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Evans School Policy Analysis and Research (EPAR)
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Agriculture-Environment Series:
Cassava Systems At-A-Glance

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C. Leigh Anderson and Alison Cullen

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

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Table 1: Crop-Environment Interactions in Cassava Production Systems in Sub-Saharan Africa (SSA) and South Asia (SA)

	Pre-Production	*Production*		*Post-Production*
Environmental Constraints	**LAND CONSTRAINTS:** Since 1975, cassava area harvested has steadily increased to 13 Mha in 2011 in SSA, but decreased to 0.25 Mha in SA.	**PESTS and DISEASE:** Cassava mosaic disease, cassava brown streak disease, and several pests have severely damaged cassava crops throughout SSA and are an emerging threat in SA.	**DROUGHT:** Severe water stress can reduce cassava yields by 32-60%. **SOIL FERTILITY:** Cassava yields are constrained by low soil fertility, though less so than many other crops.	**SHORT SHELF LIFE:** Without proper storage or processing, cassava begins to deteriorate in as little as two to three days after harvest.
Rank Importance	**6**	**DISEASE=1, PESTS=2**	**DROUGHT=3, SOIL=4**	**5**
Adaptation Strategies	**EXPAND or INTENSIFY:** Cassava continues to expand in SSA, often as a last-resort crop on depleted fields. Production has intensified in SA with input use.	**IMPROVED VARIETIES:** Disease- and pest-resistant cassava has been successfully introduced in affected areas.	**IRRIGATION:** Irrigation is used in parts of India, though rarely in SSA **FALLOWS AND INTERCROPPING**: Fallows and intercropping are traditionally practiced to maintain soil fertility.	**TRADITIONAL METHODS:** In SSA, cassava is often stored in the ground after maturity. In India, clamps can preserve cassava up to two months.
Environmental Impacts	**LAND DEGRADATION:** Continuous production of cassava on marginal land further degrades the structure and fertility of already-poor soils.	***REDUCED ENVIRONMENTAL STRAINS:*** Reduced losses from pests and disease could lead to reduced agricultural expansion.	**FERTILIZER RUNOFF:** Though used infrequently for cassava specifically, fertilizer use in intensive SA cropping systems can lead to runoff and water contamination, among other impacts.	***REDUCED ENVIRONMENTAL STRAINS:*** Reduced post-harvest losses could lead to less agricultural expansion.
Good Practices	**INTENSIFY PRODUCTION:** Over-coming disease/pest constraints should increase productivity and lessen the need for land expansion. Cassava may have a special role in areas affected by climate change.	**USE CLEAN MATERIAL:** Use of clean planting material is a key means to prevent the spread of disease. **USE BIOLOGICAL CONTROLS:** In some cases, natural enemies of cassava pests may be introduced.	**RESEARCH DROUGHT-TOLERANT VARIETIES:** Research on cassava's water conserving properties and drought tolerance may lead to better varieties for farmers. **USE FERTILIZER:** Manure and synthetic fertilizer can improve soil fertility, but use must be integrated with other crops in the	**USE IMPROVED STORAGE:** A variety of cassava storage techniques have been developed that appear to be under-utilized in both SSA and SA.

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Brief Contents

NOTE: The findings and conclusions contained within this material are those of the authors and do not necessarily reflect positions or policies of the Bill & Melinda Gates Foundation.

EPAR Brief No. 228

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Introduction

This review is one in a series that examines crop-environment interactions drawing on both the academic literature and the field expertise of crop scientists. In this brief we examine the environmental constraints to, and impacts of, smallholder cassava production systems in Sub-Saharan Africa (SSA) and South Asia (SA), noting where the analysis applies to only one of these regions. We highlight crop-environment interactions at three stages of the cassava value chain: pre-production (e.g., land clearing), production (e.g., soil, water, and input use), and post-production (e.g., crop storage). At each stage we emphasize environmental constraints on production (poor soil quality, water scarcity, crop pests, etc.) and also environmental impacts of crop production (e.g., soil erosion, water depletion and pesticide contamination). We then highlight good practices for overcoming environmental constraints and minimizing environmental impacts in smallholder cassava production systems. Literature on the environmental impact of cassava crops is relatively small compared to cereal crops in this series.

