EVANS SCHOOL OF PUBLIC AFFAIRS
UNIVERSITY *of* WASHINGTON
Evans School Policy Analysis and Research (EPAR)

*Prepared for the Agricultural Policy Team of the Bill & Melinda Gates Foundation*

# Agriculture-Environment Series – Sweetpotato & Yam Systems At-A-Glance

EPAR Brief No. 225 [Summary]

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**Table 1: Environmental Interactions in Sweetpotato & Yam Production Systems in Sub-Saharan Africa (SSA) and South Asia (SA).**

| | *Pre-Production* | *Production* | | *Post-Production* |
|---|---|---|---|---|
| Environmental Constraints | **LAND QUALITY**: Sweetpotato is often grown on waterlogged and acidified lands, or land otherwise unsuitable to grain crops, whereas yam requires relatively fertile soil. | **PESTS**: Sweetpotato weevil regularly causes yield losses up to 73%, and as much as 60-100% during times of drought. Nematodes, beetles and scaly bugs are serious yam pests in some areas of SSA. | **DISEASE**: Infection rates for sweetpotato virus in East Africa range from 10-94%. In one study sweetpotato feathery mottle virus was found in 100% of samples in Kenya. | **SHORT SHELF LIFE**: Sweetpotato roots are perishable and can become unmarketable after as little as 1-2 weeks. |
| Rank Importance | 4 | 2 | 1 | 3 |
| Adaptation Strategies | **EXPANSION:** In SSA, sweetpotato area harvested has increased from 1 to 3.3 Mha since 1980; yam area harvested has increased from 1.2 to 4.5 Mha. | **MANUAL AND CHEMICAL PEST CONTROL:** Hilling up earth to protect the crop and killing pests by hand have been employed to control pests in sweetpotato. Sweetpotato and yam farmers sometimes use pesticides to control insects. | **DISEASE RESISTANT VARIETIES**: Varieties resistant to sweetpotato virus widely grown.<br><br>**CLEAN CUTTINGS**: Using clean planting material can dramatically increase yields. | **LATE HARVESTING:** Storing sweetpotato in the ground, even after crops have matured, is a common practice in SSA. |
| Environmental Impacts | **SOIL NUTRIENT MINING:** Repeated cultivation of sweetpotato and yams on marginal soils depletes soil nutrients, reducing soil fertility. | **(+) REDUCED ENVIRONMENTAL STRAINS:** Reduced losses from pests could lead to reduced need for agricultural expansion and agrochemical use. | **(+) REDUCED ENVIRONMENTAL STRAINS:** Reduced losses from diseases could lead to reduced need for agricultural expansion and agrochemical use. | **(+) REDUCED ENVIRONMENTAL STRAINS:** Reduced storage losses could lead to reduced need for agricultural expansion. |
| Best Practices | **INTENSIFICATION:** Use of organic and inorganic fertilizers and higher yielding improved varieties can improve productivity and avoid expansion onto natural habitat. | **IMPROVED VARIETIES AND CLEAN SEED SYSTEMS**: Using deep-rooted varieties or early maturing varieties can reduce pest attack, as can the use of uninfested planting material. | **IMPROVED CULTIVARS AND CLEAN SEED SYSTEMS**: Developing disease tolerant varieties and improving local capability to produce clean planting material can increase sweetpotato and yam production. | **IMPROVED STORAGE**: Use of storage pits and clamps can reduce losses, as can improved marketing systems. |

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### Introduction

This literature review examines the environmental constraints to, and impacts of, sweetpotato and yam production systems in Sub-Saharan Africa (SSA) and South Asia (SA). The review highlights crop-environment interactions at three stages of the sweetpotato/yam value chain: pre-production (e.g., land clearing), production (e.g., soil, water, and input use), and post-production (e.g., waste disposal, crop storage and transport). At each stage we emphasize environmental constraints on production (e.g., poor soil quality, water scarcity, crop pests, etc.) and also environmental impacts of crop production (e.g., soil erosion, water depletion, pesticide contamination, etc.). We then highlight best practices for overcoming environmental constraints and minimizing environmental impacts in sweetpotato and yam production systems.

Table 1 summarizes the key environmental constraints and environmental impacts associated with sweetpotato and yam production in SSA and in SA. In reality, many crop-environment interactions are a matter of both cause and effect. For example, insect pests (an environmental constraint to sweetpotato) decrease yields, which may prompt farmers to use pesticides or biological pest control agents.  Both of these strategies to overcome pest constraints may increase the seriousness of future pest infestations, by killing off beneficial pest predators, or by exerting selective pressures that lead to the emergence of pesticide-resistant pests. Similarly, soil infertility is both an environmental constraint on sweetpotato and yam production (e.g., through poor soils) and a potential environmental impact of production (e.g. through nutrient mining). Responses to environmental constraints on crop production must therefore take into account environmental tradeoffs associated with different farm practices, and also recognize when short-term adaptations to constraints might exacerbate medium- or long-term environmental problems.

### Sweetpotato and Yam Production Systems

After cereals, root and tuber crops - including sweetpotato and yam (in addition to cassava and aroids), are the second most cultivated crops in tropical countries. Though different species, sweetpotato (*Ipomoea batatas*) and yam (*Dioscorea spp.*) are often grouped together for scientific study because they are vegetatively propagated, produce underground food, and are bulky and perishable (Lebot, 2009). Both are important food sources and are also used for animal feed (Larbi *et al.*, 2007).

