areas of governance, before any program commences, lie in the identification of needs and demands, the development of innovative working partnerships, and the involvement of other stakeholders in the joint conceptualization of the work. These are the essential founding steps for successful and sustainable research processes.

The development of the Project to unleash the potential of sweetpotato in Africa follows a tested approach: expert synthesis, wide stakeholder consultation, and final elaboration of the proposal along with partners committed to its realization. Six thematic teams are preparing papers covering the state of the art and key issues in science and technology, policy, and institutions. These teams focus on breeding, markets, seed systems, integrated crop management, adding value and partnerships and governance as related to sweetpotato. The Interim Science Council followed a similar approach of expert consultation to agree on the "potential" of science and priorities followed by regional consultations to establish commodity and thematic priorities by region. Finally, the Science Council, aided by a panel of experts, took on the task of integrating the proposals into System Priorities. This workshop is the expert consultation.

Second, the project is about innovation in sweetpotato where research is a key driver. We are operating in a world where the ability to "innovate" (i.e., to apply knowledge in a way that raises performance dramatically to a higher level) is a driving force for growth of income or poverty reduction. Research remains a key driver of increased performance but innovation requires policies, institutions and attention to the effective demand for research results. It is not only research that can stimulate an increase in performance; policies and new institutions may initiate a process of innovation or make it sustainable once started somewhere else in the system.

Third, the project is about goals: generating and applying knowledge on sweetpotato to achieve demonstrable increases in incomes and reductions in vulnerability, poverty, and malnutrition. This paper attempts to provide some insights into partnership and governance processes and experiences in the CGIAR and partner organizations so that the Project will avoid pitfalls.

Elaboration of some of the arguments and relevant excerpts from the literature are provided in Annexes.

Assumptions about the project

In order to move beyond generic lessons, the author made some assumptions about the way the Program would be structured. Participants will decide if they are in alignment with these assumptions and how any changes would affect the desired partnership arrangements. The six assumptions are:

- The project will be active in three regions: West Africa, eastern and central Africa, and southern Africa.
- The role of sweetpotato and the importance of orange-fleshed sweetpotato (OFSP) in the strategy will be different not only among the regions but also among countries and within regions of given countries.
- The project as a whole must develop the criteria and the instruments to set priorities and allocate resources across Project Level objectives, Regional Activities, and Critical Research Challenges.
- The critical challenges will change over time in any given regional or national context and, therefore, are likely to be different across regions and countries.
- There will be a number of core functions and core competencies required in each sub-region and the Project will seek to provide and institutionalize these core competencies related to achieving and sustaining the goals of the project.
- The sustainable increase in the importance of sweetpotato will be related to national level commitments to bringing research into use.

The Program is, therefore, aware of the need to have coherence among the activities at the country, sub-region and Program levels. There is an opportunity for sequencing activities across the three regions to enhance learning and capacity building. Ensuring this is a function of Program-level governance and institutional arrangements at the level of national institutes. The success of the Program in bringing research into use will depend on the voluntary commitments of a wide range of partners at the local level.

Issue 1: Will it be feasible to integrate studies, research and pilot research into use activities across three sub-regions?
Issue 2: What are the gains from integrating across three regions? Would it be easier and more productive to have three unrelated pilots?

Outline of the paper: Approach to the challenge

The author has attempted to structure the discussion in a way that provides information to participants about partnership and governance issues without prejudging what is the "best fit" for the project and each sub-region. The Challenge Workshop is an expert consultation to identify the key opportunities, trade-offs among objectives, themes and regions and to develop a proposal for resource allocations among priorities in these dimensions. The discussion of governance and partnership arrangements comes after the trade-offs have been made clear and the group will make recommendations to regional workshops and a wide range of stakeholders through strategic communication of the results. Therefore, the discussion is a synthesis of reviews of partnership principles in a CGIAR context, experiences with governance of Centers and Programs of various types (e.g., the Systemwide and Ecoregional Programs [SWEPs], Challenge Programs, Regional Programs for Collective Action). Following each synthesis, some issues for discussion and alternative actions to be recommended by the Working Groups are suggested.

In addition to this introduction, the paper contains the following sections, 1) Definitions and principles of partnerships, 2) Designing partnerships in an innovation systems perspective, 3) Governance of partnership programs, 4) Role of strategic communication, and 5) Conclusions.

Elaboration of, and supporting background information on, key sections are found in Annexes as referenced in the text.

Challenge 6.1. Partnership: definitions, rationale, principles and life cycle

"Partnership" is a term that has been used to describe everything from a mailing list to virtual integration of activities and decision-making. In this section, and in Annex 6.2, we attempt to 1) define "partnership" in terms of its attributes, 2) present commonly expressed principles found in partnership strategies, 3) suggest a life cycle for partnerships that can be used in monitoring progress, and 4) raise some issues that the Challenge Workshop should address.

Definition: "Partnership" and its attributes

Ozgediz and Nambi (1999) define a partnership as a "long term cooperative arrangement between two or more institutions involving exchange or sharing of resources to attain a common objective". They note that the three most widely used terms are "(strategic) alliances, networks and partnerships. Other terms used to define similar relationships include cooperation, collaboration, coalition and joint-venture". The common characteristic of these terms is that they refer to inter-institutional relationships.

Annex 6.2 cites a number of definitions of "partnerships" from which we derive several common features:

- A formal alliance with a win-win commitment to a commonly agreed set of goals.
- Mutual cooperation based on some comparative advantage, synergy or incentive.
- Shared risks, responsibilities, resources, competencies and benefits.
- Some form of contractual agreement that determines the sharing of responsibilities and benefits and fixes the boundaries between organizations.
- A concern for the well-being of the partner in a dynamic relationship in which their futures are linked.

This final feature was mentioned by the CGIAR partnership working group with respect to the role of the CGIAR in the global system.

Rationale for partnership

The idea that partnership is a means to an end is not new and it comes up at the system level in the CGIAR partnership working group as well as in partnerships at the institute and program levels. Partnerships may be pursued for many reasons, of which the following are not all-inclusive:
Access to skills, resources, markets, knowledge, ideas and consent.
Synergies arising from the "collaborative advantage".
Flexibility in a world where innovation is the source of growth.
Ability to maintain leadership through networking and alliances.

All transactions are an exchange of utility, and partnerships are one way of gaining a resource. They can be both an effective way and/or an expensive and restrictive way of gaining access to the needed resources.

Issue 1: When is partnership the most effective way to secure a resource and is it always mutually beneficial?
Issue 2: Who is a "partner" and what responsibilities and benefits should figure in the formal agreement?
Issue 3: How does the Program adjust to changing roles of partners over the life cycle of a project or program?
Issue 4: What sorts of exit strategy exists in partnerships? How do we deal with defaulting partners?