Cassava (*Manihot esculenta* Crantz) is a widely-grown staple food in the tropical and subtropical regions of Africa, Asia, and Latin America. It is an important food security crop, in part because it can grow on marginal soils and can tolerate more water stress than many other crops, and because its storage roots grow slowly in the soil and can be harvested progressively over many months (e.g. Alves 2002; Fermont, 2009a) This is a great advantage over most grain crops that are very seasonal and contributes to food security, particularly in remote areas in SSA. Nevertheless, the crop does require some local knowledge on processing to manage cyanogens present in roots, which is a barrier to adoption. Worldwide production of cassava has doubled from 118 million to 233 million metric ton (t) in the past three decades, and the majority of that increase has been from smallholder farms in SSA. This increased production is mainly due to increases in the amount of land under cultivation, rather than increases in yield (Fermont, 2009b), hence many of the environmental impacts of cassava production in SSA are land-use related. Meanwhile, key environmental constraints affecting cassava production include several pests and diseases, as well as the unusually poor storage qualities of harvested roots which can result in significant wasted resources and effort. *Table 1* summarizes the key environmental constraints and environmental impacts associated with cassava production in SSA and in SA.

As shown in this review, evidence on environmental issues in smallholder cassava production is relatively thin, and unevenly distributed across regions. The literature on cassava in South Asian smallholder systems is limited, reflecting a crop of secondary importance (though it is widely found elsewhere in Asia such as South East Asia), in comparison to cassava in much of SSA. The majority of the research summarized in this brief is from SSA. The last row of *Table 1* summarizes good practices currently identified in the literature. However, the appropriate strategy in a given situation will vary widely based on contextual factors, such as local environmental conditions, market access, cultural preferences, production practices and the policy environment.

Cassava Production Systems

Globally, SSA has the highest cassava consumption, representing the primary source of calories for 40% of the population (Burns et al., 2010). Africa produced 122 million t of cassava in 2010, or 53% of global production, followed by Asia at 33% and the Americas at 14% (FAOSTAT). Smallholder farmers in SSA have traditionally grown cassava for home consumption, but it is increasingly being grown as a cash crop, particularly in Nigeria and Ghana (Nweke et al., 2002) and parts of East Africa (Fermont et al., 2010a). Thirteen of the top 20 cassava producing countries are in SSA, led by Nigeria, which produced the most cassava worldwide (FAOSTAT, 2013). Cassava in SSA is a crop especially well suited to moist biomodal rainfall zones with deep, friable and fertile soils. In such areas, many cassava plant types are grown as sole crops and in associations with cereals and legumes.

Cassava in South Asia was originally used as a food security crop, but over time has become important for animal feed and small-scale starch processing (Howeler, 2000). India is the principle cassava producer in SA and one of the top ten producers worldwide, producing 8 million t in 2011 (FAOSTAT, 2013). Cassava in India is mainly grown in the southern states of Kerala and Tamil Nadu, with some production in Andhra Pradesh and in the northeast of the country (Patil & Fauquet, 2009; Onwueme, 2002). Production practices vary by region within SA: supplemental irrigation is practiced in Tamil Nadu, which has a drier climate than Kerala. Approximately 70% of cassava in India is grown as a monoculture, and 30% is intercropped with groundnut, vegetables, coconut and other crops (Hershey & Howeler, 2000; Onwueme, 2002). The 2011 average yield for cassava in India was 36.4 t/ha, compared to only 10.8 t/ha for Africa (FAOSTAT, 2013). Higher yields in India are due to relatively fewer pests and disease and more intensive crop management including irrigation and high fertilizer use, especially in Tamil Nadu (FAO, 2001).

