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Sweetpotato Seed Systems in sub-Saharan Africa

A literature review to contribute to the preparation of conceptual frameworks to guide practical interventions for root, tuber and banana seed systems

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A broad alliance of research-for-development stakeholders & partners

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Acronyms

AEZ	Agro-ecological zones
AGRA	Alliance of a Green Revolution in Africa
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
BMGF	Bill and Melinda Gates Foundation
CIP	International Potato Center
CRS	Catholic Relief Services
DFID	Department for International Development
DONATA	Dissemination of New Agricultural Technologies in Africa
DVMs	Decentralized vine multipliers
FAO	Food and Agriculture Organization of the United Nations
FFS	Farmer field school
FGs	Farmers' groups
HHs	Household(s)
IPTAs	Innovation platforms for technology adoption
ITK	Indigenous technical knowledge
NARIs	National agricultural research institutions
NCM-ELISA	Nitrocellulose membrane-enzyme-linked immunosorbent assay
NGO	Nongovernmental organization
OFSP	Orange-fleshed sweetpotato
QDPM	Quality declared planting material
QDS	Quality declared seed
RMTs	Rapid multiplication techniques
RTB	Roots, Tubers and Bananas (CGIAR Research Program)
RTB	Root, tuber, and banana (crops)
SASHA	Sweetpotato Action for Security and Health in Africa
SNNPR	Southern Nations Nationalities and Peoples' Region
SSOSPA	Soroti Sweet Potato Producers and Processors Association
SPCSV	Sweet potato chlorotic stunt virus
SPFMV	Sweet potato feathery mottle virus
SPVD	Sweet potato virus disease

SSA	Sub-Saharan Africa
TC	Tissue culture
TSNI	Towards Sustainable Nutrition Improvement in Rural Mozambique
VPCs	Vegetatively propagated crops
WTP	Willingness to pay

Abstract

This review assesses our current knowledge of sweetpotato seed systems in sub-Saharan Africa (SSA) as a contribution toward developing a conceptual framework for guiding practical interventions for root, tuber, and banana (RTB) seed systems. This is in the context of the CGIAR RTB program's theme on seed systems. The proposed framework will help to identify gaps and research needs in order to address the continuing challenge of ensuring that smallholder farmers can access timely and sufficient quantities of quality sweetpotato planting material. As part of this effort, this review proposes to field test alternative approaches to RTB seed system improvements that connect biophysical, management, and socioeconomic factors, and to draw strategic guidelines for future interventions.

Sweetpotato seed systems in SSA are highly diverse and context specific. Sweetpotato as a crop has a wide genetic diversity enabling a range of uses. It is a perennial, cultivated as an annual predominantly through the use of vine cuttings selected from the previous crop. Existing seed practices are influenced by the occurrence of bimodal or unimodal rainfall patterns. In bimodal rainfall systems, planting material is generally available from a crop in the field. In areas where there is an extended dry season, however, planting material at the beginning of the rains is scarce, which leads to late planting and reduced area planted.

Biotic factors affecting sweetpotato planting material include sweetpotato virus diseases (SPVDs), which occur singly or synergistically, with visual symptoms, symptomless, or latent symptoms; weevil infestation; sweetpotato butterfly; Alternaria; and erinose mites. Livestock and wildlife can also destroy multiplication plots. Sweetpotato has a low multiplication rate, and the bulkiness and perishability of the planting material influence seed system technologies and institutional arrangements.

Advances in multiplication methods include (1) rapid multiplication techniques (RMTs); "Triple S" (storage, sand, and sprouting) for root-based vine multiplication; sand aeroponics for vine multiplication from pathogen-tested plantlets; and the use of net tunnels to protect foundation material from insect vectors that spread SPVDs.

The choice of models for multiplication and delivery of sweetpotato planting material needs to consider the objective of dissemination (e.g., commercialization, nutritional improvements, social protection, food security) and the level of decentralization and profitability or financial sustainability needed. Primary, secondary, and tertiary multiplication sites (i.e., "1-2-3" system) are used to link sources of new varieties and clean planting to trained decentralized vine multipliers (DVMs). New institutional arrangements, such as multi-stakeholder innovation platforms, have been established to link seed multipliers, root producers, and processors. Models for delivery systems have been developed with a range of public sector, nongovernmental organizations (NGOs), and some private sector partners. Integrated agriculture-nutrition-market approaches have been used for demand creation and social marketing, and have been implemented with varying intensities of information education and communication interventions. Health facilities (e.g., ante-natal classes, and training of traditional birth attendants) and schools have been used as the institutional entry points to target particular groups for vitamin A-rich and nutritious orange-fleshed sweetpotato (OFSP) varieties. And although the predominant source of planting material has been vines recycled from previous crops and farmer-to-farmer exchange, there are increasing examples of sales of planting material and farmers purchasing material of new varieties and cleaned-up varieties. The financial viability of sweetpotato multiplication enterprises is dependent on farmers' willingness to pay (WTP). This in turn is influenced by the agro-climatic conditions; point in the planting season; proximity to strong root markets; availability of new

varieties with preferred characteristics; and possibility to buy small quantities. Various supply and demand side subsidy arrangements have been used. Voucher-based systems are used to ensure access to new varieties by particular target groups, such as resource-poor farmers, women farmers, and households (HH) with children under 5 years. Pass-on or pay-back models are also used for dissemination.

Research is required to support improvements in sweetpotato seed systems in the following areas:

- Accelerated evaluation and release process for new varieties linked to maintenance of breeder stock and multiplication and dissemination models
- Cost-effective use of pathogen-tested tissue culture (TC) plantlets
- RMTs
- Water and fertility management for vine multiplication
- Expanded validation of root-based vine multiplication methods, sand aeroponics, and net tunnel protection for foundation material.

In addition, we need a better understanding of the conditions under which different types of farmers are willing to pay for quality planting material, and how vine multiplication can be incorporated into viable business and social enterprise models. An enabling policy context is needed for nonconventional quality assurance mechanisms and to ensure managed access to swamp, river, and lake margins for multiplication of sweetpotato planting material using environmentally sustainable agricultural practices.

The financial and social sustainability of sweetpotato seed systems needs to be built on a context-specific analysis of the following: climatic and agro-ecological conditions and risks; pest and disease incidence; an understanding of existing farmer seed practices; strong links to farmer and market demand (varieties, quality, quantities, and timing) for vines and roots; socioeconomic and gender constraints analysis; and clear institutional arrangements to support coordination, information flow, and linkages between different actors in the seed and root value chains.

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A literature review to contribute to the preparation of conceptual frameworks to guide practical interventions for Root Tuber and Banana Seed Systems

1. Introduction

1.1 BRIEF OVERVIEW OF THE HISTORY OF SWEETPOTATO SEED-RELATED RESEARCH IN SSA

In SSA, seed-related research on sweetpotato started in the late 1970s after some work by the International Institute for Tropical Agriculture, and when, in 1979, the International Potato Center (CIP) established a regional office in Nairobi, Kenya. Early worked focused on breeding and varietal evaluation, and there was limited work on sweetpotato seed systems per se. But new varieties were not reaching smallholder farmers, and there were strong arguments that issues related to seed system functioning should be treated as researchable issues.

Structural adjustment policies in the 1990s reduced national and international investment in the agriculture sector. This included the closure of loss-making parastatal and state seed companies, with the expectation that the private sector would be both willing to fill the gap and spur more competitive seed marketing and distribution practices (Cromwell, Friis-Hansen, and Turner 1992). This may have happened to a limited extent for some grain crops, but not so for vegetatively propagated crops (VPCs), sweetpotato in particular. This context, together with the predominant perception of sweetpotato as a subsistence crop for women and the poor, meant that the crop (including seed-related practices and challenges) lagged behind (when compared with cereal and export crops) in research priorities, human and resource allocation, and capacity-strengthening efforts from both the public and private sectors.

Diagnostic work on the sweetpotato production system, including some investigation into existing seed practices and constraints, was carried out in Tanzania and Uganda in the early 1990s (Bashaasha et al. 1992, 1995; Ewell et al. 1995). From the mid-1990s, one of the drivers to understanding effective methods of seed dissemination was from the humanitarian and NGO community in the context of drought and conflict-related disasters. Here, the concern was to support the rehabilitation of smallholder farmers by providing seed and planting material for short-maturing crops, such as sweetpotato, using various dissemination mechanisms (e.g., subsidized vouchers and seed fairs) (CRS, ICRISAT, and ODI 2002; Longley et al. 2002; Sperling and Cooper 2003). Since the early 2000s, with the recent interest in the contribution of biofortified crops to food-based approaches to address malnutrition and food insecurity, there have been renewed efforts to explore what kind of seed system models work under what kind conditions in order to bring the benefits of improved varieties to different types of farmers (DFID 2000, 2003; PRAPACE 2005a, 2005b; Potts 2006; CIP and ASARECA 2008; CIP and BMGF 2009; HarvestPlus 2010a; AGRA 2012).

In SSA, local farmer-to-farmer sweetpotato seed systems predominate, with farmers sourcing planting material from their own fields or from the fields of neighbors and kinfolk. These seed systems may be resilient, but the amount of material available at the beginning of the rains is limited. Moreover, the recycling of material can lead to the build-up of pests and diseases and subsequent yield reduction; and extended or unanticipated dry periods can result in the loss of material. Initiatives to strengthen sweetpotato seed systems have been driven from a research and breeder's perspective focusing on varietal testing and systems to deliver new improved varieties. Public sector and donor interventions have predominated. Where the private sector has been engaged it is generally in the context of tenders from large institutional buyers in post-conflict contexts.

The PRAPACE[1] priority-setting exercise in 2003, and a CIP survey of the national agricultural research institutions (NARIs), both ranked "virus management, seed quality, and supply systems" as high priority for future research and development against all other listed sweetpotato technologies (PRAPACE 2005b; Fuglie 2006; Andrade et al. 2009). Yet, ensuring that farmers have timely access to adequate quantities of quality planting material remains a challenge. Continued work is needed to (1) identify and strengthen the interface between the upstream (or "formal" system) injection and multiplication of quality clean planting material of new and improved varieties, with leveraging the strengths of farmer-to-farmer dissemination and (2) strengthen linkages to a consistent market demand for roots, which is critical for the sustainability of the seed system. In addition to addressing specific technical constraints in the seed system, greater attention is needed to identify appropriate institutional arrangements to ensure coordination in a multi-layered seed system with multiple actors.

This literature review spans the period from the mid-1990s to 2014–2015. The majority of work has been done in East Africa (Uganda, Tanzania, Kenya, and Ethiopia) and in Southern Africa (Mozambique and Malawi). More work is now underway in West Africa (Nigeria and Ghana), where sweetpotato production system diagnostic surveys have been conducted in 2012–2013. Some preliminary findings are included in this review.

1.2 MAIN CHARACTERISTICS OF THE CROP, INCLUDING GENETIC DIVERSITY, IN RELATION TO SEED USE AND MANAGEMENT

Sweetpotato is a perennial crop but cultivated as an annual for vines and roots. There is wide genetic diversity enabling varied uses (e.g., roots and vine tips for human consumption, fresh roots for sale and for processing, and vines for sale as planting material or as animal fodder). True seed is only used for breeding purposes. In SSA propagation is largely based on vegetative asexual reproduction through the use of vine cuttings selected from the previous crop (Gaba and Singer 2009). The vine cuttings form roots at the nodes, producing daughter plants. The plant has a low multiplication rate (1:12 using conventional multiplication; 1:50 using RMTs (Stathers et al. 2013). As with other VPCs, sweetpotato planting material is bulky and perishable; therefore there are high transaction and transport costs if distributed over long distances. These characteristics, together with the limited commercialization of sweetpotato roots, have contributed to the low interest in the crop by commercial seed multipliers. The main sources of new cultivars are farmers NARIs and some CGIAR international agricultural research centers (Gibson et al. 2009). The private sector has yet to be involved in breeding.

Breeding programs for population development and varietal improvement have focused on farmer and consumer preferences (e.g., yield, yield stability, drought tolerance, virus resistance, dry matter content,

[1] PRAPACE is the French acronym for Regional Potato and Sweetpotato Improvement Network in Eastern and Central Africa.

and more recently beta-carotene content). Selection of traits that could contribute to successful vine survival and multiplication for planting material (e.g., thickness of vine stem, inter-nodal spacing, erect or spreading) are also incorporated into breeding objectives (Grüneberg et al. 2008). Vine survival as a trait is particularly important in drought-prone areas as varieties with this trait will “maintain” themselves and spread easily among farmers (Badstue and Adam 2011; Agili 2012).

Farmers also prefer early-maturing varieties (Ewell et al. 1995). These may be shallower rooting, with storage roots that mature all at the same time. These characteristics also have implications for the seed system. Shallower rooting varieties are more prone to weevil damage, and the shorter maturity period means that in bimodal rainfall areas plants do not remain in the field for so long. On the one hand, this may mean that farmers have reduced access to planting material from growing plants. But on the other hand, the shorter growing season may allow a break in the disease and pest cycle. Certain harvesting methods (e.g., piecemeal harvesting) can result in there always being some roots in the field from which planting material can be sourced. For some improved short duration varieties (e.g., ‘Kabode’, which matures after 3–4 months), the storage roots mature simultaneously and so are harvested at the same time, so the plant remains in the field for a shorter time. Therefore, further work is needed to understand how the promotion and use of early-maturing varieties influence famers’ seed management practices.

Farmers also use groundkeeper storage roots that subsequently sprout to give new plants. Recent work in East Africa has adapted and improved the use of storage root-based sprouting methods, in particular in areas with a long dry season (Namanda and Gibson 2011). TC-based methods are increasingly being used for virus cleaning, in-vitro mass multiplication, germplasm conservation, and transport of germplasm across national boundaries. CIP has ISO17025 status and is supporting regional centers to work toward “ISO-like” status to make germplasm movement within the region more efficient (Andrade et al. 2009).

2. Sanitary factors related to seed

2.1 Main diseases associated with seed degeneration or reduce seed quality in general

In SSA the most important diseases that contribute to degeneration in sweetpotato planting material are SPVDs, which infect either individually or in mixed infections. Sweet potato feathery mottle virus (SPFMV) is the most common but is largely asymptomatic as a single infection. In mixed infections, sweet potato chlorotic stunt virus (SPCSV) and SPFMV combine to present as SPVD with stunting, feathery vein clearing and yellowing observed (Carey et al. 1999; Gaba and Singer 2009;Clark et al. 2011; Gibson and Kreuze 2015). These diseases occur throughout SSA, albeit with differences in prevalence and strain (Gibson et al. 2009), and the SPCSV strain in West Africa is different than in East Africa.

Other viruses include sweet potato mild mottle virus, which in co-infection with SPCSV causes sweetpotato severe mosaic disease (Gibson et al. 2009) and may also play a role in combined infections. Sweet potato latent virus, sweet potato chlorotic flecks virus, sweet potato virus G, and sweet potato leaf curl virus are also present. Work is currently underway to determine their extent and epidemiology (Kreuze pers. comm.)