Issue 5: Are there more efficient and mutually beneficial ways of handling collaboration over the life cycle of a program?

Partnership principles

The International Livestock Research Institute (ILRI) has developed a Partnership Strategy and Management System that states a number of values which become principles that could be adopted or refined by other programs and institutions. As they note, these values enter into the criteria by which they can evaluate their partnership behavior. Annex 6.2 excerpts the complete text but the principles can be stated in short form as follows:

- Engage with partners in an inclusive, transparent and trustworthy manner where credits are shared with integrity.
- Treat partnerships as a means to an end; consider the quality of partnerships and weigh the trade offs in terms of transactions costs vs. outcomes and impacts.
- Articulate clear mutual benefits.
- Support management of partnerships at all levels (institute, theme, project).
- Commit to the supremacy of performance over politics, seniority and hierarchy in partnerships.

ILRI delegates management of the relationship to the appropriate level: the Office of the Director General (ODG), theme director or project manager.

Issue 1: Are Challenge Workshop participants "in alignment"[6] with the principles stated here? What additional ones should be added?

Issue 2: If some participants are not "in alignment" with a particular principle, how must it be modified or supplemented to serve the Sweetpotato project? If a participant is in strong disagreement it needs to be discussed in Working Groups and an alternative formulation proposed.

Partnership life cycle

Partnership relationships will evolve over the life of a project or program. Some of the functions assured by the lead organization may be taken over by partners as their human and

[6] Being "in alignment" with a particular statement means that a participant can live with the statement provisionally as a way of moving forward but reserves judgment on its exact formulation. At the end of the process, if he is not in agreement with the statement he can call for revision or withhold support for the conclusion. Innovation Expedition, Inc uses "the alignment tool" as a facilitating tool that avoids lengthy semantic discussions. Discussion is encouraged if a participant seriously disagrees with a proposition.

institutional capacity benefits from project investments linked to project outputs. Some partners that play a lead role at the beginning of a project or program may see their roles diminish as they move on to new challenges and new partners come in to work at the interface of research and technology uptake.

Sanginga *et al.*, (2007) have documented the dynamic process of partnership formation and the key elements that contribute to success. These include: (i) shared vision and complementarity; (ii) consistent support from senior leadership; (iii) evidence of institutional and individual benefits; (iv) investments in human and social capital; (v) joint resources mobilization. Their key lesson is that "institutionalizing multi-stakeholder partnerships requires participatory reflective practices that help structure and enhance learning, and incrementally help in building the capacity of research and development organizations to partner better and ultimately to innovate".

The authors adopt a three-stage classification of partnerships: 1) partnership formation, 2) partnership implementation and delivery, and 3) institutionalization of partnerships. They note that during the formation stage, a lead agency brings together participants who develop a common vision, define outcomes and develop action plans and agreements. At the implementation stage, the focus turns to program and activities as well as to maintenance and "routinization" of structures and processes. During the institutionalization stage, organizations adopt the program as their own and allocate their own resources to implementation of activities with little or no external funding. Annex 6.2 presents in tabular form the types of activities that typically occur in each stage of the partnership cycle.

Issue 1: Is the proposed phasing of activities in the Sweetpotato Project generally in line with the experience described by Sanginga *et al.*,?
Issue 2: The authors have described a strongly participatory approach with investment in learning and change? Does the Sweetpotato project give sufficient attention to these factors and will the donor agree with the priority to such an approach?

Michelsen (2003), in a study of partnerships between Cornell University's Center for International Food and Policy (CIFAP) and developing countries, describes how the success factors of partnerships change over their life cycle:

Table 6.1. Success factors over life cycle of partnership.

Foundation Phase	Evolution Phase
1. Compelling vision	1. Continuing relevance
2. Committed individuals	2. Attention to process and management
3. Strong and shared leadership	3. Effective communication
4. Shared problem definition and approach	4. Explicit decision making process
5. Financial resources	5. Trust and commitment
6. Power equity	6. Time availability
7. Interdependence and complementarity	7. Credit and recognition
8. Mutual accountability	8. Continuity
9. Enabling environment	9. Enabling environment

Annex 6.2 summarizes some of the findings from her study of Cornell which serve to remind us that partnership experiences are more about substance than about form but they are influenced by both internal and external factors weighing on the organizations individually. Understanding the pattern of change over the life cycle may help us focus on issues that are normally resolved in the establishment phase and not try to solve issues that will only become important later in the life of the partnership.

Issue 1: What lessons from their partnership experiences can participants share that can help design the project in a way that allows for evolution? Review the findings from Michelsen and share new ones.

Challenge 6.2. Designing partnerships in an agricultural innovation systems perspective

Defining the appropriate system

We have already established that the Program to unleash the potential of sweetpotato in Africa must be multi-level, multi-region, and multi-challenge. How would we define the "system(s)" and the allocation of resources among themes and regions to achieve the stated goal?

A system is a set of parts coordinated to achieve a common objective. A system is usually defined first by its objectives and then by its components, resources, environment and means of coordination (Churchman 1979). The objective of the Program is to raise incomes through productivity increases, value added in processing and transformation along the commodity chain, and impact on nutritional status through direct consumption of OFSP. This unleashing of the potential of sweetpotato will be attained by the application of knowledge of the six thematic challenges in specific environments from the local to the continental level.

Taking a "systems and contingency approach" (Kast and Rosenzweig 1985) we recognize a hierarchy of systems and sub-systems that are interdependent from the global to the regional, national and local levels (and vice-versa). We also accept that there is no universally best arrangement but only the "best fit" for a given situation (i.e., "contingency").

Issue 1: How do we define the levels of system and sub-system that make for an integrated program to unleash the potential of sweetpotato in Africa?
Do we define regional programs for each of the three sub-regions (West Africa, eastern and central Africa and southern Africa)?
Do we define an innovation system around sweetpotato? A subsidiary question is: Do we treat sweetpotato as one commodity or two (white fleshed sweetpotato and orange-fleshed sweetpotato) with different target populations and production systems?

The field visits have strengthened the author's belief that the Program will have a major opportunity (and significant task) in ensuring coherence in focus and sequencing of activities over time and among three sub-regional strategies. The target populations, the type of sweetpotato under cultivation, and the economic or nutritional goals will likely be different among the three sub-regions of the continent. Thus the research programs will be sub-regionally differentiated but coordinated. Institutional arrangements for regional support platforms will reflect these differences as will the partnership arrangements to host a platform and manage regional support. Each regional support platform will require certain basic competencies as well as specialized expertise to support the sub-regional priorities.

Issue 2: Are we in a position to define the regional system we wish to enhance and the skills that must be available in the regional support platform?