In Africa, sweetpotato and yam are primarily grown by female smallholder farmers in polyculture systems on marginal lands (Ewell, 2011). Farmers in SSA typically cultivate sweetpotato in gardens or in small field areas ranging from 0.1 ha to 0.5 ha (Andrade *et al.*, 2009). The crop is favored because of low labor needs, low cost (no inputs) and lower risk than other crops (Low *et al.*, 2009).

East and West Africa currently account for 93% of African land use for growing sweetpotato, and East Africa produces as much as 62% of all sweetpotato grown on the continent, with a noteworthy cluster of sweetpotato production around Lake Victoria (CIP, 2010). In West Africa, major farming systems for sweetpotato include: (i) *root crop systems*, where livelihoods depend on yam, cassava, legumes, and off-farm work; and (ii) *cereal-root crop mixed systems*, where livelihoods depend on maize, sorghum, millet, cassava, yam, and cattle (Andrade *et al.*, 2009).

Yields for sweetpotato in East Africa average 5.3 t/ha, less than one-fourth the yield in China, the world's largest producer (FAOSTAT, 2012). Average yields across SSA range from 3-6 t/ha if water is limited, or up to 10-12 t/ha with adequate soil fertility and rainfall (Andrade *et al.*, 2009).For yam, West Africa accounts for fully 90% of global land area for production and 90% of total global harvests (CIP, 2010).

Regionally, South Asia is not a significant producer of either sweetpotato or yam compared to Sub-Saharan Africa. South Asia produces virtually no yam, and produces less than 5% o the sweetpotato that Africa produces (FAOSTAT, 2012). In India sweetpotato production is usually commercial: the southwest monsoon supports a rainfed *kharif* sweetpotato crop, while supplemental irrigation along with the northeast monsoon allows for a *rabi* season crop (Edison *et al.*, 2009). In the past sweetpotato was considered as a famine relief crop, and it played a pivotal role in alleviating the Bengal famine of 1942 (Nair, 2000).

**Pre-production of Sweetpotato and Yam**

Sweetpotato has a flexible growing season, allowing it to be grown anywhere from 3 to 10 months of the year in some countries (Ewell, 2011). The crop is also tolerant to a wide range of growing conditions (Edison *et al.*, 2009). It can be grown on a wide range of soils, but sandy, permeable soils high in organic matter are most suitable. It requires at least 500mm rainfall, and short days with low light intensity promote root development (*ibid*).

*Land Constraints*

One of the most binding constraints on any crop system is the availability of sufficient and suitable land to cultivate. Globally, agricultural area devoted to sweetpotato fell from 10.7 Mha in 1980 to 8.1 Mha in 2010 (FAOSTAT 2012). The decrease in global sweetpotato area may reflect changes in consumer preferences in developing countries like China, where sweetpotato is no longer a major staple crop except in poor, rural areas (Huaccho & Hijmans, 2000). On the other hand, over the same period, global area devoted to yam production increased from 1.4 Mha to 4.8 Mha. Some of this growth reflects the conversion of existing cropland from other crops to yam. The remaining growth in area harvested reflects conversion of non-agricultural land to agriculture. Yam is primarily an African crop. In 2010, cropland in Africa represented 95% of the global yam area (FAOSTAT, 2012).

Adaptations to Land Constraints

Adaptations to land constraints vary by region. In areas where land suitable for agricultural production is relatively abundant, such as Sub-Saharan Africa (Bruinsma, 2009), the dominant response to land constraints is conversion of forests, grasslands and other non-agricultural land to crops. In a study on agricultural land use in SSA using remote sensing, Brink & Eva (2009) found that from 1975-2000 land under agricultural cultivation in SSA increased by 140 Mha; during the same period natural forest and non-forest vegetation decreased by a combined 131 Mha, at an annual average rate of about 5 Mha per year. Agricultural expansion at the extensive margin (i.e., land-clearing) is particularly common when possibilities for intensification through irrigation and fertilizer use are limited (Barbier, 2004). In Africa, agricultural area devoted to both yam and sweetpotato production has increased in recent years. From 1980-2010, sweetpotato area harvested increased from about 1 Mha to 3.3 Mha; over the same period, yam area harvested increased from 1.2 Mha to 4.5 Mha (FAOSTAT, 2012).

In South Asia, sweetpotato area harvested has fallen, from 2.9 Mha in 1980 to only 1.5 Mha in 2010. Yam is rarely grown in SA. Due to the unavailability of land for agricultural expansion, more intensive use of available agricultural land, particularly crop rotation, has been a common response to land constraints in South Asian sweetpotato production. The common rotation followed in Orissa is maize-sweetpotato-fallow and rice-sweetpotato-fallow and in West Bengal is moong-taro-sweetpotato. In Andhra Pradesh, sweetpotato follows maize and is succeeded by a vegetable crop. A cropping pattern of maize-sweetpotato-wheat and maize-sweetpotato-onion has been suggested for Bihar. In Tamil Nadu, sweetpotato is followed by a cereal crop. In Chhattisgarh/ Uttar Pradesh/ Maharashtra, vegetable-cowpea-sweetpotato is the common sequence (Nair, 2000; Palaniswami & Chattopadhyay, 2005).

Environmental Impacts of Land Use

In SSA, sweetpotato is often grown as a secondary crop on marginal lands (Ewell, 2011; Low *et al.*, 2009). Although no impact estimate specific to yam or sweetpotato is available, research on marginal agricultural land use more broadly suggests that crop cultivation on the extensive margin can contribute to erosion, land degradation, and desertification (Geist *et al.*, 2004; Glantz, 1994).