Reduction in root yield from the complex SPVD infection is estimated at 50% or more (Loebenstein and Thottappilly 2009). A study in China showed that the use of virus-free material (from sprouted roots) yielded 30% greater than normal planting material—with the yield reducing to the same level after five generations (Fuglie et al. 1999). The evidence for reduction in root yield from the impact of single infection (e.g., SPFMV) is more ambiguous, and varies depending on the susceptibility of the cultivar and virus involved. Landraces bred and grown by farmers in Africa, together with some researcher-bred varieties (with breeding carried out in East Africa), are said to show little evidence of degeneration (Gibson et al. 2009). However, local farmers' cultivars with high levels of resistance tend to be low yielding and late maturing compared with earlier maturing, high yielding, yet susceptible local cultivars or exotic introductions. (Carey et al. 1999). Local varieties widely grown in areas where SPVD is common are generally more resistant to infection than ones grown in areas where the disease is rare. The paper prepared by Gibson for RTB discusses this further and, in particular whether some varieties are able to revert from infected to virus free (Gibson 2012). More work is needed to determine which varieties have this mechanism, how long the reversion process takes, the yield effect of reversion, and implications for the sweetpotato seed system. In addition, there is need to improve our understanding of the relationship between virus load and yield loss, namely, when is it economically viable to provide replacement material; the relationship between symptomless and yield loss; what tolerance level is appropriate at different stages in vine multiplication cycle; and whether juvenile material is more susceptible to virus (Barker 2012).

It is reported (Gibson et al. 2009) that farmers are generally unaware of these severe diseases yet recognize that plants with such symptoms are unsuitable for planting material. Farmers associate the symptoms with drought or insect pests (Badstue and Adam 2011).

The main vectors are whiteflies and aphids, which transmit SPCSV and SPFMV, respectively. Studies on the behavior of whitefly have shown that they remain predominantly in the canopy, and are only virliferous for 1–2 days at most following access to an infected plant. The implication for seed multiplication is the importance of isolation distance (only 15 m can make a difference) and rigorous roguing, as it will be the neighboring plants that will be most easily infected (Gibson et al. 2009). Other approaches to the control of SPVDs are through the use of pathogen-tested TC and positive selection of symptomless plants. Recent trials on the use of net tunnels to protect planting material from insect vectors are discussed in section 5.6. Breeding programs in East Africa are focusing on developing virus-resistant varieties.

Alternaria, a fungus that survives in the soil and plant debris, occurs in mid- to high-altitude regions, with high humidity or free water, which aids its transmission. It causes lesions on the foliage and can kill the vine (Ames et al. 1996; Loebenstein and Thottappilly 2009).

2.2 Main pests that influence seed production or availability

Sweetpotato weevil is the main pest, with *Cylas puncticollis* and *C. brunneus* the main species causing damage and up to 60–100% root yield or economic loss in Africa (Ames et al. 1996; Stathers et al. 2005). Adult weevils oviposit at the base of vines, and therefore the eggs and larvae can be transferred to the next generation of planting material if cuttings are taken from the base of the vine and not disinfected. Weevil populations are more prevalent in the dry season, especially when soil cracking occurs. Management practices include crop rotation, removal of affected vines and crop residues, re-hilling up to cover in cracks, selection of apical portion of vines; avoiding harvesting vines in the dry season, and flooding the field at least 48 hours before harvest of vines (Ames et al. 1996). Infestation by erinose mites causes hairiness on vines and if used as planting material, is thought to reduce yield (ibid.). Little formal research has been done into this, but farmers are experimenting with different control measures

(DONATA 2013). Sweetpotato butterfly and other defoliators can cause damage in multiplication plots—especially at the end of the dry season—and with the first rains concentrate on early growth of vines. This has been reported particularly in Southern Nations Nationalities and Peoples Region (SNNPR), Ethiopia (SARI and HARC 2012).

Vertebrates, including hippo and cattle, can also cause considerable damage to vine multiplication sites close to rivers and lakes (SASHA 2012b). In the dry season, planting material may be maintained in low-lying areas with residual moisture and acts as a magnet for both free-grazing livestock and insect vectors. Porcupine and mole rats can cause damage by burrowing into sweetpotato vine multiplication plots to feed on young roots (DONATA 2013).

3. Physiological factors related to seed

3.1 Quality issues related to the crop growth cycle, seed size, and physiological state

Gibson et al. (2009) report that farmers generally prefer apical portions of vines to plant; and that in Uganda this preference is greater in areas closer to the Equator, where there is abundance of planting material compared with areas where planting material is scarce after the longer dry season. Little research has been conducted on the role of the physiological state of cuttings in determining yield. Youth generally is associated with greater yields, and this may be a greater driving force for using apical cuttings rather than weevil infestations on basal parts of the vines. In review of earlier studies, Gibson (ibid.) found that that cuttings taken from young crops (2–4 months) or from the younger apical portion of a vine generate greater yields than cuttings taken from old crops or from mid- or basal parts of the vine. This implies some physiological aspect of "youngness" that enables the resulting plant to be more vigorous.

Ongoing work in the Lake Zone of Tanzania exploring farmers' perceptions and practice around "quality" planting material indicates that farmers noted a difference in "sprouting" characteristics of planting materials sourced from TC, asserting that the cleaned-up varieties that they had received were "early maturing," compared with their own material of the same variety. Farmers in this study have also emphasized the need to select material from plants that are not too young or too old. Some farmers in this study also consider vine thickness and intermodal distance as characteristics they look for when selecting material as an indicator of plant vigor (McEwan 2012).

3.2 Climatic conditions and main abiotic constraints which influence seed production

Sweetpotato *roots* can be grown from sea level up to 2,500–3,000 masl. They are grown from 40°N to 32°S of the Equator (Woolfe 1992). Highest root yield is obtained when daytime temperatures range 25°–30°C and nighttime temperatures range 15°–20°C (Stathers et al. 2013). When temperatures fall below 10°C growth is reduced. Although there is some indication of the importance of cool nights for higher *root* production, the importance of diurnal variation in temperature for seed production (i.e., *vine multiplication*) is not clear. The crop is damaged by frost, and this restricts its cultivation to areas that have a minimum of 4–6 frost-free months and with relatively high temperatures during this period. Optimum rainfall for *root* production is 75–100 cm/year, with approximately 50 cm falling during the growing season. Sweetpotato prefers sandy-loam soils with high organic matter content and with permeable subsoil. It does not do well on clay soils; good drainage is important as the plants do not withstand water logging. Soil pH of 5.6–6.6 is preferred, the plant being sensitive to alkaline or saline conditions (Woolfe 1992).

For seed production, warm temperatures combined with good soil moisture are conducive for general vine growth. At planting, temperatures should be above 20°C to spur early sprouting (Akoroda 2009). There has been less research on ideal agro-climatic conditions for production of planting material, particularly when vine multiplication is carried out in the off or dry season (which is also cooler and thus affects vine growth) before the main planting period for root production, or where vines are produced in one agro-ecology and transported for planting to another (as occurs in Ethiopia). OFSP varieties are generally more susceptible to drought. Recent work has assessed a range of genotypes to identify some cultivars that are less drought susceptible and the physiological mechanisms that contribute to this. This has shown that genotypes that maintained high leaf area under stress condition and high root-to-shoot ratios under water stress conditions had storage roots with high beta-carotene and high dry matter content (Agili 2012).

With increasing climatic unpredictability, rainfall patterns are also affected: dry periods are longer and temperatures hotter, but also periods of excessive rain leading to flooding. Both situations may occur in the same multiplication season, with planting material being affected by both lack of water and water-logging. Farmers and multipliers trying to take advantage of low-lying areas with residual or permanent water can be caught short when these areas rapidly become flooded and water-logged (SASHA 2012b).

3.3 Seed uniformity and batch size in seed quality

The recommended practice is to use apical cuttings 25–30 cm long for planting material for root production. Cuttings 10–20 cm long (with a minimum of three nodes) can be used for planting material for further multiplication (Stathers et al. 2013). Sweetpotato planting material is distributed in bundles, bags, or by weight, depending on local practice, end use, purchaser preference, and means of transportation. Standardization has been a challenge as the number of cuttings per volume unit depends on the variety and extent of wilting; weighing becomes impractical for large volumes. The use of labeling of planting material for distribution or sale (i.e., with name of variety, multiplier name and contact number, and date of harvest) is recommended. But currently this is only used in project settings—for example, Sweetpotato Action for Security and Health in Africa’s (SASHA) “Marando Bora” (“better vines”) project in Tanzania, and the “Better Potato for a Better Life” project in Ethiopia. At small-scale decentralized sites, the multiplier may harvest the vines alone or together with the customer. At larger centralized sites—used for mass multiplication—casual labor is hired for harvesting and generally paid on a bag/sack basis. This activity needs to be well supervised (i.e., sacks sampled and inspected) to avoid poor-quality material being included. Vines should be prepared with leaves stripped off (SASHA 2011c; (Stathers et al. 2013).

3.4 Use of quality declared planting materials (QDPM) protocols

One of the earliest farmer-based vine multiplication enterprise in East Africa was the Soroti Sweet Potato Producers and Processors Association (SSOSPA), established in Uganda in 2004. This is now a network of 300 sweetpotato farmer field school (FFS) graduates and adopters multiplying vines for sale to organizations and surrounding farmers. SSOSPA established a quality assurance team for supervision and monitoring of field activities to ensure implementation of agreed standards and enforcement activities. The association operates a dual pricing structure: one price for organizations buying that require an inspection visit from the National Agricultural Research Organisation and a letter confirming the quality of the material; and a second price for local farmers who are buying (Echabu and Ekinyu 2012). The experiences from using a quality inspection process in Uganda contributed to the development of the standards and norms for VPCs by the Food and Agriculture Organization of the United Nations (FAO) (FAO 2009). In turn, these have now been tested and validated as part of community-based and institutional inspection schemes in Tanzania (SASHA 2011b) and Ethiopia (SARI and HARC 2012).

In Tanzania, two inspection visits were made. One visit was done about 4–6 weeks after planting (when the diseases will start to show, and when the multiplier can be advised to take remedial actions such as rouging, spraying, labeling, etc.). The second visit was made 2 weeks before harvest (when if the pest/ disease level is above the tolerance, the plot is rejected). At this visit, the estimated quantities that can be harvested from that plot are also calculated. The following sampling methodology was used: 3 out of every 10 beds for each variety were randomly sampled, and then two rows in those beds inspected to determine the percentage of plants showing symptoms for each parameter (SASHA 2011b). Table 1 shows the FAO tolerance levels for different parameters and the adapted tolerance levels used in the "Marando Bora" project.

The production of QDPM and associated inspection system has costs; someone has to pay for these, whether it is the producer (multiplier), customer (farmer or institutional buyer), or government. The cost will depend on the level of quality required (i.e., production practices needed) and who does the inspection. In some countries, multipliers who want to trade in quality declared seed (QDS)or QDPM need to be registered with the national regulatory body and the varieties that they multiply should be officially released. (Recall that QDPM standards should be appropriate to a specific context.) Overly stringent standards may be bypassed, encourage corrupt practices, or end up closing down multipliers so that farmers are left in a worse off situation (McEwan et al. 2012).

Table 1. FAO tolerance levels and adaptation to the "Marando Bora" project context, Lake Zone, Tanzania

	FAO QDS (G4)	"Marando Bora" levels		
		Very good	Acceptable	Not acceptable
Parameter	Percentage (%)	Percentage (%)	Percentage (%)	Percentage (%)
Mosaic and stunting	1	≤1	1.1–5	>5
Leaf curl	5	≤5	5.1–10	>10
Purpling	5	≤5	5.1–10	>10
Other varieties	2	≤2	≤2	>2
Weevil	0	≤0	≤10	>10

Source: SASHA "Marando Bora" Draft Protocol for Inspection of Sweetpotato QDPM, 2011.

In Ethiopia, the QDS standard for sweetpotato ES 3924-18: 2015 were approved in 2015 (Ethiopian Standards Agency 2015). In Tanzania, the standards for all seed classes, including QDS, are awaiting final ministerial assent. In Kenya, Rwanda, Malawi, Mozambique, Ghana, and Nigeria, standards and inspection protocols have been drafted and are in discussion with national regulatory bodies.

The inspection of a vine multiplication plot to assess whether the planting material being produced meets the agreed standards may be done by the national crop health regulatory body, the research system, or delegated to a decentralized level (e.g., a district crop protection officer, or a trained village extension officer). Farmer-multipliers can also be trained to inspect their own plots to determine whether the material reaches the quality standards. The introduction of "standards" needs to be accompanied by increased awareness among farmers as to the benefits of better quality seed. Any system of standards, where the "quality" may not be immediately visible, is also built on trust (i.e., farmers trust their local multiplier to provide them with quality material because the multiplier is also a neighbor or relative). The standards need to be appropriate to context, and take into account what level of quality farmers want (and are willing to pay for) (McEwan et al. 2012). In some countries, QDPM labels are issued to match the quantity of quality planting material produced.

4. Available technologies for multiplication

4.1 Multiplication rates

The in-situ/field multiplication rate for sweetpotato using vine cuttings is low—up to 1:10 or 1:15 after 4 months. However, this is influenced by variety, type (i.e., erect or spreading), agro-climatic conditions, management, number of ratoons from the same mother plant, and multiplication technique used. The multiplication rate using TC under optimum conditions has been reported to be 64,000 cuttings from one TC plantlet in a year (FAO 2010). Multiplication rates using RMTs can be 1:30–1:50 after 4 months with good fertilization and management (Stathers et al. 2013). Multiplication rates from using stored and sprouted roots are reported to be around 40 cuttings from one root (Namanda, Amour, and Gibson 2012; CIP and NRI 2011).

4.2 Tissue culture

Given the range of findings in improved root yields from using clean planting material, there is considerable debate on how to supply "virus-free" material in an effective and sustainable way. Meristem shoot tip cultures or explants are used as they are more likely to be virus free and combined with thermotherapy techniques to eliminate any viruses. Regenerated plants are then tested using nitrocellulose membrane-enzyme-linked immunosorbent assay (NCM-ELISA) and grafted onto *Ipomoea setosa*, a virus-sensitive indicator plant (Gaba and Singer 2009).

There is also an ongoing debate about the benefit of providing a "flush-through" of cleaned-up and virus-indexed materials on a one-off or regular basis. The frequency of the flush-though would depend on virus types, their incidence, the virus susceptibility of the varieties under consideration, seasonal characteristics, varietal response to clean-up, and economic benefits (i.e., yield increase from cleaned-up material and farmers' WTP). One challenge with using TC-based multiplication methods is the number of multiplication cycles and therefore the time required to bulk up sufficient quantities for distribution to farmers. The quantities of initial starter material obviously will influence the time required, but generally at least three multiplication cycles of 4–6 weeks each in vitro, followed by 4–8 weeks hardening for acclimatization, would be required before the first field multiplication. This period of acclimatization or hardening is important. Oggema et al. (2007) found that TC-derived sweetpotato plants were extremely sensitive to acclimatization ex vitro and established at a slower rate than conventionally propagated plants.