The choice of partners within a country will depend on the regional strategy and priorities (commodity and theme), the sequencing of research activities and the best location for work with beneficiaries. Partnerships among national agricultural research institutes (NARIs) and Universities are said to be smooth but anecdotal evidence points to the need for contracts, institutional mechanisms and facilitation to deal with questions of structure, accountability, overheads and institutional cultures. The Program will have to make provision for the resources to bring national partner institutions together.

When it comes to reaching end users, the Program will have to resolve two issues.

Issue 1: The Program will have to decide whether it will be active in coordinating Goals, Functions, Activities, Structures or People.

Issue 2: The Program will have to decide how involved it will be in building institutional and human capacity needed to achieve its objectives.

Partnership profiles

It is sometimes a diversion to introduce international comparisons among countries and national institutions because people may become obsessed with disputing nuances of rankings and meaning of variables. However, the data can sometimes be useful in highlighting the positive trends (e.g. reform of public institutions or educational equality) that affect the environment within which research partners work. Countries that have made a strong effort in educational achievement and gender equality will generally have a better pool of qualified people that increase productivity throughout the economy.

The World Economic Forum's (2008) "Global Competitive Index" and the World Bank's "Doing Business" reports both attempt to measure perceptions of the effectiveness and integrity of public institutions through the use of multiple indicators of "overall competitiveness" (Growth competitiveness, Public Institutions, Macroeconomic Environment, and Technology Index). The UN Global Gender Gap Report (2007) ranks countries on educational achievement and educational equality. Annex 6.3 reports on several countries that sooner or later will be involved with the project.

The countries all score within the top half of African countries on competitiveness. There is some noticeable variation in rank among the different indicators for individual countries but no outlying scores on which one would automatically include or exclude a potential partner.

Some objective assessment of the state of the NARS is also needed. Data from ASTI (Agricultural Science and Technology Indicators)[7] are unfortunately dated but Nigeria and Kenya still vie for second position after South Africa on the African continent in terms of human resources and national support to the NARS. The most recent figures for the ten years ending in 2001 show a growing global divide among regions of the world in which Africa is lagging and, within Africa,

[7] The Agricultural Science and Technology Indicators Project (IFPRI) provide data on human and financial resources invested in NARS that are comparable over time and across countries. The African data are somewhat out of date but are still the most reliable and are cited as a source in most recent analyses.

there is a concentration of investments in a few countries in Africa, and a decline in expenditure per scientist. (See Annex 6.4 for more detail).

Issue 1: Do recent trends in prospective partner countries give reason to believe that commitment to sweetpotato can be maintained and even increased through national contributions?

Selecting partners: Partnership readiness and the value proposition

We have defined a multilevel and multistakeholder project. How do we know if we have the right partners? The criteria for selecting partners obviously need to be specific to the level and function at which they operate. Partners may bring location specific knowledge, understanding of constraints, decision support, buy-in, political advocacy and willingness to invest their own resources. It is worth keeping in mind that a partner's role may change over the life of a project both because of incentives and changes in the tasks.

There are many "partnership readiness tools" that explore a generic list of criteria: commitment, shared goals, depth of institutional capacity and the like (Gormley and Guyer-Miller, 2007). Annex 6.5 reproduces one from a recent manual prepared by a former consultant to the Organizational Change Program of the CGIAR.

A second tool, the "value proposition" challenges a potential partner to explain what s/he (individually) or his/her organization offers to the program in terms of concrete deliverables and how these are superior to alternative sources of the product or service. A template is given in Annex 6.5 and participants are invited to complete it. A compilation of the results (with a chance to edit the draft) will provide a resource map for the project.

Issue 1: Complete the partnership readiness assessment. What do you need to do that requires action but no new resources to be ready? What do you need from the project in terms of support (financial or other) to be ready?

Issue 2: Make a first draft "value proposition" statement describing your proposed contribution to the project.

Challenge 6.3. Governance of partnership programs

Governance is where the internal management of the organization meets the external world[8]. A governance structure ensures that the internal management is focused on the realities imposed by external drivers (demand for services and realities of funding). Basically, the governance structure ensures that the project or organization has a strategy, hires (and fires) the chief executive officer, and provides due diligence over the finances, relations with customers, target beneficiaries and investors.

Criteria for governance structures

To initiate discussion, we suggest some criteria for designing a governance system:

- It needs to be coherent with the decision making structures and processes in its various sub-systems. The Project is not going to set up standalone structures so it has to be acceptable to the structures that our partners have in place. However, the different research structures across countries in a sub-region (and among the three sub-regions) create a complex tangle of relationships (and political interests).
- The Governing Body needs to bring together the development challenges and the research realities. It cannot engage in wishful thinking on either side.
- The structures need to be competent, light, innovative and capable of evolving with the phases of the project. This raises the issue of independent versus ex officio membership of institutional representatives on boards.

Issue 1. Are there additional criteria that we need to consider in designing an appropriate system for the Program?

Experiences with partnership programs

There are many experiences with "partnership programs" in the CGIAR that provide insights for the organization of the Sweetpotato project. In this section we mention three: SWEPs, Challenge Programs and Regional Plans for Collective Action.

The SWEPs (Systemwide and Ecoregional Projects) were designed to enhance partnerships within an "eco-regional" framework, a term developed by the Technical Advisory Committee to describe an agro-ecological zone set within its policy and social environment. Regions such as the sertão of Brazil and the Sahel of Africa might share some agro-ecological similarities but

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[8]This definition is of uncertain origin but the author believes it captures what governance bodies are about.

they constituted two quite different development challenges that called for different research strategies. Moving from an understanding of eco-regionality, the SWEPS developed an integrated natural resources management perspective and pioneered work on participatory learning and change. A SWEP was not necessarily time bound.

Challenge Programs were designed to open up the CG system to widen partnerships around key themes (e.g., water and food, biofortification, biotechnology, and Sub-Saharan Africa). They were meant to be time bound.

Regional Plans for Collective Action (ESA and WCA) were the initiative of the Alliance and partners to identify "flagship programs" around key challenges in two sub-regions (West and Central Africa, eastern and southern Africa). As an initiative of the 15 Centers active in each region, they were designed to create innovative programs with partners to address a need for regional and international public goods through voluntary collective action. The centerpieces were "flagship programs" of high priority to the region that offered high payoff to collaboration at the boundaries of Centers' and Partners' core business.

Issues in governance

The SWEPs adopted a basic management structure at the Global, National and Program implementation levels that included the following:

- Global level: a Convening Center, Steering Committee, Executive Committee, Coordination Unit, Special panels and Workshops (used for technical and management purposes).
- National Level: a National coordinator and Site coordinator (for benchmark sites).
- Program Implementation: participatory program development at benchmark sites, responsibility of NARS.