Estimates of the environmental impact of sweetpotato production in SA are not available. However, available evidence suggests that in the multiple crop rotation farming systems in Northern India and Bangladesh, intensive crop cultivation has led to erosion, soil nutrient mining and other environmental consequences. Lal (2009) reported that the average rate of NPK soil depletion in twelve states in India was 80 kg/ha. Gupta & Seth (2007) attribute stagnating crop yields in the Indo-gangetic plains in part to soil micro-nutrient deficiencies of zinc, boron and sulfur as a result of long-term and intensive crop cultivation.

Best Practices for Land Use

When grown using traditional methods, both sweetpotato and yam are widely considered to be environmentally friendly, relative to cereal crops. They are easily inter-cropped and do not require a complete clearing of forest for planting, and are thus amenable to agro-forestry and other relatively sustainable land-use strategies. Their fast growth and dense foliage help reduce soil erosion, and both crops are often grown without chemical fertilizers or pesticide application, resulting in less pollution compared to grain crops (ASARECA, 2005). Additionally, using improved cultivars suited to local land conditions can yield large production gains, potentially obviating the need for land expansion.

## Production of Sweetpotato and Yam

*Disease Infection*

Sweetpotato is especially susceptible to viral infections, with over 15 known viruses reported (Valverde *et al.,* 2007; Carey *et al.,* 1997). The sweetpotato virus disease (SPVD) complex, caused by *sweetpotato feathery mottle virus* (SPFMV) and *sweetpotato chlorotic stunt virus* (SPCSV), represents the most destructive viral disease of sweetpotato in Africa and perhaps worldwide (Ateka *et al.*, 2005; Carey *et al.*, 1997). A recent survey sent to sweetpotato scientists in SSA also identified SPVD as one of the most important constraints to sweetpotato production (Fuglie, 2007). SPFMV was found in 100% of crop samples in a recent experiment in Kenya (Opiyo *et al.*, 2010).

In tropical environments vine cuttings are the main form of sweetpotato propagation and are a major source of SPVD (Fuglie, 2007). In Bihar, India, about 80–90% of vines are used as animal feed, while the remaining 10 to 20% are used as planting materials for the next season's crop (Edison *et al.*, 2009). Over time, vegetative propagation causes an accumulation of viruses in the planting material that can significantly reduce plant vigor and yield. Planting material is often affected by SPVD before even being planted (Oswald *et al.*, 2009). In areas with dry periods lasting more than 4 months, for example the mid-elevation region of East Africa surrounding Lake Victoria, SPVD pressure is particularly severe (Low *et al.*, 2009; Andrade *et al.*, 2009). SPVD infection rates range from 54-94% in Tanzania, 10-40% in central Uganda, and 83% in Rwanda (Barker *et al.*, 2009), while others have found yield losses due to SPVD infection as high as 80%-90% (Valverde *et al.*, 2007; Carey *et al.*, 1997). Yam is also susceptible to disease. Studies in both Nigeria (Agbaje *et al.*, 2005; Amusa *et al.*, 2003) and Ghana (Peters, 2000) identified the fungally-propagated disease anthracnose and yam mosaic virus as the most economically important yam diseases. Peters (2000) estimated that anthracnose caused severe yield losses (over 50%) in between 5-10% of Ghanaian yam farms. Yam mosaic disease was present in an estimated 50% of yam plants surveyed, but disease damage was widely variable both within and between regions.

Adaptations to Disease Constraints

*Sweetpotato*: Broadly, adaptations to sweetpotato disease constraints include:

- *Clean planting materials:* The use of disease-free planting material can reduce the impact of disease burden in sweetpotato production. Using clean planting material has been observed to increase yields between 56-84% in sub-Saharan Africa (Barker *et al.*, 2009).

- *Disease-resistant cultivars*: Cultivars resistant to the sweetpotato virus disease (SPVD) are available and are already widely grown (Barker *et al.*, 2009). Many of the sweetpotato varieties grown in East Africa are local landraces, which, although lower yielding than non-native strains, are between 25-30% more disease-resistant (Valverde *et al.*, 2007).

There are a number of methods to reduce the prevalence of viral infections in sweetpotato planting material. Selecting vines which do not have viral infections based solely on visual inspection has enabled some farmers in southern Uganda to keep the rate of infection in their crops to below 20% (Theisen, 2006). Gibson *et al.* (2004) reported that isolating or removing diseased cuttings within one month after planting considerably reduced SPVD occurrence in African field trials.

Creating local, clean-vine production systems has also had some success reducing the impact of SPVD in both Asia and SSA. From 1994-1998 in Shandong, China, virus-free planting material was multiplied, distributed and planted on 80% of provincial sweetpotato acreage. A widely cited benefit-cost analysis of the project indicated that the adoption of virus free planting material increased sweetpotato yields by 30-40%. Over the period, the net present value of the vine dissemination program was estimated at USD$550 million, increasing the income of the province's seven million, largely smallholder, sweetpotato growers by an average of 3-4% (Fuglie *et al.*, 1999).

Similar clean vine dissemination efforts have also shown some success in SSA. The German Agency for Technical Cooperation recently piloted a number of clean seed dissemination programs, using a number of institutional mechanisms, in Kenya, Uganda, Tanzania and Ethiopia. The results of the experiment suggested that a number of institutional arrangements, including commercial vine multipliers, NGO extension, farmers associations, and small scale entrepreneurship, had some success in large-scale healthy vine dissemination. The price of improved vines was the major factor in determining success of the dissemination effort (Barker *et al.*, 2009).