A number of protocols have been developed: for sweetpotato virus indexing (CIP 2010a), health status testing and virus elimination (CIP 2010b) using NCM-ELISA (CIP 2010c), and indicator plant diagnostic procedure (CIP 2010d), and in-vitro conservation (CIP 2009) and multiplication (CIP 2010e) of sweetpotato. These are revised and updated based on experience and internal and external audit recommendations. Over the last five years in SSA, more investment has been made in strengthening capacity for virus indexing, clean-up, and in-vitro propagation (CIP and BMGF 2009). This has involved research as well as public and private sector facilities, equipment, materials, and human resources. In SSA more than 30,000 TC plantlets were mass propagated and transferred in 2010 from Kenya to Tanzania; low-cost hardening facilities were used. The experiences and lessons from transferring and hardening TC plantlets under low-cost field conditions are written up as a training manual (Namanda et al. 2015), which complements earlier guidelines by CIP on transport, receipt, and propagation of in-vitro sweetpotato plantlets (Dodds, Panta, and Bryan 1991). Further work is needed to strengthen practices for reduction of bacterial and fungal contamination in TC plantlets, and to improve low-cost but effective packaging materials and transportation.

There is also the need to strengthen the mechanisms for the rapid and safe movement of germplasm, to maximize the evaluation and testing of improved varieties that have been released in one country in similar agro-ecological zones (AEZ) with the AEZ in different countries. This requires both technical inputs and harmonization of regulations (Gibson et al. 2009; ASARECA 2011).

4.3 Multiplication in beds and pots

Under project conditions, seed beds using RMTs have been promoted. A standard bed size (e.g., 1 x 5 m) which is slightly raised can be used with 50 cm between beds, with a spacing of 10 cm between plants and 20 cm between rows. This has been recommended to allow for ease of management for planting, weeding, irrigation, and harvesting (Stathers et al. 2013). The use of a standard bed size and plant population also simplifies calculations for the estimated quantities of planting material that can be harvested. Depending on the type of irrigation technology and method used, however, ridges (with furrows for irrigation) may be more appropriate. Work in the mid-2000s under a GTZ-funded project in Kenya, Uganda, Ethiopia, and Kenya found a low adoption rate for RMTs among farmers due to the high management requirements and labor required for irrigation. It was found that only 30% of farmers trained had adopted RMTs in some modified form. These farmers generally produced sweetpotato as a cash crop on larger acreages; they were better organized for marketing the roots and could thus benefit from the higher prices received for early-planted crops (Potts 2006). Farmer multipliers who seek to diversify their risk tend to prefer to maintain conventional land preparation and spacing (e.g., 30 cm between plants and 1 m between rows) to allow for both root and vine production. This despite the fact that vines can only be harvested after 4 months, so storage root formation is not affected. Hybrid methods have also been developed and used in Malawi. For example, vine cuttings 30 cm long are planted on ridges, and planting distance between plants is 15 cm and between ridges 75 or 90 cm, depending on the locality (Abidin, Chipungu, and Mnjengezulu 2012). In Rwanda, double-dug and “mandala” beds are used to conserve fertility, and roof catchments have been used in conjunction with keyhole gardens for water harvesting and conservation. Sack gardens have also been used with school children in western Kenya (CIP and ASARECA 2013).

4.4 Multiplication in the field

The practice of field multiplication is influenced by the place of sweetpotato in the cropping pattern and overall farming system. For example, in the Lake Zone of Tanzania, the diversity of cropping patterns (cassava based, banana based, rice based, maize, mixed crop-livestock, horticultural) provides different opportunities for the conservation and multiplication of sweetpotato planting material (Ewell et al. 1995; Namanda, Gibson, and Sindi 2011). Relay and intercropping practices also influence vine conservation and maintenance practices. Rotation practices for vine multiplication plots may be constrained due to limited land availability or competing enterprises that also require access to water for irrigation in the dry season, and ease of access by customers.

4.4.1 Soil nutrient management for vine production

Plant growth and development for *storage root* production goes through three stages: an initial stage of around 9.5 weeks characterized by slow growth of vines, and a rapid growth of the adventitious roots, which arise from the underground stem a few days after planting. These may penetrate up to 2 m and allow the crop to survive during drought conditions (if these occur 6 weeks after planting). The second intermediate phase (9.5–16 weeks) consists of a rapid growth of vines and hence a large increase in leaf area, accompanied by initiation of storage root development. In the final stage, vines quit growing and a rapid bulking of storage roots takes place (Woolfe 1992). Therefore, for *vine multiplication* purposes the growing conditions need to be adjusted to be favorable for greater vine production, compared with storage root formation. This is partly achieved through closer spacing as in RMTs and fertility and water management. Choice of more fertile soils for vine multiplication will encourage more vegetative growth rather than root formation. Fertilizer recommendations for rapid vine multiplication depend on variety, soils, and existing level of fertility; rainfall and climatic conditions; and specific fertilizer formulation available locally. In some contexts, basal farmyard manure is applied in seed beds; top dressing and fertilization after the first harvest are also used to encourage re-sprouting. The FAO protocols and standards for sweetpotato recommend well-decomposed farmyard manure at 2.5 kg/m^2 to be applied before planting, and NPK 17-17-17 at the rate of 42 g/m^2 be applied after planting. Urea is applied at the rate of 13 g/m^2 after each harvest of cuttings, but watering must be ensured to avoid burning the crop (FAO 2010;Stathers et al. 2012).

4.4.2 Water management (including irrigation) for vine production

There appears to be a lack of systematic documentation for SSA on the use of irrigation technologies as part of water management for vine multiplication. Larger scale multipliers (e.g., private business multipliers in Ethiopia supplying large amounts of planting material to NGOs who distribute in disaster rehabilitation) may use petrol or diesel pumps; however, running costs are high and often not economical. On a smaller scale, treadle or “Money-Maker” pumps are used, particularly by farmers’ groups (FGs) supported by development-oriented NGOs—for example, in Malawi and Tanzania (Abidin, Chipungu, and Mnjengezulu 2012; SASHA 2012b). The use of treadle pumps may be appropriate depending on depth of water table and area that needs to be irrigated, but the labor requirements and use by women may not be acceptable in some societies. Drip kits have also been used (e.g., FAO supported projects on the island of Ukerewe, Tanzania, and in Malawi). These may be appropriate depending on the source of water, as water from sources with high silt levels can cause blockages in the nozzles. Some NGOs (e.g., Africare in Rwanda) have experimented with rainwater harvesting from roofs and the use of wastewater for keyhole gardens. These methods have reduced labor requirements for labor-constrained vulnerable groups, such as people living with HIV/AIDS (CIP and ASARECA 2013).

4.5 Root-based vine multiplication methods

One of the existing methods by which farmers acquire planting material is to use cuttings obtained from volunteer plants growing from roots sprouting at the start of the rainy season. Through research conducted in Uganda and Tanzania, this method has been adapted and transformed into a production system under the control of farmers, rather than the vagaries of nature (Namanda, Amour, and Gibson 2012). At this stage the technology is targeted for use at the HH level. Farmers can make a careful selection of small (unmarketable) but undamaged roots, which they then store during the early part of the dry season in dry sand in the home or a shed. About 5–7 weeks before the expected start of the rains, the roots are planted out in a protected bed that is watered. The roots then sprout and can provide planting material at the start of the rains. This method has been trialed in areas of Uganda and Tanzania with an extended dry season, successfully producing 40–60 cuttings/root (CIP and NRI 2011). Women in particular have reported that it gives them more control over the source of their planting material, so avoiding having to spend time "looking for vines."

To date, this work has been done on roots grown from vines selected from fields. The use of roots produced from TC-sourced materials has not been tested. We also need to know the implications of recent research findings that appear to show a higher concentration of virus in roots (Gibson 2012) (i.e., the method may be more appropriate in areas where the pressure from viruses is low, or where a long dry season acts to disrupt the virus accumulation cycle).

4.6 Use of net tunnels to protect foundation material in high virus pressure areas

In areas with high virus pressure due to a high aphid and white fly population, access to quality, clean planting material remains a key challenge. A collaborative research study was undertaken between CIP and the Kenya Agriculture Research Institute in a high sweetpotato virus pressure area in western Kenya. The study aimed to determine whether the use of net tunnels could maintain disease-free planting material and minimize new infections (CIP and BMGF 2009). A field trial was conducted to compare the efficiency of two screen–net cover technologies (tunnel vs. box) at maintaining healthy planting material, compared with an exposed control. The use of net tunnels proved to be very effective in maintaining virus-free planting material for at least 3 years. The study found that the use of the net tunnel showed significant reduction in aphid and white fly populations and virus levels. The study results also showed a significantly higher production of vine cuttings from the second cutting onwards from the net tunnels, compared with the open-field space equivalent. Moreover, the yields of roots generated from planting vines obtained from the tunnel were significantly higher than root yields from vines obtained from the open field: For each variety, root yields were 30–50% higher. An investment of $150 in the net tunnel technology gave a return of 459% for vine and root production, compared with exposed material with no management (Schulte-Geldermann, Agili, and Low 2012; Schulte-Geldermann et al. 2012).

Overall, this technology has already been proven to be very successful and cost effective; it should be taken to scale. Under the SASHA project, the net tunnel technology was only tested and proved its success under controlled, research-managed conditions. There is still the need to validate the technology under more typical farm conditions, with farmer-multipliers managing the tunnels. A project led by Lake Zone Agricultural Research Institute is currently under preparation to validate this technology with farmer multipliers.

4.7 Use of sand hydroponics for clean sweetpotato seed multiplication

Sand hydroponics was developed initially for potato but is now being adapted for sweetpotato and tested in Lima, Uganda, and Zambia. An existing greenhouse space of 15 x 5 m can be used, with a sound roof to prevent rainwater entering and managed to ensure sanitary conditions. Beds for planting in-vitro plantlets can be made from wood or concrete, black plastic bags, or recycled plastic or wooden crates. The technology can start with 100–200 plantlets and requires a clean water source, water tank, tower, piping system, and sterilized sand but no electricity (Otazu 2013). Currently, the nutrient preparation that was used for potato aeroponics has been adapted for sweetpotato vine production under sand aeroponics. Research is ongoing to determine optimum nutrient preparation—in particular, phosphorous and potassium levels—to promote vigorous vines for further multiplication.

5. Farmer knowledge and practices for seed management

5.1 Description of the main traditional practices of seed management by farmers

Sweetpotato is largely grown by women, though there are known exceptions (e.g., in parts of Ethiopia and Nigeria for cultural reasons). Therefore, women predominate in the existing sweetpotato seed management practices and the farmer-to-farmer dissemination of planting material. This includes knowledge about names and characteristics of local varieties, conservation, maintenance, and selection of planting material (Badstue and Adam 2011).

In East and Central Africa, two broad climatic systems influence farmer seed management and production practices. Closer to the Equator there is a bimodal rainfall system with a “short rains season,” from September to October through to mid-December, and a “long rains season,” from February to March through to May–June. Moving south (and east), a unimodal rainfall system predominates, with a longer dry season depending on the start and end of the rains (Gibson et al. 2009).

In the bimodal areas, sweetpotato crops can survive the short dry season and storage roots can be harvested almost all year round. Therefore farmers can source planting material from their own mature crop easily (ibid.). In these areas, planting material is freely available and rarely sold; in fact, there may be social and cultural mores that reinforce free exchange, as the proverb “to steal seed is not a sin” from Ukerewe Island in Tanzania indicates (McEwan 2012). The longer the dry season, the more challenging it is for farmers to maintain planting material, unless they have access to low-lying areas with residual or permanent moisture where they preserve planting material (Gibson et al. 2009; Namanda, Gibson, and Sindi 2011). The break in the growing season also means that the cycle of disease and pest build up in material used for planting can be broken. On the basis of the climatic context explained above, the sweetpotato root production management cycle and the seed management cycle are closely interrelated.

Eight different methods have been observed to be used to conserve, maintain, and/or multiply planting material as part of the farmer-based seed systems in parts of Rwanda, Tanzania, and Uganda (Hart 1991; Namanda, Gibson, and Sindi 2011):

1. The use of vines collected from the fields of growing crops
2. Taking cuttings from shoots sprouting from roots missed during harvest
3. Growing a dual-purpose crop in the dry season using wetlands, valley bottoms, or rice paddies
4. Growing a crop using irrigation from a river or lake or around waterholes and watering
5. Planting in the shade of bananas, avocado, coffee, or cassava—generally used when the dry season is not prolonged and only produces vines
6. Maintaining plants in the backyard, watering with “waste/gray” water, or around a waterhole—generally storage roots are not used
7. Planting a late crop that survives the dry season
8. Use of “trash” vines growing from vines discarded at harvest.

There are additional methods and variations on these methods. For example, in addition to the “passive” use of vines taken from roots missed during the harvest, in some areas, farmers deliberately leave part of their sweetpotato field unharvested and protect them from free-grazing livestock with thorn branches. Farmers may manage the conservation and multiplication of their planting material by using different plot types within their farm and/or utilize diverse agro-ecologies at different points in the seasonal and multiplication cycle. It is also possible to distinguish between seed conservation systems that use different plot types *within* the same farm, and those systems that rotate between rain-fed upland fields for root production and dry-season root production in valley bottoms or lowlands with residual water. The latter requires access (ownership, borrowing, or renting) to both types of land, which may be some distance from each other.

Planting practices for conservation, further multiplication, or for root production may vary. In Soroti, Eastern Uganda, the farmers’ association of vine multipliers, SSOSPA, uses the following practice: as soon as rains start, farmers plant and then lightly cover the vines; 2–3 days later they open up the soil to expose the vines (Echabu and Ekinyu 2012). In Tanzania and Malawi, small bundles of vines are buried in shallow trenches, holes, or termite mounds and kept moist until needed (Badstue and Adam 2011; McEwan 2011, 2012).

As noted above, some methods provide both roots and vines, while others are focused on conservation of a small number of plants or quantity of vines, which then are used to prepare planting material when needed. The majority of methods do not produce large quantities of planting material, except where valley bottoms or large swampy areas are used. And these are the areas where there is more likely to be the commercial sale of vines, with customers traveling considerable distances to purchase (see section 7.2).

There is very limited detailed information on sweetpotato seed systems from West Africa. Although a recent study was conducted in Nasarawa State, one of 12 major sweetpotato-producing states in Nigeria, located in the north-central AEZ (David and Madu 2012). The study found that farmers acquired sweetpotato vines from two sources: their own farms and from other farmers. To conserve vines from their own farms during the dry season (January–May), farmers select small roots and plant them in empty spaces near their homesteads, watering them regularly, or store small roots in wood ash until planting time. A third method involves leaving small roots in the field to regenerate. Purchasing vines was a common practice among men; women only mentioned vine conservation methods and noted the lack of funds to purchase vines as a major constraint. Farmers typically purchased vines from farmers living in the same village, which suggests that in this area widespread vine loss due to drought is relatively uncommon. Some farmers (mainly men but some women) are known to have good quality vines and specialize in vine production. In Adogi, specialized vine multipliers reported that they generated good income from producing vines in small plots around their homes. The market for vines is largely driven by the need for additional vines for area expansion and loss of vines through root sales. It appears that more men than women purchase vines (ibid.).

As the root crop shifts from being a subsistence crop for home consumption and becomes more commercialized, men are more involved in its production (including seed management) and marketing, either jointly with women or on their own account (Benjamin and David 2012). In Nasarawa State, sweetpotato has moved from being a food crop grown largely by men to a cash crop in response to increased demand from urban areas (David and Madu 2012).