Several SWEPs won a CGIAR "partnership" award. It would be surprising if they had not, given that their purpose was to engage partners at the regional level. Experiences were found to be highly correlated with the skill of the coordinator. The composition of Boards, the selection of Board members and the relationship of the SWEP to management of the host institution were continuing issues.

Challenge Programs were intended to be time-bound collaborative efforts that opened the CGIAR to a wider range of partners and stimulated inter-center collaboration around key challenges. They all created some form of steering committee or program advisory committee. Reviews of the challenge programs highlight some of the key issues and lessons. The key issues of composition of and voting rules in the Program Steering Committee (PSC) concerned a) the nature of members, b) the role of the lead Center(s) on the PSC, and c) differentiating among the different types of stakeholders.

The Regional Plans for Collective Action (RPCAs) have their natural partners in the Sub-Regional Organizations (West and Central African Council for Agricultural Research and Development [CORAF/WECARD], Association for Strengthening Agricultural Research in Eastern and Central Africa [ASARECA] and the Southern African Development Community – Food, Agriculture and Natural Resources Directorate [SADC-FANR]). In the case of the RPCA-ESA, the partners agreed that their jointly-developed flagship programs would go through the Science Council to ExCo for assessment and endorsement. The Coordinator of the RPCA attends ASARECA Board Meetings and represents the CG collectively (which does not impede individual centers from attending in their own right). With no financial support from the CGIAR, the regional plans have made some progress on "projects" and "frameworks" but not received the critical level of support for planning and take-off.

Issue 1: What should be the role of the convening Center on the Program Steering Committee?
Issue 2: Should there be any "institutional representatives", whether from NARS or Centers on the steering committees?
Issue 3: Does the autonomy and independence of arms'-length PSC members have a high cost in the lack of first-hand understanding of the issues and sometimes shallow commitment?

Challenge 6.4. The need for strategic communication

The role of strategic communication is of paramount importance throughout the process from the beginning of planning to reach end users. Strategic communication is aimed at getting the right message to the right people at the right time. This brief section serves to highlight the need for a sufficient information and communication budget for the Program.

The proposed partnership program will operate across three regions. A communication program will perform several key functions:

- It ensures transparency, symmetry of information and more equal power relations.
- It keeps the dispersed actors in a wide network on the same message so there is coherence among regions.
- It reduces demands for political involvement in "governance" because stakeholders have the information they require.

There is no budgetary "norm" in the sense of a percentage of total budgets that should go into communication activities. This will vary with the nature and stage of a project[9]. This leads us to frame two issues for the group.

Issue 1: What are the most critical needs for strategic communication at the current stage of the project?

Issue2: What will be the critical needs for information and communication in the first 5 years of the program?

CONCLUSION

This paper has been a voyage of discovery. It started with an attempt to synthesize some of the lessons on partnership applicable to the many levels at which this Program will operate. It led to the need to define those levels and the nature of the "systems" we needed to strengthen. It was acknowledged that the governance and institutional arrangements would have to be appropriate to the achievement of strategic priorities that would come out of the planning process. The author attempted to remain neutral in the presentation of experiences and formulation of issues for discussion. Where it seemed useful, extra information, lessons from external reviews of programs, descriptions of similar process, and management tools were provided to assist in analyzing the potential contributions of partners. The issues were formulated to elicit knowledge and insight of participants.

[9] A recently issued report of the Secretary General on 334 partnership programs of the UN had anywhere from 20-40% of activities aimed at policy advocacy, building awareness and training but this is a meaningless figure without knowing the nature of the individual programs.

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ANNEX 6.1. STRATEGIC TRADE-OFFS

One of the assumptions of the paper is that there will emerge a consensus on the need for a Program strategy that has three consistent and coherent sub-regional components. The governance of the Program and the institutional arrangements to manage the implementation at the sub-regional level will derive from the strategy that is adopted.

Figure 6.1
Objectives, regions and challenges.

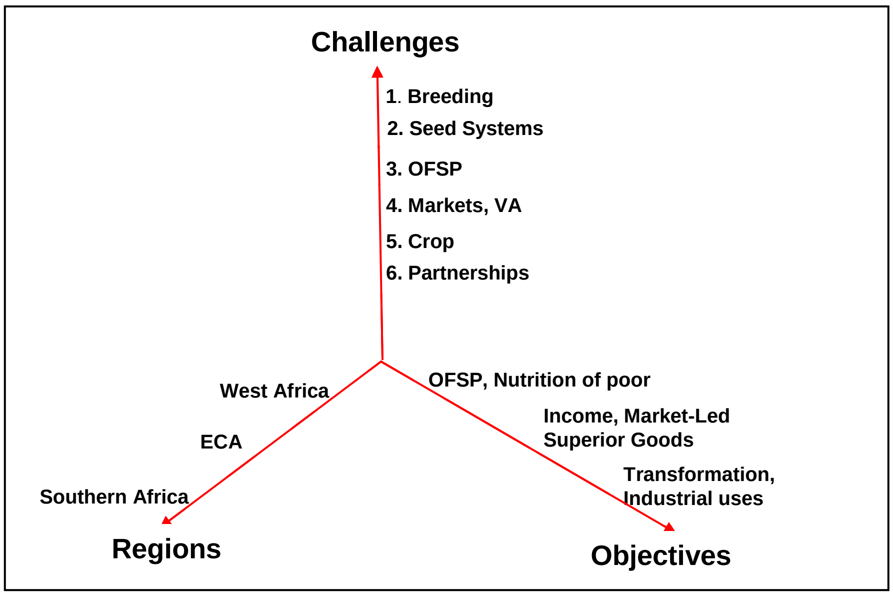


Figure 6.1 arrays the trade-offs that might be made across the measurable Objectives of the Program: 1) numbers of poor people whose food vulnerability or nutritional deficiency is reduced by production and direct consumption of sweetpotato, 2) incomes that are earned by producers of sweetpotato who sell to formal markets, and 3) incomes generated along the value chain through marketing, processing and transformation into other products. Each of these has an impact on livelihoods and distributional impacts in time and space.

This expert consultation will advise whether there should be differentiated strategies for each sub-region based on objectives, regional comparative advantages in research and production and the potential for sweetpotato to satisfy both income and nutritional objectives.

The implications of this analysis for the location of regional sweetpotato support platforms (RSPSPs), the sequencing of activities they will undertake, and the evolution of regions towards the long term (10-year) goals of the project are clear. The ability of the Project to foster inter-regional sharing will depend on the governance, partnership arrangements and communications that are put in place.