Although some non-native sweetpotato varieties are higher yielding than local African landraces, they are also often more susceptible to SPVD, negating potential yield gains (Valverde *et al.,* 2007). High-yielding and disease-resistant varieties may allow farmers to increase yields, while controlling disease outbreaks. In field trials in Uganda, some, though not all, improved varieties bred for yield and disease resistance outperformed local landraces (Gibson *et al.*, 2004).

*Yam:* Although the literature on disease management strategies for yam is thin, common strategies to control anthracnose and yam mosaic disease are similar to those employed for disease control in sweetpotato and include:

➢ *Clean planting material:* A three year study in Ghana found that clean planting material produced between 28%-61% higher yields than non-clean cuttings, depending on the yam variety (Peters, 2000).

➢ *Disease-resistant cultivars:* Yam cultivars resistant to anthracnose exist, and have been advocated to control yam yield losses in Ghana and Nigeria (Amusa *et al.*, 2004; Peters, 2000).

➢ *Planting timing*: Recent field trials in Nigeria found that later yam plantings (in June or July) had a higher incidence of anthracnose than yam plantings planted in April or May; plantings in August had the lowest prevalence of anthracnose (Egesi *et al.*, 2007).

Environmental Impacts of Disease Management

There are no quantified environmental impacts of using clean planting materials or improved cultivars that emerge from the literature. The most direct environmental impact of using clean or improved cultivars is likely the beneficial impact from decreased losses of the primary crops that would otherwise be greater if infected yam and sweetpotato planting material were used.

Best Practices for Sweetpotato and Yam Disease Management

Best practices for managing disease in yam and sweetpotato come from FAO, the International Potato Center (CIP) and the International Institute of Tropical Agriculture (IITA) and include:

➢ *Development of improved varieties*: CIP, among others, advocates the development of disease resistant sweetpotato cultivars to overcome disease constraints. Genetic improvements could increase sweetpotato yields throughout Africa by 3-40% compared to healthy local landraces (Andrade *et al*., 2009). The IITA advocates for the development of disease resistant varieties to boost African yam production (IITA, 2012).

➢ *Clean planting material production*: The FAO and CIP advocate increased local production of disease free planting material to increase sweetpotato and yam production (FAO, 2007; Barker *et al*., 2009). CIP conservatively puts the yield gains for sweetpotato from using healthy planting material at 30-50% throughout Africa (Andrade *et al*., 2009).

*Crop Pests*

Globally, the sweetpotato weevil is the most serious sweetpotato field pest, though much weevil damage also occurs to tubers in storage (Ames *et al.*, 1997; Chalfant *et al.*, 1990). Historically, the weevil has caused yield losses of up to 73% in Eastern Africa (Smit, 1997), and 60-100% during times of drought (CIP, 2010). Based on a global survey of sweetpotato experts, sweetpotato weevil was the pest identified most frequently as constraining production in Africa; in Asia, it was also among the most frequently cited (Fulgie, 2007). The CIP estimates that weevils cause average yield losses of 20%, or 198 kg/ha in Burundi, DR Congo, Rwanda, and Uganda (CIP, 2011).

A number of other sweetpotato pests are also of economic importance in some areas. In East Africa, sweetpotato leaf-feeding insect species can cause serious problems during large outbreaks, although these generally occur only sporadically, generally at the beginning of the dry season (Skoglund & Smit, 1994). Stemborers are serious sweetpotato pests in tropical and subtropical Asia, with infestation during crop establishment sometimes leading to losses of 30-50% or more (Ames *et al.*, 1997). Cutworms, hairy caterpillar and crickets cause minor losses in Bangladesh, and rats can also pose a threat (CIP, 1989).

Data on the impact of yam pests is limited, but available information suggests that the seriousness of yam pests varies by region. In surveys conducted in the intensive yam-growing regions of Nigeria, farmers reported that insects were the most important yam pests, with the yam tuber beetle, scale insects and termites the most commonly reported insect pests (Lebot, 2009). Another Nigerian study reported that yam nematodes were the most serious yam pest (Agbaje *et al.*, 2005). In a study by the Department for International Development (DFID), yam farmers from two different regions in Ghana ranked termites and mealybugs as the two most serious yam pests (Peters, 2000).

Adaptations to Crop Pests

*Sweetpotato*: Adaptations to control crop pests in sweetpotato include the following:

➢ *Traditional pest control:* CIP evaluated the effectiveness of global sweetpotato weevil control methods based on farmer field trials in Asia and Africa and reported that a number of traditional crop management practices had shown some effectiveness, including hilling earth and early harvesting and mulching (Stathers *et al.*, 2005). Another strategy is uprooting and killing pests by hand (Ebregt *et al.*, 2004).

➢ *Chemical and biological controls:* In areas that are prone to weevils, vines may be dipped in insecticide prior to replanting, although this generally only delays weevil infestation by a few months (Lebot, 2009; Stathers *et al.*, 2005). According to a study by Ebregt *et al.* (2004), 55% of farmers in northeastern Uganda use pesticides to control weevils and other pests. Traps employing weevil sex pheromones have shown some success in reducing weevil damage in Asia (Lebot, 2009). A study in Taiwan found that use of sex pheromone baited traps reduced damage by 57%-

65%; when combined with pesticide application results improved to a 62%-75% reduction (ibid).