Pre-production of Cassava

Cassava's planting season has some flexibility due to the range in life cycles of different types. Drought sensitivity, however, presents a limit to this flexibility as cassava is especially in need of water between months one and five during root development. For that reason, it can be grown year-round in areas with no marked seasonality (Lebot, 2009). Cassava can also be grown under a wide range of rainfall conditions, from less than 600 mm in unimodal rainfall areas to over 2,000 mm in bimodal rainfall areas (Alves, 2002). The most favorable climates appear to be those with 1000-2000 mm of rainfall per year, a mean temperature of 25-29 °C, and a soil temperature of approximately 30 °C (Lebot, 2009; FAO, 2001). In SSA, land preparation for cassava is generally done by hand, or in some places (such as northern Nigeria) with the help of animal labor (FAO, 2001). In SA, land preparation is usually done by hand with a hoe or animal-drawn plow, except for Tamil Nadu, where it is usually done by tractor on contract (Howeler, 2000).

<u>Land Constraints</u>

As with most major crops, the availability of suitable land on which to cultivate cassava can be a major constraint (Fermont, et al., 2008). Globally, the harvested area of cassava more than doubled between 1961 and 2010, from 9.6 million hectares (Mha) to 19.6 Mha (FAOSTAT, 2013). Some of this growth in area reflects conversion of existing cropland from other crops to cassava, and some growth reflects conversion of non-agricultural land to agriculture.

In Africa, cassava area harvested has increased steadily from 5.6 Mha in 1961 to 13.0 Mha in 2011 (FAOSTAT, 2013), as human population has also increased. In South Asia, cassava area harvested increased from 0.31 Mha in 1961 to 0.55 Mha in 1975, but has actually fallen since to 0.25 Mha in 2011. The area harvested for cassava has declined throughout Asia during the past several decades as the region has transitioned away from cassava as a food security crop and towards its use in starch processing and animal feed (Howeler, 2000) and increasingly to a mix of other food crops as incomes have risen.

Adaptations to Land Constraints

Adaptations to land constraints for major crops vary by region. In areas where land suitable for agricultural production is relatively abundant, such as much of SSA (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 to 2000 the 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 decrease of about 5 Mha per year. Cassava occasionally features as a crop planted in some recently cleared areas but information on the extent of such practices is not available (and clearing for some other crops, like maize, may be a more dominant crop-related driver of deforestation). 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) (and where there is a tradition of slash-and-burn) as in many SSA cassava systems.

Due to its tolerance to abiotic stressors, cassava can be grown on marginal lands not suitable for other staple crops (El-Sharkawy, 2006). In SSA, cassava often occupies hillsides, drought-prone areas, and acidic soil regions where other crops can be successfully grown only with high inputs (Hershey & Howeler, 2000). In areas with relatively limited availability of land, such as East Africa and South Asia, more intensive use of the land is a common response to land constraints. In wetter parts of East Africa, increasing population density and high levels of land pressure have led to continuous farming systems with successively shorter fallow periods, and continuously farmed cassava has replaced crops such as millet or cotton with longer fallow periods (Fermont et al., 2008).In some parts of SSA with mixed cereal-root crop systems, farmers gradually replaced cassava with maize a few decades ago, but then as soil fertility declined substantially, farmers have re-introduced more cassava in some areas.

Environmental Impacts of Land Use

Both agricultural expansion and agricultural intensification have potential negative environmental impacts. Agricultural expansion of cassava into marginal lands exposes the soil surface to higher temperatures and direct rainfall, which leads to increasing soil degradation and erosion. Additionally, in SA soil preparation with heavy machinery increases soil density and creates hard pans, further degrading the soil (El-Sharkawy, 2006; FAO 2001).

Agricultural intensification in the form of continuous cassava farming systems leads to declining soil fertility and lower crop yields overall (Fermont et al., 2008). This in turn causes farmers to allocate larger amounts of land to cassava since little else will grow in the increasingly common poorer soils, perpetuating this soil damage. Eventually, cassava no longer grows well in these soils and farmers leave the degraded land to revert to bush fallow.