ANNEX 6.2. FURTHER ELABORATION OF "PARTNERSHIP ISSUES"

Definitions and common elements

Ozgediz and Nambi (1999) define a partnership as a "long term cooperative arrangement between two or more institutions involving exchange or sharing of resources to attain a common objective. They note that the three most widely used terms are (strategic) alliances, networks and partnerships. Other terms used to define similar relationships include cooperation, collaboration, coalition and join-venture. The common characteristic of these terms is that they refer to inter-institutional relationships.

Other definitions and common elements are given below, most of which further highlight the importance of common goals, formal contracts, agreements on division of responsibility and benefits, and voluntary nature of the arrangement:

1) Formal alliance, usually through one or more business contracts.
2) Long term, win-win, commitment between two organizations for the purpose of achieving specific business objectives.
3) A legal contract entered into by two or more persons in which each agrees to furnish a part of the capital and labor (for a business enterprise), and by which each shares a fixed proportion of profits and losses.
4) A relationship between individuals or groups that is characterized by mutual cooperation and responsibility often recorded in a memorandum of understanding.
5) Partnerships are commonly defined as voluntary and collaborative relationships between various parties, both State and non-State, in which all participants agree to work together to achieve a common purpose or undertake a specific task and to share risks, responsibilities, resources, competencies and benefits (United Nations 2007).
6) A dynamic relationship among diverse actors, based on mutually agreed objectives, pursued through a shared understanding of the most rational division of labor based on the respective comparative advantages of each other (FARA 2008).
7) Suggestions from the literature (most based on purpose or core function) include a simple breakdown between primarily operational v. advocacy-oriented partnerships or between process, project and product-oriented partnerships (Murphy and Bendell 1997). Witte *et al.*, (2003) identify three ideal types of networks: negotiation, coordination and implementation; while the Global Action Network Net (Waddell 2003) has proposed a typology of seven types including, among others: knowledge, task, societal change and generative change networks (United Nations 2004).

General partnership issues in the CGIAR

The CGIAR Change Management Team created a Partnership Working Group that laid out four main issues. At the time of writing, the working group had not yet reported its conclusions. The issues they identified[10] can be posed within the context of the present Program development:

1) The objective of partnerships: Partnerships can be seen as a means to increase the efficiency and effectiveness of CGIAR activities. In this perception it is a means to an end….[On the other hand, does the CGIAR have a responsibility in the construction and development of a well articulated GARS (Global Agricultural Research System)?]
2) What makes a Partner to be a Partner? Partnerships imply a long term relationship with common objectives and a clear understanding of complementarities and potential synergies. In this view a Partnership implies that Partners seek a common objective and, at the same time, are mutually interested in the well being and success of its partner. This characterization excludes Collaborators, which implies a lighter, more circumstantial and short run relationship. A Partnership strategy of this type would naturally lead to a Network Mode of working with the selected Partners and probably to the development of a conglomerate of institutions working together. In this limited conglomerate the CGIAR would have, because of its international nature and relative size, a major role. A fully developed Network mode could have implications for the optimum CGIAR physical structure;
3) Should selected Partners participate in Governance? Who has the legitimacy to make the final decision on strategy, priorities and resource allocation? Who are the real "partners" that may be considered part of governance? Finally, how do you ensure that independent representatives in Governing bodies fully assume the responsibilities that the position demands?
4) Partnerships and their contributions to the CGIAR Functions. Partnerships should contribute to the following CGIAR functions:
    - To define the strategic task and the priorities of the work carried out by the CGIAR and its Centers.
    - To develop work related to the anticipation function.
    - To develop activities related to awareness raising.
    - To produce research outputs.
    - For technology dissemination activities including activities related to knowledge management and the promotion of innovations.

[10] CGIAR Change Management WG2. Issues Paper: Our thinking prior to Ottawa (draft 19-04-08).

- To develop activities related to support to decision making on policy and institutional matters.
- To develop activities related to capacity building, including training.

Rationale for partnership

In the main text, we have argued that an organization may seek partnership for a number of reasons: 1) to gain access to skills, resources, markets, knowledge, ideas and consent; 2) to realize synergies from the "collaborative advantage"; 3) to create flexibility to exploit new opportunities across wide areas; 4) to maintain leadership through networking. An organization may get access through commercial transactions, temporary strategic alliances with a normal competitor, and direct acquisition or merger.

A partnership is presumably voluntary on both sides and represents gain on both sides. However, transparency and symmetrical information is needed to ensure that partnerships are fair. In the absence of full information, an "alliance" may become in effect a "forced sale" of the weaker partner. In a business alliance, for example, one partner may have full access to the key asset or knowledge of the other party and effectively strip that partner of the main capital value of his assets. At that point the stripped enterprise becomes a cheap acquisition in a take-over or is liquidated. The relevance of this is seen with respect to intellectual property rights and protection of rights to strategic genes in biotechnology. Other methods of gaining access include: a) commercial contracts, b) temporary strategic alliance with a competitor, c) direct acquisition or merger and d) concessions (as in the case of the African Agricultural Technology Foundation [AATF]).

The notion of "collaborative advantage" originally came up in the context of multinational corporations that realized economies of scope principally by utilizing physical assets and exploiting a companywide brand. The new economies of scope are based on the ability of business units, subsidiaries and functional departments within the company to collaborate successfully by sharing knowledge and jointly developing new products and services. "Collaborative advantage will be achieved when something unusually creative is produced—perhaps an objective is met—that no organization could have produced on its own and when each organization, through the collaboration, is able to achieve its own objectives better than it could alone"(Huxham, 1993).

Innovation occurs at the boundaries among organizations. Resources can be accessed in a virtual manner across large distances and not require a partner to abandon its core business while trying new ideas. Low overhead arrangements allow multiple experiences from which one can learn. This was the logic of the Regional Plans for Collective Action.

The issue of whether collaboration is more effective than competition in driving profits and wealth is being hotly debated in the software industry[11].

Finally, a well networked organization may by itself be a small player on the global scene but may be able to play a much more important role on the global scene through its ability to bring its networks along with it (CGIAR Change Management draft, 2008).

Partnership principles: the ILRI statement

ILRI has formalized its partnership principles in the following statement which may stimulate reflection by the Sweetpotato Project:

It is critical to establish a common vision and understanding of ILRI's partnership mandate and orientation as these define the criteria by which we evaluate our partnership behavior. All partnerships need to be consistent with the vision, mandate and orientation of ILRI. We can summarize these values as principles, which are (ILRI, 2008):

- ILRI commits itself to engage with **partners in an inclusive, transparent and trustworthy manner where credits are shared with integrity** and obligations are implemented in a mutually accountable way while being fully committed to the impacts and strategic goals.
- Partnership and collaboration, however, are considered a means to an end and ILRI must carefully consider the **quality of partnerships and weigh the trade-offs** in terms of transaction costs vs. outcomes and impacts.
- ILRI enters into a partnership with another institution if and only if both ILRI and the potential partner can identify and articulate clearly their expected **mutual benefits**. [A partnership in which only one partner derives benefits is unhealthy and likely to fail].