The various examples discussed above from different parts of SSA show that local farmer-based seed systems are socially, seasonally, and spatially defined. They are influenced by who is sourcing/buying, who is providing or selling, at what point in the seed multiplication and root production cycle, the agro-ecology, and seasonal conditions. There is need to understand in more depth how seed practices are guided by local knowledge and standards, and how local structures and norms influence seed practices.

5.2 Factors influencing seed quality and access to improved planting material among poor households and by gender

Sweetpotato is often considered a woman's and poor man's crop (Woolfe 1992), although there are many countries where root production and sourcing of seed are considered a man's responsibility (e.g., in Ethiopia; Elias Urage, pers. comm.) and parts of Nigeria (David and Madu 2012)). A limited number of studies have been conducted that carry out in-depth analysis of gender roles and gender-based constraints in sweetpotato root production and vine multiplication. For example, the Nigerian study, and a current study in Ghana, used specific survey tools to understand gender constraints in the sweetpotato production and seed multiplication system (ibid.). One study in the Lake Zone Region of Tanzania argued that sweetpotato was a woman's crop and entirely in the female domain, as women were in charge of all practical work surrounding the production of sweetpotato, in particular as the traditional custodians of sweetpotato knowledge and planting material (Badstue and Adam 2011).

Female and male farmers engaged in root and seed production practice negative selection of healthy planting material and roguing out of plants that look diseased. The extent to which individual farmers use these practices depends on availability of planting material, seasonal climatic conditions, stage in season, objective of growing the crop, and knowledge of the crop.

In many contexts there has been the practice of sharing seed, which is viewed as a common good. As noted earlier, conservation of planting material is a key constraint, particularly in areas with extended dry seasons. This constraint is normally overcome by having access to low-lying areas with residual moisture, purchase of vines, and/or traveling long distances to obtain planting material. Access to land depends on local inheritance and customary user rights, and is often influenced by status, gender, and age. In Tanzania women have user rights through their husband or father (or other male relative). This influences decision-making and prioritization of crops to grow and allocation of different types of land. Women may also have less available cash with which to purchase sizeable amounts of planting material, and are less likely to be able to travel longer distances to source the material.

Where local farmer-based seed systems are mediated by women—and as sweetpotato as a root crop becomes more commercialized—men become more involved in both marketing and production of roots. This influences the seed system in terms of the types of varieties that are preferred for commercialization for fresh root sales or for processing vis-à-vis home consumption. Project-based support to seed multiplication interventions may also be captured by male farmers or those who are better off, and overlook women's roles and contributions; thus women lose out on opportunities for benefit (resources, training, new markets) (McEwan and David 2012). The literacy levels of women and resource-poor HH may also affect their ability to access written information about new varieties or seed technologies, unless additional efforts are made to provide oral and visual information. The timing, location, and structure of extension provision may be biased against women's participation by not taking into account their reproductive and family caregiver roles. Thus specific actions may be needed to ensure that women can meet any criteria set down (e.g., access to land, capital investment in irrigation equipment, recordkeeping) for projects supporting the emergence of commercial sweetpotato seed multipliers.

The commercial viability of seed enterprises is also influenced by farmers' WTP, which in turn depends on whether or not they have witnessed improved yields from using quality planting material. Targeted subsidies through the use of vouchers have been used to ensure that poor and vulnerable HH can access quality seed. However, very poor HH may not participate in NGO-, public-, or private sector-mediated interventions (e.g., FGs, field days, FFS, participatory farmer evaluations), and so may not access new varieties or cleaned-up material of existing varieties.

6. Socioeconomic factors related specifically to access to seed among smallholders

The nature of the crop (i.e., vegetatively propagated) is a key factor that influences farmers' willingness to pay for seed per se, or new varieties, as well as the quantities that farmers are willing to buy. In post-conflict or post-disaster contexts, there are large institutional buyers who play a role in seed demand, and may distort prices for seed and undermine longer term efforts to develop commercially viable sweetpotato seed systems (Andrade et al. 2009). As the root crop becomes more commercialized, consumer, trader, and processor preferences will also influence the demand characteristics for seed (Kapinga et al. 2003). In SSA there appears to be a lack of documented formal supply and demand studies for sweetpotato planting material.

6.1 Returns to investment

Low et al reviewed studies on the potential economic impact of key sweetpotato interventions (Low et al. 2009). On the basis of work that Fuglie (2007) carried out in the mid-2000s, research on virus control in sweetpotato and the provision of clean planting material alone could yield rates of return of 56–84%, depending on adoption rate and adoption ceiling. The anticipated aggregate impact of the technology (assuming status quo adoption ceiling) was calculated at $74 million/year, with annual benefits to the rural poor calculated to be $49 million/year. The maximum potential aggregate benefits and benefits to the rural poor for SSA (i.e., assuming no adoption constraint) were calculated to be $434 million/year and $287 million/year, respectively (Low et al. 2009). If seed systems could be strengthened so that the more drought-susceptible OFSP varieties could be effectively distributed, there is also the potential health and economic impact based on the metric Disability-Adjusted Life Years. Replacing white-fleshed varieties with biofortified sweetpotato could reduce the burden of vitamin A deficiency by 15–22% in 17 SSA countries. Ex-ante analysis has determined that if OFSP varieties were adopted by one in six Ugandans within 10 years of becoming available, this would achieve an estimated internal rate of return of 16–30% and yield a net present value of $23 million and $67 million (Fuglie and Yanggen 2007, reviewed in Low et al. 2009).

6.2 Willingness to pay and perception of added value of seed by farmer typologies

It has been argued that commercially oriented vine multiplication schemes, if economically viable, are preferable to subsidized distribution schemes, because profits would ensure their sustained presence, thus providing local farmers with access to high-quality material over time. But there is still discussion and research needed to identify the most appropriate strategies to commercialize vine production in different settings (Andrade et al. 2009).

In unimodal rainfall areas, or where an extended dry season makes it difficult for farmers to conserve or maintain material, there are existing practices of sale and purchase of planting material by farmer multipliers (Gibson et al. 2009). The prices and quantities purchased in a specific context are likely to vary, depending on current seasonal climatic conditions; the point in the growing season (i.e., early or late planting); importance of sweetpotato in the diet; and the extent of commercialization of the root crop (i.e., larger areas are put under production). In bimodal rainfall areas, there may be higher purchases of planting material in the first (often shorter) rainfall season, after which farmers bulk up their own material for planting for root production in the (main) second season. In both uni- and bimodal rainfall systems, sale or purchase of vines is mediated by social, kin, and spatial factors (Badstue and Adam 2011). HH characteristics (socioeconomic status and purpose of production—i.e., home consumption or commercial production) will influence both WTP and the quantities purchased; however, insufficient work has been done on this.

Survey work in Rwanda, Kenya, and Tanzania, which has included questions about the source of planting material, found that in western Kenya, 4% of farmers interviewed purchased vines (SASHA 2012d); 12–13% purchased in areas of the Lake Zone, Tanzania (Ewell et al. 1995; Namanda, Gibson, and Sindi 2011), and in the northern region of Rwanda 56% purchased, compared with 25% in the southern region (SASHA 2013).

Operations research under the HarvestPlus “Reaching End Users” project conducted studies in Mozambique and Uganda to (1) determine whether small-scale sweetpotato growers are willing to pay for OFSP planting material (HarvestPlus 2010b). In Mozambique, the project carried out a real-choice WTP experiment in which HH that had received free vines in the first year of the project would have to pay for any additional vines desired in the subsequent year. Choice experiments let respondents face real market conditions and a budget constraint, and allowed them to buy a product at the price they indicated during the WTP elicitation. Results from the experiment revealed that sweetpotato growers had a higher WTP for any OFSP variety than for local varieties, which are readily available. ‘Persistente’ was the preferred OFSP variety (WTP $0.12/kg) because of taste and, most important, because it is the most drought resistant of the OFSP varieties. This WTP was higher than the fixed value of $0.06/kg that the project established in its first year of operation. The expressed WTP was, however, for small quantities. In the second year, the project implemented a policy of vine sales in 50% of the intervention areas, allowing the prices to go up to $0.10/kg for small quantities. As a result, 38% of the targeted farmers bought their OFSP vines, paying on average between $0.07/kg and $0.08/kg. These prices were higher than the subsidized price of $0.06 in year one for those who wanted more vines in addition to the 2 kg of free vines. The cost of vine production by farmers was lower than the fixed selling price, with $0.02/kg being the total cost of multiplication using conventional spacing and watering cans for irrigation (Labarta 2009; HarvestPlus 2010b).

In Uganda, the project reported that the real-choice experiment revealed that farmers did not fully understand the relationship between clean, virus-free seed and root yields. Although they expressed preferences for varieties that could increase root yields, they did not fully grasp the concept of clean planting materials. Ugandan farmers (in some areas) were willing to pay more on average for clean OFSP vines, compared with the average price of the unclean vines of these varieties in local markets. In many areas, however, the price of the unclean vines in local markets was similar to the elicited WTP for clean OFSP vines. In addition, all WTP values of OFSP planting material elicited were still lower than the prevalent price paid for sweetpotato vines by emergency programs that perform large, free distributions in northern Uganda. Even the highest elicited WTP for clean 'Kabode' vines ($0.62 for a 5-kg bundle) was 35% lower than the price paid by emergency programs (HarvestPlus 2010b).

The REU report (ibid.) summarized the following factors identified as contributing toward WTP for OFSP varieties: (1) the availability of new varieties; (2) drought-prone conditions; (3) recognition of OFSP nutritional benefits; (4) awareness of the yield benefits of disease-free vines; (5) markets with specific varietal preferences; (6) awareness of where vines can be obtained; and (7) access to appropriate transport for distantly located vines. In contrast, major factors working against WTP are (1) the existence of a tradition of vine sharing within the community; (2) the presence of other organizations distributing vines for free; (3) limited purchasing power; and (4) the limited importance of sweetpotato in the diet.

The approach used during dissemination also influences WTP and the perception of the added value of seed. Under emergency and rehabilitation projects, seed is often provided free of charge. This has implications as to whether farmers "care" for this seed if they have not paid for it, or whether they think that if it is lost the following season, another project will distribute free material again (Potts 2006). The distribution of free seed can also distort the market for local multipliers who have a cash market. In an attempt to overcome this, different mechanisms have been tried. These include fully or partially subsidized vouchers with a monetary face value that can be targeted at more vulnerable HH (see section 10 for more discussion on voucher-based systems).

6.3 Vine multiplication as a business enterprise

The REU project (HarvestPlus 2010b) also conducted operations research to determine whether vine multiplication under smallholder conditions is an attractive enterprise. The study of 18 Ugandan vine producers revealed that multiplying sweetpotato vines using bottom valleys or tree shade schemes can make vines available in time for the main planting season, but these schemes had the highest production cost per 30-kg sack ($0.67 and $0.50, respectively). The lowest production cost was found among farmers using root beds ($0.23/30-kg sack) and farmers using traditional sprouting ($0.30/30-kg sack). The use of traditional sprouting has a major drawback, however, because vines are not available until 2 months into the first growing season. In Uganda, several serious high-quality vine multiplier associations do exist, though trained through different projects. These groups have profitably engaged in larger-scale vine multiplication in response to demand from NGOs seeking vines for distribution to refugees returning to their homes. Such organizations pay above market rates for vines ($4–$5/30-kg sack in 2009, for example), a practice that encourages many farmers to specialize solely in vine production.

Farmer multipliers face the major challenge of estimating demand for their vines on an annual basis. Since different spacing regimes are used for vine production (10–15 cm between plants) than for root production (typically 30 cm between plants), correctly estimating demand enables farmers to maximize their returns. Vine multipliers preferred signing contracts for specified amounts of material (ibid.).

A recent sweetpotato seed system consultation in Nairobi invited presentations from the private sector and small- to medium-scale commercial multipliers (Ssemakula et al. 2012). The experiences revealed the following emerging lessons:

- It is important to conduct gross margin analysis to compare with other agricultural/horticultural enterprises competing for the same resources.
- Access to water, irrigation facilities, and good soils, and physical access to markets are needed.
- The key factors influencing profitability of vine multiplication as a business enterprise are irrigation and labor costs:
  - Irrigation costs depend on the length of the dry season, source of water, and equipment used.
  - Labor costs in turn depend on the production model (group, individual) and within a group how labor is organized (e.g., joint activities, rota, communal plot divided into portions for individual responsibility).
  - Groups operating as social enterprises (or mixed social and business enterprises) may consider other forms of benefit as important as economic benefit (e.g., social capital, status in the community, or nutrition benefits in the case of OFSP). These social benefits may be key in contributing to the sustainability of a seed enterprise.
- The use of a root-based vine multiplication system may reduce the amount of time that vines are under field multiplication requiring irrigation (i.e., reduce the costs of production).
- The importance of managing the inter- and intra-annual seasonal variation in demand for vines. For example, by using agro-meteorological early warning information; actively soliciting contractual agreements with buyers; and combining root and vine production to spread risks.
- The benefits of leveraging synergistic relationships between different sub-enterprises, such as:
  - Vertical integration, whereby the income from root and processing enterprises subsidizes the vine multiplication enterprise; but the distribution of vines to farmers is essential to ensure a stable supply of roots (Makokha 2012).
  - Integration into livestock feed enterprise (Woldegiorgis 2012).
- Many private sector multipliers (e.g., Lozane Farms in Mozambique) are still highly dependent on the institutional market (in this case, CIP).

A key challenge for vine multiplication enterprises is in projecting the demand for planting material (either of existing or new varieties) from season to season. In areas that experience cyclical drought (e.g., parts of Ethiopia), when there is good rainfall emerging commercial vine multipliers have no market for their planting material. But when it is a drought year there is high demand from institutional buyers involved in disaster relief and recovery programs. However, the tenders or orders for planting material are placed too late for the specialized vine multiplication cycle, leading to the risk that vines are sourced and distributed from old fields that had been used for root production and have higher pest and disease build up. This implies the need for better use of agro-climatic early warning information systems and better coordination and planning among the different stakeholders in the seed system. Together, these steps could contribute to a better articulation between demand and supply.

7. Institutional factors

As Cromwell, Friis-Hansen, and Turner (1992) pointed out more than 20 years ago, within the seed sector itself, more attention has been devoted to the physical aspects of production, processing, and storage than to the difficult organizational issues that must be addressed if the sector is to function well. The same could still be said for sweetpotato seed systems today. And while some research on the institutional arrangements for sweetpotato seed systems is in process (McEwan 2012), continuing research is needed on the organization and structure of the seed sector, and how these impact on different types of farmers. These same authors also underscored the shortcomings of complete reliance on the private sector and the contribution a reformed public sector could potentially make. More recently, the Integrated Seed Sector Development project has also emphasized the importance of linking the informal and formal seed sectors and balancing public and private sector involvement (Louwaars and de Boef 2012).

Tripp (1997) has emphasized the importance of information and its attendant transaction costs as a component of the institutional conditions for seed enterprise development. The efficient exchange of information is supported by the development of norms and trust, and is associated with the concept of social capital. He also stresses that adequate incentives must be provided for undertaking the various tasks of seed provision. This requires the coordination of several different organizations to accomplish these tasks. There is often the mix of public and private (commercial or voluntary) entities in the process, which adds to the importance of coordinating the flow of information.