Good Practices for Land Use

Traditional methods of growing cassava are environmentally friendly in comparison to cereals and many other crops. Cassava is easily intercropped and does not require a complete clearing of forest for planting, although soil disturbance for harvesting of roots can lead to soil erosion. Conservation technologies for erosion control, reduced till, and ground cover are not developed for cassava and root crop systems in general, but some of the practices promoted for cereal/legume systems are relevant to cassava systems with some adaptation. Cassava is often grown without chemical fertilizers or pesticide application (Fermont, 2009b; Bellotti, 2002), resulting in less pollution compared to grain crops (ASARECA, 2005). Additionally, using improved cultivars suited to local land conditions can lead to large production gains, potentially obviating the need for land expansion. More research on good land stewardship may reveal other good practices for cassava land use.

Production of Cassava

Disease Infection

Disease infection is a major constraint to cassava production. Cassava disease threats have changed over time, and diseases that have existed for decades sometimes evolve into more damaging strains (FAO, 2010). Two diseases in particular have become more serious threats in recent years: cassava mosaic disease (CMD) and cassava brown streak disease (CBSD).

➢ *Cassava Mosaic Disease (CMD):* CMD occurs everywhere that cassava is grown in Africa, and frequently features (along with related issues of poor quality stakes/cuttings and unsuitable varieties) among the most important constraints reported (e.g. Waddington et al., 2010). It has also been observed in India and Sri Lanka (Patil & Fauquet, 2009). CMD is spread by planting infected cuttings or by the whitefly vector *Bemisia tabaci* (Bouwmeester et al., 2012). A CMD epidemic began in the 1990s in Uganda, which spread to neighboring countries (Thresh and Cooter, 2005). By 2005, CMD had become a pandemic affecting nine countries in East and Central Africa over an area of 2.6 million km^2, causing 13 million t of annual damage, or 47% of production. In a survey of 775 sites in Rwanda, Burundi, and surrounding areas, 97% of all fields were affected by CMD (Bouwmeester et al., 2012). In India, spread of the disease is more closely tied to infected plant material than to spread by whiteflies. CMD causes easily identified leaf symptoms that are green or yellow in color, which leads to slower root growth (Lebot, 2009). Symptom expression is influenced by environmental factors, and leaves produced during cool weather are generally more affected than those produced during warmer weather.

➢ *Cassava brown streak disease* (CBSD) is the second most important cassava disease, occurring mainly in East and Central Africa, and is caused by the *Cassava brown streak virus* (CBSV) and *Ugandan Cassava brown streak virus* (UCBSV) (Ogwok et al., 2012; Mbanzibwa et al., 2011). CBSD is transmitted by the same whitefly vector as CMD. CBSD leads to a dry brown-black rot of the tuberous roots that makes them unsuitable for consumption.

Adaptations to Disease Constraints

Adaptations to cassava disease constraints include:

➢ *Disease-resistant cultivars:* Cassava breeding programs for CMD-resistance in SSA began as early as the 1930s. After the CMD epidemic in Uganda began in the 1990s, several IITA-developed varieties with resistance to CMD were widely distributed in Uganda, as well as Kenya and Tanzania as the epidemic spread to neighboring countries. CMD-resistant germplasm has been one of the most successful means of combating the CMD pandemic, and resistant varieties are now the primary cassava varieties used in affected areas. However, efforts to identify natural resistance to CBSD in cassava varieties have been less successful to date (Legg et al., 2006; Vanderschuren et al., 2012). Germplasm improvement efforts for combating CBSD have focused on varieties that express root rot symptoms either late or not at all, since this is the main cause of yield loss from CBSD (Legg et al., 2011; Ogwok et al., 2012). Even when resistant varieties are identified, cleaning and keeping plants and cuttings disease free for dissemination is challenging in a farm setting.

➢ *Debris removal:* In addition to using clean planting materials, improving crop hygiene by carefully removing debris and plants from previous crops can decrease the risk of disease spread. This includes not only leftover cassava stems, which can easily regenerate and potentially spread disease, but alternative hosts such as tree cassava (*Manihot glaziovii*) which are sometimes infected with whiteflies. However, the benefits of this practice have not been measured (Thresh and Cooter, 2005).