- *Improved varieties*: Efforts to engineer weevil resistance in sweetpotato have been largely unsuccessful to date (CIP, 2011; Lebot, 2009; Stathers *et al.*, 2005). However, some traditional sweetpotato varieties do have low levels of natural resistance to weevil attack (Stathers *et al.*, 2003a & 2003b). Furthermore, varieties that have deeper root systems are less vulnerable to attack by weevils; early maturing varieties can also facilitate earlier harvests and less damage (Stathers *et al.*, 2005).

- *Site selection, intercropping and rotation:* Selecting sites clean of weevil infestation reduces pest susceptibility. Site cleaning (e.g., burning infected plant material) and crop rotation are all strategies that farmers have employed to mitigate weevil damage (Stathers *et al.*, 2005). Intercropping and other practices to increase the prevalence of natural weevil enemies can also decrease weevil damage (Stathers *et al.*, 2005; Chalfant *et al.*, 1990).

Mounds of earth placed around sweetpotato roots to fill in cracks have worked well in controlling weevils in both East Africa and India. Early sweetpotato harvesting has also been employed to avoid losses in East Africa, Vietnam and the Philippines. Harvesting two weeks early led to a reduction in weevil losses of between 5%-30% in Vietnam, and also showed good results in other locations. Applying mulch soon after planting reduced weevil damages in both East Africa and India, and also improved soil moisture retention. Irrigation and field flooding, which keeps the earth from cracking thus reducing accessibility by weevils, also reduced weevil in some parts of Asia (Stathers *et al.*, 2005: Ames *et al.*, 1997).

*Yam:* Data on adaptation strategies for yam pest constraints are scarce. Available strategies to control pest constraints in yam production are broadly similar to those used for sweetpotato and include:

- *Traditional pest control:* Coating of yam tubers with wood ash before planting is a traditional practice in Nigeria that can facilitate growth in the presence of the yam nematode *Scutellonema bradys*, without actually controlling the nematode; apparently a means of preventing insect damage. One alternative adaptation in Nigeria is using leguminous cover crops to control the yam nematodes (Agbaje *et al.*, 2005). Incorporating cattle manure into yam mounds before planting increases yields and significantly decreases nematode populations (Bridge *et al.*, 2005). Rotations with paddy and cowpea have been shown to reduce the incidence in India (CIP, 1989).Production practices involving intercropping with okra, maize, melon, sorghum, or cassava increase nematode pressures on yam (Agbaje *et al.*, 2005).

- *Chemical controls:* Peters (2000) reported that pre-planting treatments of yam planting material was used for pest control in Nigeria.

<u>Environmental Impacts of Pest Management</u>

Although estimates on the impact of pesticide use specific to sweetpotato in SA or SSA are not available, previous studies of other crops suggests that the use of pesticides can lead to a number of negative environmental outcomes including the destruction of beneficial insect species that control rice pests (Pimental, 1992), harm to non-target bird and fish species (Cagauan, 1995), and acute poisoning and other negative health impacts in communities where pesticides are not optimally applied (Gupta, 2012). Pesticide use has also led to the increased prevalence of pesticide resistant insects and herbicide resistant weeds (Pimental, 1992).

In SSA, especially given the cluster of sweetpotato production around Lake Victoria, and the reliance of local populations on the lake for water and fish, pesticide runoff could have severe consequences. High levels of pesticide-related persistent organic pollutants (POPs) have already been found in the Nzoia River basin (Twesignye *et al.*, 2011).

<u>Best Practices for Pest Management</u>

*Sweetpotato:* Best practices for pest management according to CIP and FAO broadly include:

- *Prevent primary infection by pests:* Weevil larvae are often spread through seed that is not properly sanitized (Barker *et al.*, 2009), or because larvae is already present on the sweetpotato land from previous plantings (Strathers *et al.*, 2005). Clean seed systems, site selection and field sanitation can help reduce weevil prevalence in the field (FAO, 2007), as can Integrated Pest Management (IPM) practices such as hilling up soil and the use of deep-rooted varieties (Low *et al.*, 2009).

- *Resistant varieties:* Developing improved sweetpotato varieties remains an attractive and potentially environmentally sustainable option for controlling sweetpotato weevil. CIP ranks the development of BT sweetpotato as one of its top research priorities for SSA (CIP, n.d.).

*Yam:* Information on controlling yam pests is limited, but suggests best practices for pest control include:

- *Prevent primary infection:* Researchers recommend the planting site be tested for the presence of the pathogen prior to planting pests (Amusa *et al.*, 2003). Additionally, crop rotation, the use of pesticides, and dipping planting materials in Nemacuron can all prevent the presence of pests (Amusa *et al.*, 2003). FAO (2007) recommends the development of clean seed systems for yam to reduce pest and disease infection. In Nigeria, Increasing the length of the fallow period has led to decreased infection rates of nematodes in yam (Agbaje *et al.*, 2003).

*Weeds*

Both sweetpotato and yam are susceptible to competition from weeds, particularly in the early months after planting. Early studies by Oerke *et al.* (1994) found yam crop losses due to weeds could be as high as 70-91%. A study by Ampong-Nyarko (1994) estimated potential yield reductions due to weed competition at between 40-90% for yam, and up to 90% for sweetpotato. Sweetpotato faces weed problems only during the first few months of growth. After this period, vigorous growth of the vines causes rapid and effective coverage of the ground surface and smothers the weeds present (Iyagba, 2010; Lebot, 2009). As a result, many sweetpotato farmers in Nigeria do not bother to weed sweetpotato plots (Iyagba, 2010).