As seed systems are value chains in themselves, and are linked to value chains for roots, trust and information exchange are needed between farmers and seed providers. Stakeholders may be part of different types of organizations (association, producer groups, firms), and institutional arrangements (markets, norms, legal systems) need to evolve that contribute to information exchange. Sweetpotato seed systems are an example of a complex process with decentralized and layered components dispersed over space and time. These individual components need to be organized (referred to as “transformation costs”), and the links between the components (referred to as “transaction costs”) managed (ibid.). Institutions that mediate and facilitate the flow of information between actors, that negotiate different interests and incentives, and that allocate roles (particularly between public and private sector) are needed.

We also need to ask why institutional linkages are not easy to make within a sweetpotato seed system. This may be influenced by the following factors, some of which are generic and others specific to sweetpotato as a crop:

- Both duplication in institutional mandates (thus creating conflict or competition) and/or an absence of mandate for particular seed system functions.
- Difference in geographical scope and coverage for different institutional players (e.g., some institutions operate at a national level only, some on administrative units, some based on AEZ).
- The crop has a low priority because it is not considered “commercial.”
- The mandate for coordination of seed system is not explicit, or the resources and capacity to fulfil this role are not in place.

- Overdue emphasis on either the "formal' seed system or the "informal" seed system, without considering how to leverage the synergies between the two.
- Given the diversity of sweetpotato seed systems, the stakeholder configuration and institutional arrangements need to be context specific and reflect particular agro-ecologies and objectives for the seed system.

7.1 Policies and regulations related to seed

A brief review of seed policies in Ethiopia, Kenya, and Tanzania shows that although cuttings and tubers of VPCs may be mentioned as part of the definition of "seed," the particular characteristics of these crops may not be fully taken into consideration when developing legislation (United Republic of Tanzania 2003; Government of the Republic of Kenya 2010; Federal Democratic Government of Ethiopia 2012). As different modalities for the distribution and sale of sweetpotato planting material are put in place and the crop moves from being purely subsistence to commercial, there will be more pressure for formal standards and certification procedures to be put in place. (See earlier section.)

For VPCs, plant health and site adaptation are more important in managing seed quality than for grain seed, whereas genetic instability is less important than for cereal crops (Lynam 2011). Seed health is related to diagnostic capacity—in particular for virus diseases—as embodied in TC laboratories. There is a trade-off, then, between guaranteeing seed health and proximity of seed to farmers; therefore, quality management of VPCs needs to be organized differently. This can lead to yet a further trade-off: between diagnostic capacity and proximity to farmers—one that becomes more complicated if the mandates for plant health and seed certification are held by different organizations (as is the case in Tanzania) and if federal and regional bodies have overlapping roles (as in Ethiopia).

The objectives of seed health and quality regulations are to prevent the spread of seed-borne diseases and protect farmers from unscrupulous seed traders. But policies and regulations without the capacity to implement them can widen the gap between paper and practice. If seed certification is to be effective, a participatory approach for the design, management, and modification balancing internal quality assurance control with external inspection is required. It should involve farmers, extension agents, and seed multipliers, as well as regulatory authorities (IFPRI 2010; McEwan, Namanda, and Lusheshannija 2012).

7.2 Public, private, and civil society organizations involved in seed supply and distribution

Sweetpotato seed production has remained predominantly in the public domain, with state-supported research system involved in breeding and the production of breeder and basic seed. In some countries (e.g., Tanzania, Ethiopia), responsibilities for coordination of seed multiplication are allocated across both research and extension services in the public sector, depending on the level of decentralization and devolution and how resources flow.

In the SNNPR of Ethiopia, for example, the research institute contracts land from former state farms now under private ownership to produce basic seed, which is then sold to private multipliers or distributed to the Bureau of Agriculture. Seed produced from the research-managed farms is also sold directly to NGOs or individual farmers. This undercuts the market for the private multipliers, as the state seed production is subsidized and therefore cheaper; however, NGOs are more confident in the quality of the seed from the research-managed seed production.

In Tanzania, the reduction in investment in the agriculture sector from the early 1990s, also witnessed the breakdown of mechanisms to support research-extension linkages. Since the mid-1990s,NGOs have been more involved in supporting the dissemination of new varieties (Jeremiah et al. 2007). With the research system organized around AEZ, and the extension system organized around administrative boundaries, it is not clear whether there is a recognized mandate for the *coordination functions* required for the seed system to plan activities (e.g., demand projections, timing of supply, roles of different stakeholders, and quality assurance).

Given the characteristics of the crop and the hierarchical organization of the flow of planting material, private sector involvement is predominantly at the level of TC production or multiplication of foundation material. There has also been private sector involvement in contexts where there is an institutional market and high demand from NGOs involved in post-conflict or post-disaster relief (e.g., northern Uganda and southern Ethiopia). Farmer entrepreneurs either specializing in vine multiplication alone, or combining vine multiplication with other segments of the sweetpotato value chain are emerging, as in Kenya and Rwanda (Makokha 2012; Habumuremyi 2012).

8. Integrated perspectives on challenges and opportunities for small farmer access to improved planting material

8.1 Results of diagnosis studies and attempts to analyze constraints to seed production, delivery, and dissemination in an integral way

BMGF commissioned a situation analysis of seed systems for VPCs in SSA with the objective of proposing seed system strategies for these crops (Nweke, Akoroda, and Lynam 2010). The report laid out a number of components for a sustainable seed system: demand for seed; supply of breeder seed of appropriate varieties in sufficient quantities; multiplication of foundation seed; standards and certification of seed; coordination between demand and supply; efficient and coordinated distribution arrangement for delivery from source to beneficiary; and affordability of the seed (i.e., WTP and proof of economic superiority of purchased seed over own seed). Across all VPCs studied, the authors identified a number of key constraints:

- Farmers' limited ability and WTP for quality seed
- Regionally specific interventions needed
- Free seed distribution under emergency seed projects
- Low seed technologies
- Limited national capacities and need for intensified advocacy
- Pest and diseases
- The "gender issue"
- Low farmer education (ibid.).

In preparation for the BMGF-funded SASHA project, a series of challenge papers were commissioned to review the current status of sweetpotato research in a range of areas. This included a review of sweetpotato seed systems by Gibson and colleagues (2009), and emphasized the potential for farmer-based, demand-driven seed systems as the most sustainable approach. The review identified the following areas of improvement that were needed in the quality of planting material in areas with bimodal rainfall: the range of good varieties, freedom from weevils, SPVD, and physiological vigor. In unimodal rainfall areas, the same constraints existed but the overriding constraint was lack of planting material at the beginning of the rains, leading to late planting and limited areas planted. This review focused on biotic and abiotic challenges related to seed production, and did not consider organizational constraints and issues of scaling-up.

In a challenge paper prepared as part of the review, Andrade et al. (2009) identified the following challenges for seed systems:

- Efficient mechanisms for introducing and multiplying new and improved varieties
- Inadequate supplies at the onset of the rains
- Improving the role of sweetpotato in disaster relief and mitigation
- Ensuring the quality of sweetpotato planting material for purchasers

- Efficient and safe germplasm movement programs.

The following areas were recommended for action: improved availability of planting material in drought-prone areas through the use of root-based vine multiplication systems; breeding, in particular of improved SPVD-resistant varieties; training; germplasm movement; the use of true seed; and documentation of private sweetpotato seed enterprises and the role of women in sweetpotato seed systems (Gibson et al. 2009). As part of the same SASHA project preparation, Elliot (2009) considered partnerships and governance in the project context and how to manage the implementation of a multiscale, multipartner project.

The GTZ-supported project "Large-scale Deployment of Improved Sweet Potatoes in sub-Saharan Africa" tested different multiplication and delivery system models in the mid-2000s. These included:

- Establishment of a farmers' vine-producer association
- Involvement of large NGOs
- Support for a sweetpotato forum (VITAFOW) in western Kenya
- Use of small entrepreneurs
- Use of schools as centers of dissemination (vines and knowledge)
- Use of large institutions (e.g., prisons) for multiplication
- Humanitarian projects for delivery of planting material.

Each strategy had merits and drawbacks, but the comparison demonstrated the need for flexibility and matching the strategy to the local conditions (Potts 2006).

The project "Understanding How to Achieve Impact-at-Scale through Nutrition-focused Marketing of African Indigenous Vegetables (AIVs) and Orange-Fleshed Sweetpotatoes (OFSP)" (2007–2009), supported by Kilimo Trust, was implemented by CIP in collaboration with the World Vegetable Center, Urban Harvest, and the marketing specialist NGO Farm Concern International. The project took a market linkage approach and aimed at commercialization and expanding markets for African indigenous vegetables; technology development and dissemination; seed and vine multiplication; and commercialization and distribution through the "commercial village" approach. The lessons learned from this project highlighted the challenges of ensuring that the appropriate sweetpotato varieties had been evaluated before efforts were put into commercialization, and that seed multipliers need to develop and use production and marketing plans (CIP 2010f).

Under the SASHA project (2009–2014) and the umbrella Sweetpotato for Profit and Health Initiative, there are various components that are exploring and testing different delivery and dissemination approaches. These are based on some analysis of what type of seed production and delivery approach is appropriate in different contexts and with different target groups in mind. These can be categorized into efforts to address seed delivery and dissemination constraints as part of a "stand-alone" sweetpotato seed system, or linking seed delivery to other objectives (e.g., improved nutrition and food security through improved consumption of the root crop, or value chain upgrading and processing activities (CIP and BMGF 2009).

In Tanzania the "Marando Bora" component of SASHA has been testing two delivery systems to determine which approach leads to a higher level of adoption. The first model was based on DVMs at village level to multiply improved varieties. A voucher-based system was used to target women farmers and vulnerable HH (e.g., those with children under 5 years). The beneficiary farmer collected the planting material from the DVM's plot at a mutually convenient time. The second model multiplied planting material at medium- to large-scale sites. The material was harvested and transported to a central point for distribution on a pre-agreed day. Analysis of the advantages and disadvantages of these two approaches are reviewed in Tables 10.1 and 10.2.

Another component of the SASHA project in western Kenya is "Mama SASHA," which also uses DVMs to multiply planting material at village level through a voucher-based system. In this case, the objective is to target pregnant women and encourage them to attend ante-natal clinics, early and regularly, and to increase the consumption of vitamin A-rich foods. At the ante-natal clinic the woman receives nutrition education and a voucher entitling her to collect planting material of beta-carotene–rich OFSP varieties (SASHA 2012a).

The "Rwanda Super Food" component of the SASHA project is using a value chain approach to link contracted sweetpotato root producers to both food processors (large-scale biscuit and bread production that substitutes sweetpotato flour for a proportion of wheat flour), and to sources of quality sweetpotato planting material (SASHA 2012c).

The "Rooting-out Hunger in Malawi with Nutritious Orange-fleshed Sweetpotato" project is also using variations on the DVM and voucher approach, working with the NARI and extension system and NGOs, who in turn work with FGs (Abidin, Chipungu, and Mnjengezulu 2012).

Under the "Dissemination of New Agricultural Technologies in Africa" (DONATA) project, innovation platforms for technology adoption (IPTAs) have used multi-stakeholder platforms to bring together value chain actors to identify and act on sweetpotato seed system constraints. The IPTAs have provided opportunities for wider varietal testing, economies of scale in training extension providers and farmers in seed conservation and multiplication technologies, better coordination of demand and supply projections, and linkages with root producers (CIP and ASARECA 2013; Kimenye and McEwan 2014).

8.2 Emerging opportunities—what could help drive the RTB seed sector for sweetpotato?

Current thinking is that the sweetpotato seed system will "work" better where it is linked to demand for roots or specific initiatives that are promoting the demand for roots (McEwan et al. 2015). Three examples are:

- Contexts where there are extensive efforts to promote nutritional benefits of the crop (in particular OFSP)—for example, the "Mama SASHA" component (SASHA 2012a), the "Rooting-out Hunger in Malawi with Nutritious Orange-fleshed Sweetpotato" (Abidin, Chipungu, and Mnjengezulu 2012), and Hellen Keller International's work to promote homestead gardens with diversified crops including OFSP.
- Contexts where value chain approaches are used to develop linkages between value chain actors and where there are contractual arrangements between processor, root producers, and vine multipliers. Examples are the Siwongo Processing Company in western Kenya (Makokha 2012), and Company Ibyiwacu Ltd. in Rwanda (Habumuremyi 2012) . The OFSP flour processing enterprises require a consistent root supply, which is in turn dependent on a reliable supply of

vines. So the vine enterprise is conducted by the company on its own fields, and the company also contracts out vine multiplication to individual farmers and groups. The companies also provide technical support to contracted farmers and groups on vine multiplication and root production techniques and pest and disease management practices, and can call in additional backstopping from colleagues at the Kenya Agriculture Research Institute or the Rwanda Agriculture Board. The vine enterprise is more profitable, but the root and flour processing enterprise provides a more consistent income. In these cases, an IPTA fulfils a coordinating or clearinghouse function to assess seed need and seed availability, and provides training of trainers in different aspects of vine multiplication and root production (Mayanja et al. 2012).

- Contexts where the sweetpotato vine enterprise is linked into other agricultural enterprises. For example, the Minora Agricultural Investment Share Company (Tigray, Ethiopia) is using an integrated crop and livestock model to support its vine multiplication enterprise (Woldegiorgis 2012). The farm earns diversified benefits from the vine multiplication enterprise through vine sales to customers (farmers, CIP, FAO); vines for livestock feed and fattening supplements; sale of sweetpotato roots as food to farm laborers and retailers; and feed for poultry at farm-gate price.

9. Review of major implementation models

There are a range of options that can be considered for both the multiplication and dissemination planting material depending on the overall objective (e.g., rapid dissemination of new varieties, nutritional improvement, food security, and commercialization). Decisions related to multiplication models need to be based on an understanding of the agro-ecological, climatic, socioeconomic, and institutional context. It is also important to understand how existing farmer seed practices work, and what would be the most appropriate linkage to the formal components of the system (e.g., breeding, varietal release, and regulatory bodies). Depending on the quality of material needed and desired level of decentralization, multiplication may be undertaken by a combination of research institutions, TC laboratories, individual farmer entrepreneurs, farmer seed multiplication groups, small- to medium-seed enterprises, and public institutions. The type of multiplication model influences the delivery system or dissemination model, and vice versa. There are broad parameters within which decisions need to be made.

The first of these is between a “single-shot approach” or an “ongoing access approach” for multiplication and dissemination. The former has often been used in post-disaster rehabilitation contexts and has been associated with experiences of “truck and chuck.” A single-shot approach, however, may be appropriate in bimodal rainfall systems or areas with low virus pressure. Here, new varieties or cleaned-up material is distributed, and farmers are able to maintain and conserve them using their existing seed practices and to exchange with other farmers. In such a context multipliers selling planting material on a seasonal basis may not be commercially viable. In unimodal or drier areas where farmers are more likely to need to obtain replacement seed on a seasonal basis, trained farmer multipliers may be able to sustain a viable vine multiplication enterprise as either a stand-alone or in combination with general agro-input supplies and services or other livelihood enterprises.

The second major differentiation in implementation models (for both multiplication and dissemination) is the degree of centralization or decentralization. This depends on the objective of multiplication and dissemination and the constraints being addressed in a particular context. Decentralized models may be more appropriate in areas with high population density.