[11] Economist. July 2008. The proprietary models of the giants are being challenged by the claims of collaborative efforts such as Wikipedia.

- **Transparency** promotes healthy partnerships. Making sure that roles and expectations are discussed and agreed, and then clearly stated and documented, avoids misunderstandings later.
- **ILRI will support effective management of partnerships at all levels,** through valuing and helping to develop the skills of ILRI staff in managing partnerships and defining and recognizing good performance, and by allocating the time and resources needed for effective partnership management.
- ILRI is committed to **the supremacy of performance over politics, seniority and hierarchy in partnerships**. It will operate in the least bureaucratic and hierarchic way possible to ensure efficient, effective, accountable services and provide space for innovative and entrepreneurial high-performing staff while maintaining inclusiveness and equal opportunity.

The challenge to the Workshop is to express alignment with the principles stated here and suggest where they require modification to fit the Sweetpotato project or provide an alternative statement of partnership principles that fit the strategy that has been developed in the previous theme sessions.

The partnership life cycle

Sanginga *et al.*, (2007) identify three phases of participatory partnership formation for rural innovation and indicate the activities that are typically found in each phase:

Stages of partnerships key milestones and activities

1. Partnerships formation stage

- Field visits or presentation.
- Institutional assessment (criteria for selecting partners).
- Partnership start up meetings with senior managers.
- Needs assessment workshops.
- Joint proposal development.

2. Partnerships delivery and implementation stage

- Training workshops on methodology and concepts.
- Development of joint action plans, workplans and budget.
- Negotiation of memorandum of understanding.
- Find motivating ways to share information, and to communicate successes.

- Building social capital (teamwork, mutual accountability, credit sharing, trust and communication).
- Dealing with communication challenges.
- Some partners drop out.
- Staff turnover and over commitment.

3. Partnerships institutionalization stage

- Train a critical mass of staff in partner's organization.
- Openly discuss potential barriers to partnership, and establish norms of working together.
- Joint resources mobilization.
- Hold review and planning meetings at regular intervals.
- Find motivating ways to share information, and to communicate successes, keep managers informed.
- Develop a strategy for joint resource mobilization, co-financing and sustainable funding mechanism.
- Develop plans for scaling up.
- Shared leaderships, and emergence of small clusters.
- New partnerships emerge.

Michelsen (2003) reports on a study of Cornell University's partnership experiences. The following points summarize her findings:

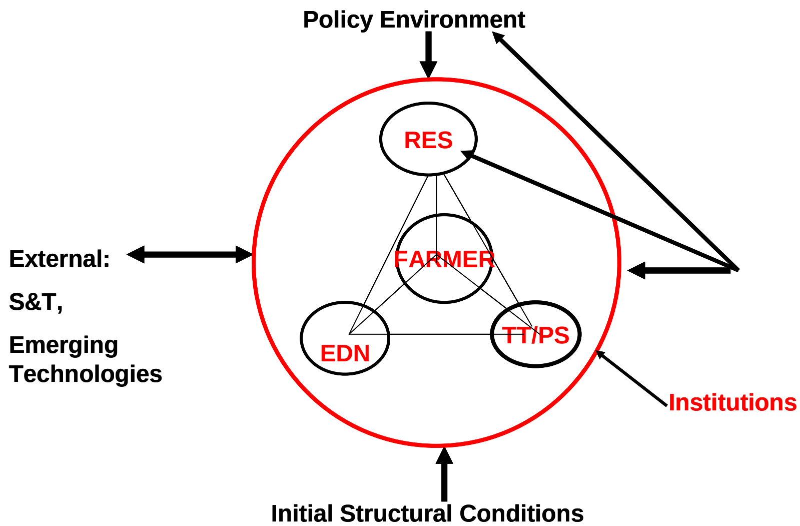
- It is more substance than form that determines a partnership.
- Partnerships are initiated mostly through individual contacts, but institutionalization was key for their survival.
- Reasons for success and failure are partly determined by the environment of partner organizations.
- Motivations can be very different, but there should be common interests, joint contributions, and joint ownership.
- Expectations always change over time.
- Characteristics of partnerships often conflict with those of funding opportunities.
- Partnerships are not static; they need time to develop.
- Partnership is a learning process.
- Every partner has its own definition of success.

- Mutual benefits are important but are difficult to compare between partners.
- There is danger of imbalances between Northern and Southern partners.
- Partners don't appreciate, and are often frustrated by, each others characteristics and constraints.

Understanding the change in concerns over a life cycle may help us to focus on issues that are normally resolved in the establishment phase and not try to solve future issues that will become important later in the life of the partnership.

ANNEX 6.3. DESIGNING PARTNERSHIPS IN AN AGRICULTURAL INNOVATION SYSTEMS PERSPECTIVE[12]

Figure 6.2 Evolution of key components in an agricultural innovation system (AIS).



Source: Adapted from Elliott, 1987.

The author finds it useful to think of a generic AIS in which the Agricultural Knowledge and Information System (AKIS) is represented with the farmer at the center of the knowledge institutions (research and universities) and the uptake system (agricultural advisory services, nongovernmental organizations [NGOs] and private sector).

These organizations respond to an environment conditioned by 1) the systems initial structural conditions (resources, economic blocs, and physical environment), 2) donors and investors, 3) exogenous scientific and technological advances, and 4) a policy environment. Various institutions (rules and norms) and organizations grow up to mediate the influence of the environment.

[12] This section is based on Elliott, H (2008) Evolution of Systems Thinking towards Agricultural Innovation Systems. Paper presented at IFPRI-ISNAR workshop, Addis Ababa, April 2008.

One may think of three approaches that co-exist but emphasize different drivers of the system:

1) A learning and change approach that begins with the farmer first and has been applied through farmers field schools, Prolinova and the Convergence of Sciences school (Wageningen) that adds the institutional and policy environment.
2) A scientific and technical approach that has two schools: 1) a breeding and biotechnology focus that seeks either the breakthrough that will drive change in technology and institutions, and 2) a farming systems, integrated natural resources management approach that has added the policy, economic and social environment to become Integrated Agricultural Research for Development and has begun to use the language of innovation systems.
3) A policy and institutional approach (associated with the World Bank) that began with strengthening the NARS, moved to encompass the entire AKIS and sees policy and institutional reform as the driver of the system.