Adaptations to Weeds

Literature on weed control in sweetpotato and yam is limited. Broadly speaking, the following strategies have been used by smallholder farmers in SSA and SA:

- *Hand weeding:* A study by the FAO (2005) on farm power in SSA reported that weeding in major SSA cropping systems is done primarily by hand. Although agrochemicals are more widely used in South Asia, a large proportion of smallholder farmers still do not use chemicals or machines for weed control, implying that hand weeding is the primary means of weed control available (Devendra & Thomas, 2002).

- *Intercropping:* Studies in Nigeria reported that intercropping yam with melon (Iyagba, 2010) or legume species (Ikeorgu *et al.*, 2007) reduced the prevalence of weeds on yam plots.

- *Chemical controls*: Although the use of herbicides to control weeds has long been the dominant strategy in the developed world, adoption of these technologies in Africa remains low. However, glyphosate application is becoming increasingly common to clear soil of weeds prior to planting as part of tuber production in Nigeria (Iyagba, 2010). In the rice-wheat cropping system of SA, herbicides are also more widely used (Balasubramanian & Hill, 2002), although estimates of herbicide use among smallholder sweetpotato farmers are not available.

Environmental Impacts of Weed Management

Estimates of environmental impacts of weed control specific to sweetpotato are not available for either SSA or SA. However, research on other crops indicates that overuse of herbicides for weed control has led to increased prevalence of herbicide tolerant weed varieties (e.g., Powles, 2008). In SA, a number of organizations have advocated the use of zero-tillage systems to maintain soil fertility and reduce erosion (Hobbs *et al.*, 2002), which might increase the prevalence of weeds if soil tillage is the primary method of weed control. However research has found that zero-tillage systems combined with herbicide use actually reduced the prevalence of weeds in some cases compared to traditional weed control (Erenstein & Laxmi, 2008).

Best Practices for Weed Management

Best practices for sweetpotato and yam weed management according to CIP and Akobundo (1987) include proper timing of weeding and judicious use of herbicides. Due to a relatively short window of weed vulnerability, chemical weed control has long been considered a promising avenue for sweetpotato (Akobundu, 1987). A 2005 CIP manual on pest control advocated the use of glyphosate or other broad spectrum herbicides for weed control, but also points out that herbicide may not be feasible for many small-scale farmers (Stathers *et al.*, 2005). In areas where herbicide is not feasible, traditional methods such as hand weeding may be the most practical method of controlling weeds.

*Drought*

*Sweetpotato:* Sweetpotato is susceptible to drought in areas with a prolonged dry period. In a survey of farmers in Tanzania, Uganda, and Rwanda, drought was identified as the largest production constraint (Fuglie, 2007). Water availability also has a large impact on the availability of sweetpotato planting material. In drought prone regions of Africa, the area planted to sweetpotato is heavily constrained by a limited availability of vines at the most appropriate planting times (Namanda *et al.*, 2011). Sprouting from unharvested roots begins only with the onset of the rains. Hence, in dry areas valuable time is lost while farmers wait to accumulate sufficient planting material and, as a consequence, planting too late to maximize yield is the norm (ibid).

*Yam:* Literature on the impact of drought on yam is limited. Lebot (2009) reported that yam is generally considered drought tolerant, and are planted during the dry season in most countries. Generally, the internal moisture content of the tuber is sufficient to initiate root growth, even under dry conditions, although yields may be adversely affected (Ibid).

Adaptations to Drought Constraints

*Sweetpotato:* In drought prone areas of Africa, farmers use a number of strategies to find planting material for use in the dry season including the following:

- *Volunteer crops:* Volunteer crops, or vines that were overlooked during the harvest, often provide planting material in some East African countries at times when other planting material is unavailable, although the use of volunteer crops generally results in late planting as they do not emerge until the first rains (Namanda, *et al.*, 2011).

- *Irrigation:* The use of small scale irrigation can increase the availability of cropping material at appropriate planting times, ultimately increasing production (Low *et al.*, 2009). Famers in Tanzania sometimes use nearby swampland or flooded rice paddies to increase the availability of vines (Namanda *et al.*, 2011).

In SA, adaptations to drought have focused on increasing yield under dry conditions.

- *Irrigation:* Use of irrigation can increase sweetpotato yields. In a study in Tamil Nadu, Goswami *et al.* (1995) reported that irrigating three times during the growing season increased yields by 24% over non-irrigated sweetpotato crops. Crossman *et al.* (1995) reported that irrigated sweetpotato produced almost twice as much yield (8.1 tons/ha) than rainfed sweetpotato(4.4 tons/ha).

- *Yam:* No literature on yam adaptation to drought is available.

Best Practices for Drought Management

Best practices for drought management in sweetpotato include (Fuglie, 2007; Namanda *et al.*, 2011; Low *et al.*, 2009):

- *Drought-tolerant varieties: Developing or selecting more drought-tolerant sweetpotato varieties could help mitigate the impact of soil water scarcity (Low et al., 2009) and was identified as a breeding priority during a survey of international sweetpotato experts (Fuglie, 2007). Setting sweetpotato testing protocols to aid in plant breeding can make selection more efficient (Gruneberg et al., 2004).*
- *Irrigation: Small-scale dry season irrigation could increase the availability of sweetpotato planting material and ultimately increase sweetpotato production (Low et al., 2009). In areas without irrigation, swamplands or rice paddies may provide a means of maintaining sweetpotato planting supply in the face of water constraints (Namanda et al., 2011).*

*Yam:* Best practices for yam are not available at the writing of this brief.