The third major factor to consider is the degree of commercialization that is necessary. This is dependent on farmers' WTP, which is more likely in the following situations:

- Availability of new varieties, where sweetpotato is the main crop
- A long dry season
- Recognition of nutritional benefits (e.g., OFSP)
- A well-developed market for roots
- Awareness of the yield benefits from early planting and the use of disease-free vines
- Awareness of and access to vines for sale at the start of the rainy season.

WTP may not be high where there is a tradition of sharing planting material within the community, the presence of other organizations distributing planting material for free, limited purchasing power, limited importance of sweetpotato in the diet, or continuous production of sweetpotato such that vines are always available.

For the dissemination of new varieties, or in the case where there are clear nutritional objectives, there is an argument for state or donor subsidy. In other cases, there may be opportunities for full commercialization, particularly where there are strong value chain linkages to root markets and processing enterprises. In many cases, there may be the need to provide a supply or demand side subsidy for 2–3 years until the vine market is well established. One way of providing a subsidy is through the use of vouchers. Voucher-based systems can have a range of different objectives, such as providing a demand side subsidy (to particular farmer or vulnerable groups) to reduce their risks of trying a different variety. On the supply side, the voucher system can provide a multiplier a guaranteed market, and the subsidy can be operated on a partial, total, or tapered system. The voucher system can be designed to offer customers more choice in terms of variety, multiplier, and preferred timing to obtain vines, or as a supply (multipliers) side subsidy. The vouchers are issued to farmers based on agreed criteria. The farmer can then exchange the voucher for vines, either at a centralized point (e.g., a seed fair) or with a DVM; the voucher is then redeemed for cash by the program's sponsor.

A subsidized voucher program can have high transaction costs, including the printing of a type of voucher that cannot easily be forged; training partners in the implementation of the voucher system; sensitization of community leaders and members; time taken to complete the information requirements on the voucher, voucher distribution, and redemption; monitoring; and data collection and entry (SASHA 2011a). The costs of setting up and running a voucher system may be higher than the actual value of the planting material. Such a system may crowd out the opportunity for local sales, either because the potential catchment area has been saturated by the voucher distribution, or the multiplier has produced only enough material for the guaranteed (i.e., voucher) market. The dissemination model can also emulate farmer practice by encouraging "pay-back" or "pass-on-the-vine" (by gift or sale) system, in which target beneficiaries undertake to pass on the equivalent quantity of vines to the initial provider or other farmers (Potts 2006; CIP and ASARECA 2013). The disadvantage of this approach is that it is difficult to monitor both the dissemination chain and the quality of the material being passed on.

Increasing farmer knowledge and awareness of the advantages of new varieties and the benefits of clean seed, together with linkages to credit institutions, risk insurance providers, and quality assurance mechanisms, are also important components of any implementation approach.

The “Reaching Agents of Change” training course, “Everything you ever wanted to know sweetpotato,” includes one module (Topic 5) on Sweetpotato seed systems. This guides the practitioner through a series of factors that should be considered when designing seed system interventions and, in particular, choosing a planting material multiplication and dissemination strategy. Some of these are agro-ecological and climatic factors, varietal factors, socioeconomic and demographic factors, institutional factors, existing seed system factors, and project-specific factors (Stathers et al. 2013).

9.1 Brief list and reflection on major models used for seed multiplication

Model	Cost per unit of production	Quantity of production/season	Quality of product (Relative)	Advantages & disadvantages for different stakeholders	Potential for sustainability
TC plus hardening (public or private sector)	$0.30/plantlet	3 sub-cultures from each TC plantlet every 6 weeks	TC virus-indexed material; bacterial contamination can occur	Expensive (requires subsidy)	Small starter quantities; combine with TC facilities for other VPCs
Primary multiplication (research managed: public)	$2–3,000/ha per season; depends on AEZ, method, level of inputs, and type of irrigation used	1 ha: RMT (~500,000 pp/ha) = 7.5–10-m cuttings in 4–5 months	High: dependent on virus pressure and management	Close link to breeder source	**Technical:** requires irrigation **Financial:** requires public sector support or revolving fund arrangement
Secondary multiplication (e.g., NGO, community-based organization, farmer-based organization, prison, school, local government/public extension managed)	Depends on level of inputs and type of irrigation used	10–15 cuttings/plant (4–5 months) dependent on variety, method of multiplication, no. of ratoons, agro-climate, inputs and management	Good: dependent on virus pressure and management; fewer but larger plots may make supervision easier	May link to NGO-supported FGs	**Technical:** requires irrigation **Financial:** some subsidy or revolving fund arrangement; public extension service may include in annual budget **Institutional:** depends on sustained commitment from institutional heads, unless part of mandate
Tertiary: may be contracted or DVM **(trained *individual* farmer)**	$0.04–5/cutting (30 cm); use of own, family or hired labor	5–10 cuttings/plant (4–5 months) dependent on variety, method of multiplication, no. of ratoons, agro-climate, inputs, and management.	Dependent on source of material, level of knowledge and management, and frequency of obtaining fresh material.	DVMs need careful selection, appropriate site conditions, training, and ongoing supervision. Customers within a 10–12 km radius able to purchase/	**Technical:** needs dry season access to irrigation; needs link to sources of fresh/new material

		Methods: - RMT: 3 nodes 10 x 20 cm spacing - conventional spacing to get vines and roots (Malawi upland: 30-cm cutting at 30 x 75–100 cm spacing) - adapted (Malawi: vine cutting: 30 cm; planting on *ridge* (5 m long); planting distance: between plants: 15 cm; between ridges: 75 cm **Uganda:** Conventional: *mounds* 0.6m^2 Plant 30-cm long cuttings 3 cuttings/1 m^2 = 60–70 bags harvested per 4,000 m^2 Specialized: shorter cuttings of 20 cm long at 50 cutting/m^2 = 400–600 bags harvested/ 4,000 m^2 with fertilizer application	More resources needed for training, supervision and quality control	collect vines when required. DVMs can provide additional information on varieties, vine conservation, and root production. Can host demo plot, field days, etc.	**Commercial:** in unimodal rainfall areas In areas where commercial market for roots and vines Integration with other agriculture-based enterprises Alternative use of land may be more profitable (e.g., high-value horticultural crops) **Social:** depends on trust and community standing
DVM **(trained farmer *group*)**	$0.02 c/cutting (30 cm); use of group labor	See above	Depends on source of material, level of knowledge and management, and frequency of obtaining fresh material	See above. Group approach *may be* more accessible to women and vulnerable groups. FFS and other group extensions approaches can be used more effectively.	Social enterprise combined with other IGA in group situation. May be dependent on NGO support.
Mass multiplication (institution based or large-scale private seed entrepreneurs)	Need to add cost of harvesting and transport; institutional overhead costs,	Potentially high production if managed well. Fewer sites make supervision and may increase impact of risk	Good: depends on virus pressure and management	Easier for institutional buyers to tender and contract May be suitable for “single-shot” campaigns to	Contracts provide more certainty for multiplier, if issued with sufficient lead time.

	and hired casual labor costs	events (e.g., drought, floods, disease outbreaks)		disseminate new varieties in bimodal rainfall systems, where farmers are able to maintain planting materials more easily	
Medium-scale multiplication (individual farmer or farmer group)	Need to add cost of harvesting and transport	Potentially high production if managed well. More sites make supervision costs higher. More sites may spread impact of risk events (e.g., drought, floods, disease outbreaks)	Good: dependent on virus pressure and management	May provide opportunity for emerging individual or group seed enterprises to access larger and more geographically dispersed markets	Contracts provide more certainty for multiplier, if issued with sufficient lead time
Existing multiplier	$0.01/cutting	Depends on demand and rainfall. Generally, produces vines as byproduct of root crop	Normally selected from own previous crop; depends on variety, disease, and pest pressure	Customer able to purchase/ collect vines when required. More difficult to provide training, etc.	Access to dry season water source; has existing customer base (small)
Voucher-based supply subsidy	High as needs to incorporate costs of voucher system	Depends on number of vouchers issued and balance between voucher and open market sales	Depends on virus pressure and management	Provides multiplier with guaranteed market, so can plan ahead	Tapering system could be used
Piggy back onto another seed multiplication VPC (e.g., cassava)	Theoretically some costs of production, training and supervision can be shared	Depends on multiplication cycle of other crop (i.e., where land and resources are required at the same time)	Depends on virus pressure and management; rotation between crops may contribute to better pest & disease management	May reduce capital set up costs (e.g., irrigation) if can be shared between crops; and supervision costs.	**Technical:** Sweetpotato has higher water and management requirements than cassava **Social:** in some contexts crop "ownership," and knowledge is gender differentiated

Reflections:

1. There is a limitation in considering multiplication, dissemination, and demand creation models separately. In practice, decisions or objectives related to one activity affect the others. For example, the context, objective, and type of farmer to be reached influences the type of dissemination model and therefore the type of multiplication model.
2. One “model” can have sub-models, depending on who is implementing or managing the activity. For example, decentralized multiplication can be carried out by individual farmer multipliers, FGs, or a specialized commercial seed enterprise.
3. The level of decentralization also influences the models.
4. Models can be combined (e.g., the 1-2-3 model can be implemented sequentially or simultaneously; the tertiary level can be either the final point for mass dissemination or the basis of a DVM system.
5. Other factors that influence the choice of model include population density, rainfall pattern (i.e., bimodal or unimodal), level of subsidy, and whether subsidy is on the supply or demand side (or both).
6. Different multiplication models will have differential benefits according to gender (men, women, and youth). Models that are more commercially oriented and/or require access to resources (capital, equipment, new information) may be more biased toward participation by men and youth. Social enterprise models may be more biased toward participation by women and vulnerable groups (e.g., HIV support groups).
7. Information flow and communication are required among all actors: varietal preferences, quantities needed, timing, quality management.
8. Objectives: initiate new varietal dissemination and promotion; replace planting material, or promote alternative crops after drought, disease outbreaks, non-market-driven dissemination; market-driven dissemination.
9. Different models have different establishment/set-up costs. Key challenge for sweetpotato is that it takes 9 months to bulk up seed.

Source of cost estimates

1. Production costs (field multiplication) depends on agro-ecology (dry/wet) and method of multiplication (RMT, conventional).
2. TC plantlet: private laboratory in Kenya.
3. DVM individual: Mr. Kibipi DVM in Sengerema, Tanzania (Nov. 2012). Based on Tsh 8,000 for 1,000 cuttings (1 bag) (Exchange rate $1 = 1,550 Tzsh).
4. DVM group: Marando Bora, Tanzania price used (Apr. 2012). Based on 3 Tsh/cutting, so 3,000 Tsh/1 bag.
5. Farmer interviews, Tanzania (Nov. 2012).
6. Other information: 1 bag = 1,000–1,200 x 30 cm cuttings dependent on variety.

Country and project examples:

1. TC plantlet production (SASHA Marando Bora project, Tanzania; Kenya: DONATA and Mama Sasha; Rwanda: DONATA and Rwanda Power foods).
2. DVM approach: SASHA Marando Bora, Tanzania.

9.2 Brief list and reflection on major models used for seed delivery/dissemination

Model	Scale of delivery - # farmers reached in X time period	Geographic coverage	Type of farmer who can be reached	Potential for sharing seed knowledge w/ physical material	Who benefits/loses	Potential for sustainability
Farmer-to-farmer	Small scale: neighbors, kin, neighboring village	Village and neighboring villages	Women farmers (if sweetpotato seen as “woman’s crop”); noncommercial farmers; vulnerable groups	Medium for indigenous technical knowledge (ITK)	Subsistence-oriented farmers, but may be low-yielding material and limited choice of varieties. Reinforces social networks and reciprocal obligations.	High social sustainability, although quality and quantities of material available may be low or variable
Existing local multiplier: *Sale to individual farmers at multiplication plot*	Small scale: depends on scale and level of multiplication, population density < 100 customers/ season	Customers may be very local or travel up to 60–100 km	Farmers WTP and able to travel to neighbors & kin	High for ITK	Multiplier if commercially viable enterprise, although depends on season. Farmers who are WTP may be more choice of varieties	High in unimodal system where more difficult for farmers to maintain own material
Farmer group/FFS dissemination (group plot or group member plot) *-free to members* *-sale or free to other farmers* *-pass-on or pay-back system*	Members (25–30/ group) and then pass-on system	10–12 km/group	Those farmers who belong to group (i.e., not best resourced or least resourced)	High	Group members *and other community members*	Depends on ongoing interest of group; sometimes one member will continue
Decentralized Vine Multiplier (DVM)	100-400 farmers/season	10-12 km	Can be targeted and subsidized	High if multiplier has been trained in improved technologies and practices	Multiplier if commercially viable enterprise, although depends on season; farmers who are WTP	**Financial:** High in unimodal system where more difficult for farmers to maintain own material

Model	Scale of delivery - # farmers reached in X time period	Geographic coverage	Type of farmer who can be reached	Potential for sharing seed knowledge w/ physical material	Who benefits/loses	Potential for sustainability
						Institutional: Depends on ongoing links to sources of new varieties and clean material **Social:** Depends on trust in community
Mass dissemination at single point *-May be one-off or every 4–5 years* *-May be part of regular seed fair* *-May be free, subsidized, or for sale*	Can be large scale (e.g., disaster rehabilitation); one-off per season	10–20 km? from dissemination point	Can be targeted; depends on pre-event promotional activities and information	Usually limited. Depends if information and education communication extension activities included (pre-awareness, day of dissemination, follow up afterwards). Material can be labelled with minimum information.	Farmer less choice when & where to obtain planting material. Depends on rainfall for planting. Higher spoilage/loss of material	In bimodal rainfall system where easier for farmers to conserve material. Depends on public sector/donor subsidy
Sale of vines in local markets or especially established sales points	Medium scale depends on market catchment and frequency; seasonal	10-20 km from market?		Depends on knowledge of seller at sales point (i.e., may not be multiplier) Potential for market promotion/storms	Farmer can purchase at weekly market. Farmer may purchase small quantities to “test” varieties High potential loss/ wastage unless multiplier can use “pre-order system”	**Social:** Increased market exposure **Financial:** Depends on cost of transporting vines to market, and loss spoilage

Model	Scale of delivery - # farmers reached in X time period	Geographic coverage	Type of farmer who can be reached	Potential for sharing seed knowledge w/ physical material	Who benefits/loses	Potential for sustainability
					Multiplier may need to invest in "market search" to secure new customers	
Voucher-based demand subsidy	Depends on objective, resources available and multiplication model	10–12 km		High if source of material (multiplier) has been trained in improved technologies and practices, or if linked to facility-based dissemination (e.g., health center, school)	Farmer incentive to test new varieties with less risk. Targeting and promotion of varieties with particular benefits to particular farmer types (e.g., OFSP). Vouchers can be distributed at a different point to the multiplication/ collection point. Farmer can contribute partial cost of voucher/ material. Voucher can be used to monitor distribution/ collect data on farmer characteristics and choice. Cost of set up and running voucher system can be more than value of planting material.	**Financial:** Depends on state or donor subsidy
Facility-based dissemination (e.g., schools, health facilities)	Can be high, depends on catchment area of facility (e.g., primary school 800–1,000 learners)	10–12 km?	Households who are accessing facility	Potentially high: if integrated into curriculum school learners can take messages home	Particular target groups (school learners, pregnant women, children under 5)	**Financial:** Depends on state or donor subsidy

Model	Scale of delivery - # farmers reached in X time period	Geographic coverage	Type of farmer who can be reached	Potential for sharing seed knowledge w/ physical material	Who benefits/loses	Potential for sustainability
				to family and community. Health facilities can pass on nutrition message.		**Social:** May be high as using an integrated approach

Reflections:

1. To what extent can seed delivery/dissemination models be linked to extension approaches which include root production activities as well?
2. Model for seed delivery depends on:
    a. Existing farmer seed practices
    b. Unimodal or bimodal rainfall pattern (i.e., agro-ecology)
    c. Context: disaster recovery, development (general, food security, nutritional benefit, commercial)
    d. Centralized/decentralized multiplication
    e. WTP
    f. Extent of integration between "formal" seed system and existing farmer practices
    g. Degree of targeting necessary
    h. Degree of demand subsidy
    i. Type of partners involved
    j. Geographical scope to be covered
    k. Information and education communication, communication for behavior change, extension, promotion support available
    l. Information flow and communication among all actors.
3. Depends on type of and management of partnership for seed system (multiplication and dissemination) and links to other segments in the value chain: FGs, farmer associations, public sector (research and extension), private sector, NGOs, consumers, and special interest groups (health, schools, prisons) link to postharvest activities and marketing.
4. Demand creation campaign through behavior change communication (e.g., market promotion, theatre, dance, poetry, songs, and banners).