All three of these can be compatible with an innovation systems approach that gives due attention to both the supply and demand for technology, the incentives for people and institutions to behave in certain ways and to apply knowledge (tacit or formal) to increase productivity or reduce vulnerability and poverty. Donors and investors can influence the supply of and demand for technology in three ways: 1) increase the level of resources to the system, 2) induce policy changes that affect relative prices and the demand for technology, and 3) direct investment in the organizations that generate technology.

Designing the Sweetpotato project in an innovation systems perspective encourages a look at all these forces. The six themes of the project fit within this model which can be applied at all levels of system hierarchy from the local to national and regional innovation systems.

Extending a participatory approach

Sanginga *et al.*, (2007) outline the key steps in applying a participatory approach to rural innovation:

1) Engagement of appropriate research and development partners and the reaching of consensus on the approach, where to intervene and respective roles and responsibilities;
2) Participatory diagnosis with the community, focused on their vision and opportunities for the future, with strong emphasis on gender and stakeholder analysis;

3) Formation of farmer research group and market research group, and building their capacity to participate actively in selecting, testing and evaluating marketing strategies, technology options, and approaches to sustaining their natural resources.
4) Participatory market analysis to identify market opportunities for competitive products that will increase farm income and employment.
5) Prioritization of opportunities and selection of household food consumption and agro-enterprise options based on social differences, including gender and wealth.
6) Identification of research and development questions related to the entire resource-to-consumption system.
7) Planning and implementation of experimentation and enterprise development strategies with farmer research and market research groups.
8) Feedback of results to the community and research and development (R&D) research, and identification of further research questions.
9) Strengthening the access to information for decision-making at all stages of the process, through formal facilitation mechanisms and novel communication media.
10) Participatory monitoring and evaluation, and learning to derive lessons and impacts, scaling-up and out of participatory research results, and of community enterprise development processes.

The International Potato Center (CIP) is one of the strong proponents of Participatory Impact Pathway Analysis and it is not necessary to elaborate it further in this paper.

ANNEX 6.4. PARTNERSHIP PROFILES: COUNTRY LEVEL

Country competitiveness profiles

All the countries interested in the Program score among the top 25 countries in Africa on the World Economic Forum's Global Competitiveness Report and several score very well on a global scale on the UN Gender Gap Report.

Table 6.2. Partner countries ranked internationally by competitiveness and gender.

Country	Nigeria	Ghana	Kenya	Uganda	Tanzania	Mozambique	Malawi
Rank in top 25 African Countries: Competitiveness (1 is highest)							
Growth Competitiveness Index	16	10	15	14	9	20	12
Public Institutions Index	24	10	21	18	9	16	3
Macroeconomic Environment Index	13	11	15	12	14	20	23
Technology Index	13	14	8	10	12	17	19
Gender: Overall Rank (Achievement and Equity) (1 is highest)							
Gender: Overall Rank out of 128	107	63	83	50	34	43	87
Gender: Educational Achievement	118	106	97	104	109	120	108

Source: World Economic Forum, 2008.

The state of NARS (ASTI)

A realistic assessment of a potential partner's commitment and ability to deliver what is promised under the joint venture, consortium agreement or contract is necessary. Only in this way can the project make the case and donors make provision for institutional, infrastructure and human capacity building needed to meet project expectations. It is recognized that a particular institute or program may be excellent within a system that is generally failing. However, such excellence is often associated with a particular leader or a particular donor and is likely to be quite vulnerable to changes. Moreover, private sector research is generally strong only where public sector research is strong and provides a base of talent and support. The implications for partnerships are clear.

A clear understanding of gaps in national capacity can lead to corrective measures: 1) donors have a basis for investment in capacity building, 2) the program can schedule activities among its regions to allow training to take place, and 3) the program can plan for the risk of default if a partner loses essential staff. Where capacity building is required, the scheduling of activities may take this into account. If each partner is responsible only for his deliverables and a partner defaults, who is ultimately responsible to pick up the slack and what resources are provided for this? This is an issue that every coordinator of a sub-regional network has faced.

Data from the ASTI (Agricultural Science and Technology Indicators) are unfortunately dated. However, Nigeria and Kenya still vie for second position after South Africa on the African continent in terms of human resources and support to the national system. Many of the other programs have a high degree of dependence on donor funding or have experienced sharp declines with the loss of major projects. The World Bank has moved away from "NARP" (National Agricultural Research Projects) to "NAPPs" (National Agricultural Productivity Projects) in which research was one of several components needed to achieve increased productivity. After several years of declining support (Beintema and Stads 2006) there are two trends: 1) declining expenditures per scientist and 2) a growing divide among countries within Africa (Pardey *et al.*, 2006). The growing divide is also a global phenomenon which appears among regions of the world and among countries within regions. It has many implications for the way research links to development challenges at the national and local levels.

In 2000, just 5 of the 48 countries in the region employed about 40 percent of all full time equivalent (fte) research staff in agriculture. Nigeria (in West Africa) and South Africa (in southern Africa) reported the largest capacities, at 1352 and 1029 fte researchers, respectively, while Kenya, Sudan, and Ethiopia (in East Africa) employed 740780, and 822 fte researchers, respectively.

Gender

The position of women scientists in research in SSA merits some attention. Beintema and Stads (2006) note:

> In 2000, 18 percent of African agricultural researchers in our 27-country sample were female (Figure A). Close to one-third of agricultural researchers in Botswana, South Africa, and Mauritius (all within the southern African region) were female, while the corresponding share in 9 of the 14 West African countries was 10 percent or lower. In East Africa, large variations existed across countries: of total research staff in 2000, female researchers accounted for more than a quarter in Sudan; about one-fifth in Kenya, Uganda, and Tanzania; but only 7 and 4 percent in Ethiopia and Eritrea, respectively.

While the available data is limited and out-of-date, the ASTI figures (Beintema and Stads 2006) show that a larger proportion of female scientists hold PhD degrees than male scientists. Interviews with University leaders suggest that the pool of female students in relevant undergraduate disciplines is growing as a proportion of the total. A joint strategy by universities and research institutes to capture this growing potential would make sense.

ANNEX 6.5. PARTNERSHIP READINESS AND VALUE PROPOSITION TEMPLATES

In this Annex we present tools for use by partners. The first is a "partnership readiness" template that invites a potential partner to assess their institute's ability and willingness to commit to a partnership. The second tool is more specific to a particular role and challenges partners to describe their "value proposition": what products and services they will directly contribute to the partnership and how these are preferable to products and services of competing providers. Templates are provided for both and may be used formally or informally in the course of the workshop.

Tool #1: Assessing partnership readiness[13]

Organizations should engage in rigorous critical and strategic thinking before agreeing to join a collaborative venture. The human and financial resources of an organization must be carefully focused to achieve the purpose and goals of that organization. Whether or not to join an alliance is often a difficult decision to make.