*Soil Fertility Constraints*

Although sweetpotato is considered a low-input crop and is often grown as a no-input crop (Andrade *et al.*, 2009), soil fertility is a major concern as repeated cropping of sweetpotato removes nutrients from the soil, adversely affecting subsequent yields (Lebot, 2009). Similarly, soil fertility was the most frequently identified constraint among yam growers in the more intensive producing regions of West Africa (*ibid*). Intercropping yam with maize or cassava extracts high levels of nitrogen from the soil due to intense competition for nitrogen among the three crops (Agbaje *et al.*, 2005). Yam yields in southwestern Nigeria decreased by more than 50% between 1995 and 2000 because of declines in soil fertility (*ibid*).

In SA sweetpotato production, soil fertility is also a serious constraint (Edison *et al.*, 2009). Estimates of the yield gap attributable to soil fertility in SSA and SA are not available. In India, production is similarly hindered by low soil quality and a lack of plant nutrients (Edison *et al.*, 2009). As sweetpotato removes large quantities of plant nutrients, incorporating considerable amounts of organic manure at planting has been recommended to maintain soil health.

Adaptations to Soil Fertility Constraints

Adaptations to soil fertility constraints in yam and sweetpotato are similar and include:

- *Fertilizer use:* The use of fertilizer and irrigation is not common in sweetpotato cultivation in SSA (Oswald *et al.*, 2009). A study in Nigeria found that 88% of sweetpotato farmers do not use fertilizer, and when they do, it is applied incorrectly (Adewumi & Adebayo, 2008). In Tanzania only 5% of households use inorganic fertilizer on sweetpotato (Low *et al.*, 2009). Meanwhile 60% of farmers growing yam in Nigeria used NPK[1] chemical fertilizers that resulted in increased yam yields (Agbaje *et al.*, 2005). The planting of leguminous cover crops by farmers to increase soil fertility has also been reported (Ibid).

Andrade *et al.* (2009) estimate yield gains through improved management of local sources of nutrients can exceed 60%, without the introduction of inorganic fertilizers. In India, fertilizer use is common in non-fertile growing conditions, however plants utilize only 40–50% of applied nitrogen in the form of urea and the rest of the is lost through leaching, volatilization and denitrification (Edison *et al.*, 2009). Such low efficiency of utilization can be improved by modifying the urea to release nitrogen in a regulated fashion throughout the growing season (Nair, 2000). Furthermore, excessive nitrogen application can result in profuse leaf production at the expense of root yield (Edison *et al.*, 2009).

Sweetpotato does not require large quantities of phosphate for root development, and little research has been conducted on the response of sweetpotato to phosphate fertilizers in India (Edison *et al.*, 2009). Other micronutrients such as boron and magnesium also matter; zinc is now regarded as

[1] NPK fertilizers contain nitrogen, phosphorous and potassium.

the third most important limiting nutrient element in crop production after nitrogen and phosphorous (Gupta, 1995).

- *Intercropping:* Intercropping yam with legumes increased soil fertility and yield in a study in Nigeria, particularly if combined with inorganic fertilizer use (Ikeorgu, 2007). Leguminous cover crops generally have positive environmental impacts as they add to the nitrogen content of soils (Agbaje *et al.*, 2005). Field trials in Orissa, India have shown intercropping sweetpotato with pigeonpea can increase soil quality, water retention and tuber yields under rainfed conditions (Nedunchezhiyan, 2011).

<u>Environmental Impacts of Nutrient Management</u>

The negative effects of fertilizer runoff have been well-documented; however, there are no quantified effects in the literature of fertilizer runoff from applications to sweetpotato and yam in Africa.

<u>Best Practices for Nutrient Management</u>

Best practices for soil nutrient management include:

- *Fertilizer use:* Applied fertilizer and manure can be advantageous to sweetpotato production. Applying 5 Mt/ha of poultry manure can raise yields by 43% (Agbede & Adekiya, 2011). Added nitrogen levels of between 40-80 kg/ha from inorganic fertilizers can raise sweetpotato yields in Nigeria to 27.2 Mt/Ha and 24.8 Mt/Ha for white-fleshed and orange-fleshed cultivars, respectively (Okpara *et al.*, 2009). For Nigerian yam production, the production of organic fertilizer from crop residues such as cassava peels, yam peels, maize crops, and animal dung increases yam yields (Agbaje *et al.*, 2005).

- *Improved varieties:* In a survey of international sweetpotato experts, developing varieties adapted to acidified and water-logged soils was one of the identified priorities (Fuglie, 2007). Breeding is underway in India to increase salt tolerance, improve yield for fodder, and increase Vitamin A content (Attaluri *et al.*, 2010).

**Post-production of Sweetpotato and Yam**

*Short Shelf Life*

Sweetpotato is the world's seventh most important food crop but its potential to contribute to food security and income is limited in tropical countries by its short shelf-life (Kihurani *et al.*, 2012). Roots are perishable and either rot or become non-marketable after 1-2 weeks (Thiele *et al.*, 2009). A report by Opara (1999) reported post-harvest losses of yam ranging from 10-60%, depending on the period of storage.