    Scale and coverage of multiplication and dissemination depend on institutional entry point (e.g., individual farmers, FGs, schools, health centers, NGO, public, private sector), how extension and support is being provided.

9.3 Brief list and reflection on major models used for awareness raising/ demand creation

For sweetpotato, raising awareness and demand creation for planting material to a large extent are connected to raising awareness about the value and benefits of the crop itself and, in particular, biofortified varieties of OFSP.

The "Towards Sustainable Nutrition Improvement in Rural Mozambique" (TSNI) research project sought to use OFSP as an entry point for improving dietary habits and child-caring behaviors among resource-poor HH with high levels of child malnutrition. The project was implemented over four growing seasons between 2003 and 2005, in a drought-prone area in northern Mozambique. This integrated agriculture-nutrition-marketing approach aimed to improve access to OFSP planting material; increase demand and enhance knowledge and practices through extension; and increase income through market development and expanded production (Low et al. 2005). The study found significant improvements in vitamin A intake and serum retinol concentrations (a proxy for vitamin A status) (Low et al. 2007). Communication for behavior change strategies, including trials for improved practices, were used with mothers of young children to incrementally change consumption patterns and practices toward the inclusion of OFSP in the diet. A market communication strategy was also used, with murals at markets depicting the benefits of OFSP, kiosks where OFSP vines were available, and supported by radio programs, theatre, promotion materials, and development of new products such as "golden bread" (Low et al. 2005). The evidence from this study has since supported the expanded implementation of food-based approaches using OFSP to improving vitamin A status. It has thus been a key driver in ensuring that there is an effective sweetpotato seed system in place.

Building on the findings from the TSNI project, the HarvestPlus "Reaching End Users" project in Mozambique and Uganda (2006–2009), an integrated model was used to reach an estimated 22,000 HH (HarvestPlus 2010b). This included:

- Developing an OFSP vine distribution system, including subsidized vines to HH
- Providing extension to men and women in farm HH on OFSP production practices and marketing opportunities
- Providing nutritional knowledge, in particular about vitamin A deficiency, to women in these same HH
- Developing markets for OFSP roots and processed products made from OFSP roots.

In both countries, two dissemination strategies (with different intensities of extension visits) were implemented: a more intensive and costly "Model One" and a "lighter" "Model Two." The latter model was cheaper to implement, by about 30% in both countries. Yet, importantly, no differences in impact between Model One and Model Two on rate of adoption of OFSP, increase in vitamin A intakes, or other key metrics were found in either country. In this intervention, creating awareness and demand for the nutritional benefits of the crop "pulled" the seed system. The finding that there was no difference in adoption or vitamin A intakes between the different intensity dissemination strategies raises the question as to what intensity and coverage of demand creation are required to achieve sufficient mass of adopters that internal or existing diffusion practices take over (ibid.).

The “Marando Bora” project, which reached an estimated 110,000 farmers in Lake Zone, Tanzania, is one of the few examples where promotion messages included the benefits of using cleaned-up material of existing varieties. Branding, signboards, “market storms,” demo plots and field days, and posters and flyers were used to raise awareness about location of DVMs, varieties available, and the potential yield benefits of using disease-free material. The use of a voucher-based distribution system also contributed to encouraging farmers to try new varieties and the cleaned-up material of the existing varieties (SASHA 2012b).

10. Gaps in the literature and emerging areas of research

The current review has focused on SSA—in particular East, Central, and Southern Africa—with some information from West Africa. Information from the United States on root-based systems and experiences from Latin America and the Caribbean, China, and south Asia has not been included.

Emerging areas of research that were highlighted during the sweetpotato seed systems consultation in Nairobi (June 2012) (Ssemakula et al. 2012) were:

- Matching consumer preference and use (home consumption, different types of processing) with varieties and agro-ecological suitability
- Cost-effective mechanisms for the movement of material to link new varieties and/or fresh seed to farmers
- Developing appropriate and cost-effective systems for implementing QDPM and QDS inspection schemes
- Studies on the relationship of seed value chain with other segments in the sweetpotato value chain, and how this influences demand for vines and roots
- Understanding how differing institutional arrangements influence sustainability of the seed system.

11. Conclusions

The purpose of this review has been to assess our current knowledge of sweetpotato seed systems in SSA as a contribution toward identifying gaps and research needs to address the continuing challenge of ensuring that smallholder farmers can access timely and sufficient quantities of quality sweetpotato planting material. This is in the context of the RTB theme on seed systems, which aims to strengthen knowledge support systems for improved seed-related planning, investment, and implementation. Within this it is proposed to field test alternative approaches to RTB seed system improvements connecting biophysical, management, and socioeconomic factors, and to draw strategic guidelines for future interventions.

This review has only touched on the high diversity of contexts for sweetpotato seed systems, and a broad review of the biotic and abiotic factors and the socioeconomic and policy context. The initial findings from this review point to the highly contingent and emergent nature of sweetpotato seed systems in SSA. Therefore, any approach to model decision-making needs to be complemented by a process-oriented and participatory approach to be able to identify what mechanism might trigger a desired outcome and respond to local specificities.

Varieties need to respond to market demand (e.g., farmers, rural and urban consumers, traders, processors, and livestock fodder). It is critical to ensure that more genetic material is flowing through the system and evaluated under different agro-ecological and socioeconomic conditions. There is also the need to integrate the breeding and seed system, as both have and will continue to need substantial public sector involvement. Returns on investment in public sector breeding can be increased through linking and designing the two together (Lynam 2011).

Seed production opportunities are location specific in both a technical and economic sense, due to the influence of environmental conditions on production costs, seed quality, and market requirements (Cromwell, Friis-Hansen, and Turner 1992) This needs to be considered in assessing the most appropriate organizational structure and the functional integration between the farmer-based and formal seed systems for sweetpotato. The relative strength and importance of each will be context specific. Seed demand and seed needs are context and season specific, too, and a systematic but iterative planning process is needed that involves all stakeholders. The institutional linkages for sweetpotato seed systems are complex; they cross organizational mandates (research and extension) as well as administrative and geographical boundaries (district, AEZ, national). Organizational issues are normally dealt with at the individual multiplier or group level (organization of production, training, input source, marketing) and not necessarily at the seed system level. Recognition of and effective linkages among the different actors from public, private, and civil society in the seed system are essential for improved coordination, information flow, and trust. But owing to the current low prioritization of the crop, there is often a lack of clear coordination roles and communication channels.

The financial and social sustainability of sweetpotato seed systems needs to be built on an analysis of a wide array of context-specific factors. These comprise climatic and agro-ecological conditions and risks; pest and disease incidence; understanding of existing farmer seed practices; strong links to farmer and market demand (varieties, quality, quantities, and timing) for vines and roots; socioeconomic and gender constraints; and clear institutional arrangements to support coordination, information flow, and linkages between different actors in the seed and root value chains.

12. References cited

Abidin PE, Chipungu F, Mnjengezulu G. 2012. Sweetpotato Seed Systems: consolidating knowledge for improved practices and identifying new challenges. PowerPoint presented at the Sweetpotato Support Platform for East, Central and Southern Africa: Seed Systems Consultation Meeting held in Nairobi, Kenya, 7–8 June 2012.

Agili S. 2012. Yield Evaluation, Selection and Drought Tolerance Indices of Orange-Fleshed Sweetpotato (*Ipomea Batatas* LAM) Under Water Stress Conditions. PhD diss., Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya.

[AGRA] Alliance of a Green Revolution in Africa. 2012. AGRA in 2011—Investing in Sustainable Agricultural Growth: A Five-Year Status Report. Nairobi, Kenya.

Akoroda MO. 2009. Sweetpotato in West Africa. In: Loebenstein G, Thottappilly G, eds. *The Sweetpotato*. Springer Netherlands. p. 441–468.

Ames T, Smit NEJM, Braun AR, O'Sullivan JN, Skoglund LG. 1996. *Sweetpotato: Major Pests, Diseases, and Nutritional Disorders*. Lima: CIP.

Andrade M, et al. 2009. Unleashing the potential of sweetpotato in Sub-Saharan Africa: Current challenges and way forward. Working Paper 2009-1. Lima: CIP. 197 p.

[ASARECA] Association for Strengthening Agricultural Research in Eastern and Central Africa. 2011. Tracking successes in rationalization and harmonization of seeds policies in the region. Policy Analysis and Advocacy Programme. Entebbe: ASARECA. p. 14.

Badstue L, Adam R. 2011. Gender and Vines. Production, management and exchange of sweetpotato planting material among smallholders in the Lake Victoria Region, Tanzania. Technical Report. Nairobi: Helen Keller International.

Barker I. 2012. What do we know about virus degeneration and why does it matter? Presented at the Sweetpotato Support Platform for East, Central and Southern Africa: Seed Systems Consultation Meeting, Nairobi: CIP.

Bashaasha B, Mwanga ROM, Ocitti p'Obwoya, Ewell P. 1992. Sweetpotato in the farming and food systems of Uganda. In Akoroda A, ed. Proceedings of the *5th Triennial Symposium of the International Society for Tropical Root Crops–Africa Branch* held in Kampala, Uganda, 22–28 November 1992. p. 225–228.

Bashaasha B, Mwanga ROM, Ocitti p'Obwoya, Ewell P. 1995. Sweetpotato in the Farming and Food Systems of Uganda. A Farm Survey Report. Nairobi: CIP.

Benjamin M, David S. 2012. The impact of the Marando Bora Project communication strategy on knowledge, attitudes and practices related to sweetpotato among producers, consumers and policy makers in the Lake Zone of Tanzania, Helen Keller International.

Carey EE, Gibson RW, Fuentes S, Machmud M, Mwanga ROM, Turyamureeba G, Zhang L, Ma M, Abo EL-Abbas F, EL-Bedewy R, Salazar LF. 1999. The causes and control of virus diseases of sweetpotato in developing countries: is sweetpotato virus disease the main problem? CIP program report 1997-98, Lima: CIP. p. 241–248.

CIP. 2009. In vitro conservation of sweetpotato -OP26. Lima: CIP.

CIP. 2010a. Sweetpotato virus indexing procedure - OP23. Lima: CIP.

CIP. 2010b. Health status testing and virus elimination in sweetpotato - OP18.Lima: CIP.

CIP. 2010c. NCM-ELISA detection of sweetpotato viruses - OP21. Lima: CIP.

CIP. 2010d. Indicator plant diagnostic procedure - OP22. Lima: CIP.

CIP. 2010e. In-vitro multiplication of sweetpotato - OP59. Lima: CIP.

CIP. 2010f. Understanding How to Achieve Impact-at-Scale through Nutrition-focused Marketing of Traditional African Vegetables (TAV) and Orange-Fleshed Sweetpotatoes (OFSP) Final Report for Kilimo Trust. Annex A. Nairobi: CIP.

CIP and ASARECA. 2008. Dissemination of New Agricultural Technologies in Africa (DONATA). Transfer and dissemination of proven and emerging agricultural technologies in orange-fleshed sweet potato. Project proposal. Nairobi: CIP.

CIP and ASARECA. 2013. Dissemination of New Agricultural Technologies in Africa (DONATA). Transfer and dissemination of proven and emerging agricultural technologies in orange-fleshed sweet potato. Final Technical Report. Nairobi: CIP.

CIP and BMGF. 2009. Sweetpotato Action for Security and Health in Africa (SASHA) Project Proposal. Nairobi: CIP.

CIP and NRI. 2011. The Triple S System: Storage in Sand and Sprouting. Nairobi: CIP and N.R. Institute.

Clark CA, Davis JA, Abad JA, Cuellar WJ, Fuentes S, Kreuze JK, Gibson RW, Mukasa SB, Tugume AK, Tairo FD, Valkonen JPT. 2011. Sweetpotato Viruses: 15 Years of Progress on Understanding and Managing Complex Diseases. *Plant Disease* 96(2):168–185.

Cromwell E, Friis-Hansen E, Turner M. 1992. The Seed Sector in Developing Countries: A framework for performance analysis. ODI Working Paper. London: Overseas Development Institute.

CRS, ICRISAT, ODI. 2002. Seed vouchers and fairs: a manual for seed-based agricultural recovery after disaster in Africa. Nairobi: Catholic Relief Services; Nairobi: ICRISAT; and Westminster Bridge Road, London: ODI. 72 pp.

David S, Madu T. 2012. A Gender Situation Analysis of Sweetpotato Production in Nigeria: a report on preliminary fieldwork carried out in Nasarawa State. RAC Project. Nairobi: Helen Keller International and CIP.

[DFID] Department for International Development. 2000. The distribution of NASPOT and Tanzanian varieties in the Lake Zone of Tanzania. London: DFID, Natural Resources Institute (NRI).

DFID. 2003. Dissemination of high yielding Ugandan NASPOT varieties and orange-fleshed varieties of sweetpotato in Uganda 2001–2003. London: DFID and NRI.

Dodds JH, Panta A, Bryan JE. 1991. Transport, receipt and propagation of in vitro sweetpotato plantlets. Lima: CIP.

[DONATA] Dissemination of New Agricultural Technologies in Africa. 2013. Final Technical Report Nairobi: CIP.

Echabu S, Ekinyu E. 2012. Soroti Sweet Potato Producers and Processors Association (SSOSPA) Sweetpotato Seed Systems Experiences in Uganda. Presented at the Sweetpotato Support Platform for East, Central and Southern Africa: Seed Systems Consultation Meeting held in Nairobi, Kenya, 7–8 June 2012.

Elliot H. 2009. Partnership, Governance and Strategic Communication. In: M. Andrade et al., eds. Unleashing the potential of sweetpotato in Sub-Saharan Africa: Current challenges and way forward: Lima: CIP. p. 161–175.

Ethiopian Standards Agency. 2015. Quality Declared Seed (QDS) – Vegetatively propagated sweet potato Seed-Specification. ES 3924-18:2015. Addis Ababa: Ethiopian Standards Agency.