The following questions can help focus your thinking.

Please use the following point scale:

1 = Definitely not able/willing to do this
2 = Possibly, but would seriously stretch our capacities
3 = We could do this sufficiently
4 = Definitely able and willing to do this quite well

When finished, total up your points.

The scores reflect the degree of confidence in your readiness. Lower scores (10 to 20) indicate a real concern, perhaps the partnership is not right for you now; middle scores (20 to 30) say you have some concerns, but with special attention devoted to what concerns you most, you think you should proceed; and the higher scores (30 to 40) indicate that this is a very good partnering opportunity for you.

[13] Gormley W and Guyer-Miller L. 2007. Training Resources Group (TRG), Inc. Capacity Project Toolkit: Practical Partnership Building: Practical tools to help you create, strengthen, assess and manage your partnership or alliance more productively. Capacity Project and USAID. (TRG and the authors reference the CGIAR Organization and Change Project of the CGIAR which commissioned the early work on such a manual.)

_______ 1. Is it clear how joining this partnership will facilitate the achievement of our strategic goal(s)?

_______ 2. Does my organization have the resources—financial, people and technology—needed to contribute our portion of the partnership being considered?

_______ 3. Can we honestly say these resources can be accessed when required?
(Meaning they have not already been committed to several efforts and are seriously overloaded).

_______ 4. Are we willing and able to work in collaboration and mutuality with the other organizations that comprise this partnership?

_______ 5. Have we worked with any of these other organizations before, and was that a positive experience?

_______ 6. Are we willing and able to share control and participate in shared decision making with these particular organizations?

_______ 7. Are we willing and able to be flexible about how things get done and not be insistent that it be done our way, and will this meet our expectations of quality work?

_______ 8. Have we in the past and are we now able to work with our less resourced partners with mutual respect, avoiding any sense of domination and superiority? Would these organizations give us a high rating in this regard?

_______ 9. Is there support for this project within our organization, and would this Partnership become a valuable part of our organization's portfolio?

_______ 10. Can we commit to devote the leadership and management time required of us in this partnership effort?

_______ 11. Have we had sufficient experience in working in partnerships so that we can say that our "partnering" competencies are good enough to carry out our performance commitments?

Tool #2: Value proposition prepared by partner[14]

Name of Individual or Organization: [Note: A value proposition could be that of an organization or an individual. A participant is encouraged to complete one for both himself and his organization.]

NAME: (Organization or Individual) ________________________________

FOR: The CIP/BMGF Project on Unleashing the Power of Sweetpotato in Africa

WHICH REQUIRES: [Describe the specific need of the Project which the respondent proposes to meet]

OUR PRODUCT OR SERVICE: [Describe what you will actually produce or do in terms commonly understood by the project organizers]

THAT: [Describe the key benefit that the Project will gain from your product or service]

UNLIKE: [Identify any key competitors for this role including those who might also be potential strategic allies or partners]

OUR PRODUCT IS BETTER: [because of the following key differentiators):]

AT A COST THAT [(is less than, equal to or higher than alternative partners but) is justified by:]

[14] Adapted by the author from various formulations on Internet

ANNEX 6.6. GOVERNANCE ISSUES IN PARTNERSHIP PROGRAMS

The key issues have been mentioned in the main text. However, it is useful to summarize in point form some of the issues arising from perceptions that partners (Center and NARS alike) have of the governance of Challenge Programs.

A wide range of stakeholders was contacted for their perceptions of the Program Steering Committees (PSC) and the influence of certain classes of members. The results of those surveys suggest:

1) If lead Centers are present on the PSC, there will be a perception by other Centers and some partners that the program is in danger of being biased in favor of the "institutional interests" of the convening or lead Center.
2) Attempts to have a large PSC that reflects the composition of stakeholders creates other problems:
   - The PSC can become unwieldy if too large.
   - If the stakeholder group is sufficiently diverse the members of the PSC are not seen as "representative". For example, in the Challenge Program of Food and Water (CPFW) it was difficult to explain why one river basin commission was selected and while representatives from the host institutions of others were excluded;
   - Majority voting is not the way to get scientific consensus on key issues (CPWF had announced a "new" approach that introduced majority voting on strategic issues where only 5 of 18 partners were CG Centers).

Review panels for the Challenge Programs have ended by recommending against "institutional representation" or commented favorably where the convening centers have effectively delegated authority to an autonomous PSC (as with the HarvestPlus).

There are a number of practical considerations relating to clarity of the shared goals, clear roles and responsibilities and the means of enforcing them. Lessons include:

1) The need for the PSC to be independent from the institutional interests of any of the members (and not just the convening Center).
2) The need for a clear Governance and Management Manual. The Generation Challenge Program considers itself a collaborative program "held together by contracts".
3) The need to recognize collective responsibility for deliverables. The CPWF operated under a Joint Venture Agreement that was supposed to allow the program to build on

existing capacities in the lead Centers and not have to create a major administrative secretariat. However, the fact that each member was liable only for its own deliverables and not the collective output proved to be a weakness.

4) The operation of a widely distributed program with the posting of scientists far from Headquarters of the convening Center had its risks. The review of the Participatory Research and Gender Analysis (PRGA) program commented that "without a scientific constituency in the convening Center, broad based support for the program will not be forthcoming" and suggested that the posting of scientists away from HQ led to a decline in interdisciplinary research.

5) HarvestPlus was seen to have struck the right balance in many things –a gender and origin balance in membership; hands-off governance by the International Food Policy Research Institute (IFPRI) and the International Center for Tropical Agriculture (CIAT); and responsibility of the PSC for most of the functions of a governing body: a) strategic direction, b) management oversight, c) stakeholder participation, d) risk management, e) resolving conflicts of interest and f) audit and evaluation.

The International Potato Center (CIP) seeks to reduce poverty and achieve food security on a sustained basis in developing countries through scientific research and related activities on potato, sweetpotato, and other root and tuber crops, and on the improved management of natural resources in the Andes and other mountain areas.

THE CIP VISION

The International Potato Center (CIP) will contribute to reducing poverty and hunger; improving human health; developing resilient, sustainable rural and urban livelihood systems; and improving access to the benefits of new and appropriate knowledge and technologies. CIP, a World Center, will address these challenges by convening and conducting research and supporting partnerships on root and tuber crops and on natural resources management in mountain systems and other less-favored areas where CIP can contribute to the achievement of healthy and sustainable human development.
www.cipotato.org

CIP is a Future Harvest Alliance Center and receives its funding from a group of governments, private foundations, and international and regional organizations known as the Consultative Group on International Agricultural Research (CGIAR).
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