<u>Adaptations to Storage Constraints</u>

*Sweetpotato:* There is little use of pits, clamps, or other storage techniques throughout SSA (Stathers *et al.*, 2005) for fresh and processed storage products. Current adaptations to storage constraints include:

- *Traditional storage:* Storage of sweetpotato in pits in Uganda can prevent rot for up to 4 months (Hall & Devereau, 2000). Although time intensive, drying sweetpotato can allow for a storage period of between 4-6 months; however dried sweetpotato is still susceptible to damage from storage pests (Theisen, 2006).

- *Late harvesting:* Due to limited storage options, many farmers leave sweetpotato in the ground until long after the crop has matured, resulting in relatively lower losses in yield quantity or quality (Stathers *et al.*, 2005). The ideal harvest time depends on the variety and on whether production is for forage or for tubers (Larbi *et al.*, 2007). Piecemeal harvesting is also common – whereby the most disease-susceptible parts of the potato are eaten first, and the rest of the crop remains stored in the ground for up to six months after the harvest (Low *et al.*, 2009).

*Yam:* Broadly speaking, adaptations to post-harvest constraints in yam are similar to those used for sweetpotato and include:

- *Traditional storage:* In the main yam producing regions of Africa, farmers typically use traditional storage methods, including yam-barns, clamps and pit storage (Opara, 1999).

<u>Environmental Impacts of Post-Harvest Management</u>

No quantified environmental impacts of storage methods emerge from the literature. However, reducing post-harvest losses would decrease the pressure for agricultural expansion.

<u>Best Practices for Crop Storage</u>

Best practice for crop storage of yam and sweetpotato include:

- *Careful handling*: In general careful handling of sweetpotato tubers during harvest and transit to avoid unnecessary wounding is recommended for reducing the intensity of fungal diseases. Proper curing of the tubers and use of safe protective fungicide and improving the storage conditions can also help in reducing the incidence of storage diseases (Edison *et al.*, 2009).

- *Clamp and pit storage:* CIP recommends the use of pit and clamp storage as well as improved packaging and transport to reduce sweetpotato post-harvest losses (Stathers *et al.*, 2005).

➢ *Sanitation:* Treatments of yam tubers with insecticide dust decreased both fungal infections post-harvest as well as physical damages acquired during harvest (Amusa *et al.*, 2003). Post-harvest losses from storage are relatively lower if clean planting materials are used from the start (Akoroda, 2009).

**Climate Change Impacts**

Climate change has the potential to adversely affect sweetpotato and yam production in SSA and SA, due to decreased rainfall and drier conditions (Srivastava et al., 2012). There have been few studies to date that quantify this impact, but many of those that do suggest climate change may impact these crops more severely than other staple crops. Ringler et al. (2010) predict climate change impacts on crop yield in SSA in 2050, and suggest that sweetpotato and yam yields will decrease by approximately 14%. In comparison, the study projects wheat yields to decrease by more than 20%, but cassava, maize, and rice yields to decrease by less than 10% and millet and sorghum yields to increase slightly. Lobel et al. (2008) projected production impacts from climate change in 2030 by region, and suggested that in West Africa yam yields face a median decrease of approximately 5%, which is slightly less severe than groundnuts but slightly more severe than the other major crops examined, including maize, rice, wheat, and cassava. Srivastava et al. (2012) predict a decrease in yam yield in Benin of 18-48% by 2050, depending on the soil type and scenario.

Conversely, other researchers suggest that sweetpotato and yam may be relatively resilient to climate change, and could fill the gaps left by declining production in other crops. According to this view, this is because sweetpotato and/or yam provide good yields in marginal climatic and soil conditions and are tolerant of extreme temperatures and dry seasons. (Thornton, 2012; Kyamanywa et al., 2011; Claessens et al., 2010; Bagambda et al., 2012; Paeth et al., 2008).

**Conclusion and Overall Best Practices**

Sweetpotato and yam face similar environmental stressors. In particular, because sweetpotato and yam are vegetatively propagated, the most significant (and avoidable) environmental constraints to crop yields include disease and pest infection transmitted through the use of contaminated planting materials. Published estimates suggest yield gains in the range of 30–60% can be obtained through using healthy planting material (Clark & Hoy, 2006; Fuglie *et al.*, 1999; Gibson *et al.*, 2004; Karyeija *et al.*, 1998). Moreover, reducing pest damage in the field can greatly increase the storage life of root and tuber crops after harvest – currently losses from rot and desiccation can claim up to 100% of stored sweetpotato and yam on smallholder farms.

**Methodology:**

This literature review was conducted using databases and search engines including University of Washington Library, Google Scholar and Scopus, as well as the following websites: CIP, World Bank, UNFAO, UNEP, Millennium Ecosystem Assessment, FAOSTAT and IPCC. Searches used combinations of the following terms: sweetpotato, yam, environment, environmental, environmental impacts, developing world, Sub-Saharan Africa, South Asia, rain-fed agriculture, emissions, biodiversity, water, water resources, water quality, irrigation, soil, land, natural resource use, climate change, global warming, air pollution, smallholder, sustainability, Ipomoea, Diascorea. The methodology also included searching for sources that were identified as central works and examining relevant lists of works cited. This literature review draws upon over 50 cited sources, and relied in equal parts on peer-reviewed publications and data and publications from major international organizations, especially FAO and CIP.

*Please direct comments or questions about this research to Leigh Anderson and Mary Kay Gugerty, at eparx@u.washington.edu.*



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