Ewell PT, Jeremiah SC, Kileo R, Kapinga RE. 1995. Sweetpotato in Tanzanian Farming and Food Systems: implications for research. Nairobi: CIP; Tanzania: Ministry of Agriculture.

[FAO] Food and Agriculture Organization of the United Nations. 2009. Quality declared planting material - protocols and standards for vegetatively propagated crops. FAO Plant Production and Protection Paper 195. Rome: FAO.

FAO. 2010. Quality declared planting material - protocols and standards for vegetatively propagated crops. FAO Plant Production and Protection Paper 195. Rome: FAO.

Federal Democratic Government of Ethiopia. 2012. Seed Proclamation (draft). Addis Ababa: Federal Democratic Government of Ethiopia.

Fuglie KO. 2006. Priorities for sweetpotato research in developing countries: results of a survey. Lima: CIP.

Fuglie KO. 2007. Research priority assessment for the CIP 2005-2015 Strategic Plan: projecting impacts on poverty, employment, health and environment. Lima: CIP. p. 105.

Fuglie KO, Zhang L, Salazar LF, Walker TS. 1999. Economic impact of virus-free sweetpotato planting material in Shandong Province, China. Lima: CIP.

Gaba V, Singer S. 2009. Propagation of Sweetpotatoes, *In Situ* Germplasm Conservation and Conservation by Tissue Culture. In: Loebenstein G, Thottappilly G, eds. *The Sweetpotato*. Springer Netherlands. p. 65–80.

Gibson RW. 2008. Review of sweetpotato seed systems in Africa, especially East Africa. University of Greenwich, UK: NRI.

Gibson RW. 2012. Degeneration due to viruses, virus free planting material and reversion in sweetpotato. Review for CGIAR Research Program on Roots, Tubers and Bananas. University of Greenwich, UK: NRI.

Gibson RW, Kreuze JF. 2015. Degeneration in sweetpotato due to viruses, virus-cleaned planting material and reversion: a review. *Plant Pathology* 64(1):1–15.

Gibson RW, Mwanga, ROM, Namanda S, Jeremiah SC, Barker I. 2009. Review of sweetpotato seed systems in East and Southern Africa. Working Paper 2009-1. Lima: CIP. 48 p.

Government of the Republic of Kenya. 2010. National Seed Policy. Nairobi: Ministry of Agriculture.

Grüneberg W, Mwanga R, Andrade M, Dapaah H. 2008. Challenge Theme Paper 1: Sweetpotato Breeding. In: M. Andrade et al., eds. Unleashing the potential of sweetpotato in Sub-Saharan Africa: Current challenges and way forward: Lima: CIP. p. 1–42.

Habumuremyi JMV. 2012. Company Ibyiwacu Ltd, Rwamagana District, Rwanda. Presented at the Sweetpotato Support Platform for East, Central and Southern Africa: Seed Systems Consultation Meeting held in Nairobi, Kenya, 7–8 June 2012

Hart D. 1991. Sweetpotato production practices in Maswa and Meatu districts in an on-farm study. Field Note No. 10. Netherlands, Tanzania/Netherlands Farming Systems Research Project, Lake Zone. District Agricultural Office, Maswa; Ukiriguru Research Institute, Mwanza and Royal Tropical Institute, Amsterdam.

HarvestPlus. 2010a. HarvestPlus statement on potential benefits of biofortification on nutritional status of populations. Washington, DC: HarvestPlus.

HarvestPlus. 2010b. Reaching and Engaging End Users (REU) with Orange-fleshed Sweetpotato (OFSP) in East and Southern Africa. Executive Summary of Final Report submitted to the Bill and Melinda Gates Foundation. Washington, DC: HarvestPlus.

[IFPRI] International Food Policy Research Institute. 2010. Seed system potential in Ethiopia: constraints and opportunities for enhancing production. Working Paper. Washington, DC: IFPRI.

Jeremiah SC, Kulembeka HP, Kanju E, Chirimi B, Amour R. 2007. The role of community based organizations, NGOs and farmers in technology transfer. Proceedings of the XIIIth Triennial Symposium of the International Society for Tropical Root Crops held in Arusha, Tanzania. p. 686–688.

Kapinga RE, Jeremiah SC, Rwiza EJ, Ree D. 2003. Trader and consumer criteria for selection of sweetpotato varieties. In: Rees Q, Oirschot V, Kapinga R, eds. *Sweetpotato Post-harvest Assessment: Experiences from East Africa*. University of Greenwich, UK: NRI.

Kimenye L, McEwan M, eds. 2014. Scaling up Dissemination and Adoption of Agricultural Technologies using Innovation Platforms-Lessons from Eastern and Central Africa. Entebbe: ASARECA.

Labarta R. 2009. Are small Sub-Sahara African farmers willing to pay for vegetative propagated orange fleshed sweetpotato planting material? Evidence from Central Mozambique. Selected paper prepared for the Agricultural & Applied Economics Association 2009 AAEA & ACCI Joint Annual Meetings held in Milwaukee, Wisconsin, 26–29 July 2009.

Loebenstein G, Thottappilly G, eds. 2009. *The Sweetpotato*. Springer Netherlands.

Longley C, Dominguez C, Saide MA, Leonardo WJ. 2002. Do farmers need relief seed? A methodology for assessing seed systems. *The Journal of Disaster Studies, Policy and Management* 26(4):343–355.

Louwaars NP, de Boef WS. 2012. Integrated Seed Sector Development in Africa: A Conceptual Framework for Creating Coherence Between Practices, Programs, and Policies. *Journal of Crop Improvement* 26(1):39–59.

Low JW, Arimond, M, Osman N, Cunguara B, Zano F, Tschirley D. 2007. A food-based approach introducing orange-fleshed sweet potatoes increased vitamin A intake and serum retinol concentrations in young children in rural Mozambique. *Journal of Nutrition* (137):1320–1327.

Low JW, Arimond, M, Osman N, Osei AK, Zano F, Cunguara B, Selemane ML, Abdullah D, Tschirley D. 2005. Towards Sustainable Nutrition Improvement in rural Mozambique: Addressing Macro and Micro-nutrient malnutrition through new cultivars and new behaviors: Key Findings Mozambique. (Available from http://fsg.afre.msu.edu/tsni/TSNI_FINDINGS1_TEXT_DONOR_REPORT.pdf)

Low J, Lynam L, Lemaga B, Crissman C, Barker I, Thiele G, Namanda S, Wheatley C, Andrade M. 2009. Sweetpotato in Sub-Saharan Africa. In: Loebenstein G, Thottappilly G, eds. *The Sweetpotato*. Springer Netherlands. p. 359–390.

Lynam J. 2011. Strategy for sustainable seed systems for Vegetatively Propagated Crops in Sub-Saharan Africa. Nairobi, Kenya. Prepared for Bill and Melinda Gates Foundation.

Makokha PS. 2012. Siwongo Processing Company Ltd—OFSP Seed Systems. Presented at the Sweetpotato Support Platform for East, Central and Southern Africa: Seed Systems Consultation Meeting held in Nairobi, Kenya, 7–8 June 2012.

Mayanja S, McEwan M, Obong Y, Manasseh R, Ndolo P, Lukonge E. 2012. Building sustainable market linkages through innovations platforms for technology adoption: Case studies from Uganda, Kenya and Tanzania. In: Okechukwu RU, Adebowale AA, Bodunde H, Eruvbetine D, Idowu M, Atanda O, Dipeolu A, Ayinde AI, Obadina AO, Sobukola OP, Adebayo K, Sanni LO, eds. *The roots (and tubers) of development and climate change: Book of Abstracts, conference programme*. The 16th Triennial Symposium of the International Society for Tropical Root Crops held in Abeokuta, Nigeria, 23–28 September 2012, p. 23–28.

McEwan MA. 2011. Field notes during monitoring visit to "Rooting out Hunger in Malawi with nutritious OFSP" project, Mulanje and Zomba Districts, Malawi. CIP.

McEwan MA. 2012. Field notes for study on farmer perceptions related to quality planting material, Lake Zone, Tanzania. CIP.

McEwan MA. 2012. Ready for the rains: What kind of socio-technical arrangements meet farmer demand for quality sweetpotato planting material in Sub-Saharan Africa? PhD proposal, Wageningen School of Social Sciences, KTI Chair, Wageningen University, Netherlands.

McEwan M, David S. 2012. Sweetpotato Action for Security and Health in Africa (SASHA) Marando Bora: Testing delivery systems for the distribution of quality sweetpotato planting material at scale. Case study material. Gender and Agriculture Community of Practice in Tanzania. Dar es Salaam, Tanzania.

McEwan MA, Namanda S, Lusheshannija D. 2012. Whose standards matter? Piloting Quality Declared Planting Material inspection guidelines for sweetpotato in Lake Zone, Tanzania. The 16th Triennial Symposium of the International Society for Tropical Root Crops held in Abeokuta, Nigeria, 23–28 September 2012.

McEwan M, Almekinders C, Abidin PE, Andrade M, Carey EE, Gibson RW, Naico A, Namana S, Schulz S. 2015. Can small still be beautiful? Moving local sweetpotato seed systems to scale in sub-Saharan Africa. In: Low J, Nyongesa M, Quinn S, Parker ML, EDS. *Potato and Sweetpotato in Africa. Transforming the Value Chains for Food Security and Nutrition*. Oxfordshire, UK: CABI. p. 289–310.

Namanda S, Gibson R. 2011. The Triple S System. Storage in Sand and Sprouting. Nairobi: CIP and NRI.

Namanda S, Amour R, Gibson RW. 2012. The Triple S Method of Producing Sweet Potato Planting Material for Areas in Africa with Long Dry Seasons. *Journal of Crop Improvement* 27(1):67–84.

Namanda S, Gibson R, Sindi, K. 2011. Sweetpotato Seed Systems in Uganda, Tanzania, and Rwanda. *Journal of Sustainable Agriculture* 35(8):870–884.

Namanda S, Gatimu R, Agili S, Khisa S, Ndyetabula I, Bagambisa C. 2015. Micropropagation and hardening sweetpotato tissue culture plantlets. A manual developed from the SASHA Project's experience in Tanzania. Lima: CIP. p. 39.

Nweke F, Akoroda MO, Lynam J. 2010. Seed Systems of Vegetatively Propagated Crops in Sub-Saharan Africa. A Situation Analysis. Prepared for Bill and Melinda Gates Foundation, Seattle, WA.

Oggema JN, Kinyua MG, Ouma JP, Owuoche JO. 2007. Agronomic performance of locally adapted sweetpotato (*Ipomoea batatas* (L) Lam.) cultivars derived from tissue culture regenerated plants. *African Journal of Biotechnology* 6(12):1418–1425.

Otazu O. 2013. Construction of a sand hydroponic module for clean potato and sweetpotato seed multiplication. Lima: CIP.

Potts MJ. 2006. Large-scale Deployment of Improved Sweet Potatoes in sub-Saharan Africa 2003-2006: Final Report to GTZ. Kampala: CIP.

PRAPACE. 2005a. The potato and sweetpotato sub-sector analysis. A review of sub-sector status, constraints, opportunities and investment priorities. Draft Final Report, Regional Potato and Sweetpotato Improvement Programme in Eastern and Central Africa. Kampala: ASARECA.

PRAPACE. 2005b. Strategic Research and Development Priorities for the ASARECA Potato and Sweetpotato Network (PRAPACE). Kampala: PRAPACE, ASARECA.

[SARI] Southern Agricultural Research Institute, [HARI] Hawassa Agricultural Research Centre Sweetpotato Team. 2012. Production of Quality Declared Planting Material (QDPM), Ethiopia. *Reference book for informal seed inspection system for sweetpotato vines*. Hawassa, Ethiopia. p. 19.

[SASHA] Sweetpotato Action for Security and Health in Africa. 2011a. SASHA Marando Bora Project Voucher System Operation Guideline. Mwanza, Tanzania: CRS.

SASHA. 2011b. Research Study. Validation of a Community Based Quality Declared Planting Material (QDPM) Inspection Scheme. Draft protocol for inspection of sweetpotato QDPM in Marando Bora Project. Nairobi: CIP.

SASHA. 2011c. A Guide for Mass Dissemination of Sweetpotato Planting Materials (Vines) in the Marando Bora Project. Mwanza, Tanzania: CRS.

SASHA. 2012. Year 3 annual technical report for Mama SASHA component. Nairobi: CIP.

SASHA. 2012a. Year 3 annual technical report for Marando Bora seed systems component. Nairobi: CIP.

SASHA. 2012c. Year 3 annual technical report for Rwanda Super Food component. Nairobi: CIP.

SASHA. 2012d. Mama Sasha Baseline Survey Report (Draft). Nairobi: CIP.

SASHA. 2013. Using Sweetpotato to Improve health and Incomes of Rural Households in Rwanda. Rwanda Super Foods Component. A Baseline Survey Report (Draft March 2013) Nairobi: CIP.

Schulte-Geldermann E, Agili S, Low J. 2012. Production and conservation of sweetpotato planting material using insect-proof net tunnels. Poster presented at the Sweetpotato Support Platform for

East, Central and Southern Africa: Seed Systems Consultation Meeting held in Nairobi, Kenya, 7–8 June 2012.

Schulte-Geldermann E, Agili S, Ndolo P, Low J. 2012. Net Tunnels to Protect Sweetpotato Planting Material from Disease: A Guide to Construct and Maintain Tunnels (SASHA). In: Low J, ed. Nairobi: CIP. p. 12. (Available from https://cgspace.cgiar.org/handle/10568/65696)

Sperling L, Cooper HD. 2003. Understanding Seed Systems and Strengthening Seed Security. Effective and Sustainable Seed Relief: A stakeholders' workshop. Rome: FAO.

Ssemakula G, Gorrettie S, Mwanga R, Tumwegamire S, McEwan M, Carey T. 2012. Workshop Report. Sweetpotato Support Platform for East, Central & Southern Africa: Seed Systems Consultation Meeting held in Nairobi, Kenya, 7–8 June 2012.

Stathers T, Benjamin M, Katcher H, Blakenship J, Low J. 2013. Everything You Ever Wanted To Know About Sweetpotato: Reaching Agents of Change ToT Manual 2: Orange-fleshed sweetpotato and nutrition. vol. 2. Nairobi: CIP. p. 92. (Available from http://cipotato.org/wp-content/uploads/2014/10/006192.pdf)

Stathers T, Namanda S, Mwanga ROM, Khisa G, Kapinga R. 2005. Manual for sweetpotato integrated production and pest management farmer field schools in sub-Saharan Africa. Kampala: CIP.

Tripp R. 1997. The Institutional Conditions for Seed Enterprise Development. Working Paper 105. Overseas Development Institute Working Paper. London: ODI.

United Republic of Tanzania. 2003. The Seeds Act. N. Assembly, United Republic of Tanzania. No.18.

Woldegiorgis DM. 2012. Minora Agricultural Investment Share Company: Experience from Tigray, Ethiopia. Presented at the Sweetpotato Support Platform for East, Central and Southern Africa: Seed Systems Consultation Meeting held in Nairobi, Kenya, 7–8 June 2012.

Woolfe JA. 1992. Sweet Potato: an untapped food resource. Cambridge, UK: Cambridge University Press.

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