➢ *Roguing:* Another practice which can be encouraged is roguing, or removing diseased plants as they are found during regular inspections. Guthrie (1990) recommended inspecting cassava plantings and removing diseased plants at least weekly during the first 2-3 months of growth. However, roguing may be more useful for maintaining virus-free cassava stocks than for use in farmers' fields, where there may be a high percentage of infected plants and roguing could be counterproductive (Thresh and Cooter, 2005). Roguing is common in some CMD-affected countries, such as Kenya, where a survey of cassava farmers found that 38% employed roguing to control CMD (Kamau et al., 2005).

Even if farmers are aware of the benefits of clean planting materials, it can be difficult to distinguish between diseased and disease-free cuttings in cases where the plants are leafless due to drought or pests (Lebot, 2009).

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 crop that would otherwise be greater if infected cassava planting materials were used. Such benefits may come from reduced areas that need to be planted to the more productive crop, with reduced impact on biodiversity/habitat loss, soil erosion, etc.

Good Practices for Cassava Disease Management

Good practices for managing cassava diseases for the most part are reflected in current practices, including:

- *Development and use of improved varieties:* Replacing disease-vulnerable cassava varieties with disease-resistant varieties is the response most highly recommended by the International Institute of Tropical Agriculture (IITA) and similar research institutes (FAO, 2010). However, many of these transformed varieties have not yet been evaluated under field conditions (Legg et al., 2006). A drawback of this approach is that it may reduce the diversity of varieties grown in an area, which renders the cassava production system more susceptible to future pests and disease (FAO, 2010).
- *Clean cultivar production:* A basic approach to CMD control is to use CMD-free planting material. Damage from CMD is more severe in plants that are exposed to the disease through infected cuttings, rather than infected during growth by a whitefly vector. The yields of initially healthy plants are also much greater than infected ones, even if they become infected during their growth by whitefly (Thresh and Cooter, 2005). Legg et al. (2011) suggest that while farmers in some areas have received training on the importance of clean planting materials, in most cases farmers do not (or find it difficult to) distinguish between clean and infected cuttings. The main finding of a~~n~~ FAO review of cassava disease work in SSA was that there is a current and desperate need for clean planting material of improved cassava varieties (FAO, 2010).
- *Crop management:* Several crop management practices have the potential to reduce disease incidence. Because whiteflies are most prevalent in the outermost rows of plantings and in the direction of the prevailing wind, planting cassava in large, compact blocks (or placing elongated plots along the prevailing wind direction rather than against it) may reduce infection. Where possible, isolating cassava plots could also help prevent the spread of disease from one plot to another. Evidence from Uganda and Ivory Coast (Fargette & Thresh, 1994) suggests that CMD spread is greater in lower-density areas of cassava plots, such as footpaths, and that uniform dense stands may reduce CMD spread. Finally, in areas with longer rainy seasons where farmers have some flexibility in when they plant, such as in large parts of West and Central Africa, it would be advantageous to plant when whiteflies are less abundant (usually later in the planting season). However, limited evidence is available on the effectiveness of these techniques, and in many cases they may be difficult to routinely implement on small farms in SSA (Thresh & Cooter, 2005; Lebot, 2009).Additionally, the intercropping of cassava with other spp. can reduce the incidence of the whitefly vector of CMD (see the following section on pests).

<u>Crop Pests</u>

At least 200 species of pest have been reported to attack cassava worldwide, although they are generally isolated by region, with many of the highly damaging species in the Americas (Lebot, 2009). Some of the most common types of cassava pests present in SSA or SA include mites, mealybugs, and whiteflies (Bellotti et al., 1999). Both the cassava green mite (*Mononychellus tanajoa*) and cassava mealybug (*Phenacoccus manihoti*) were accidentally introduced into Africa from the Americas, leading to significant crop loss (Bellotti, 2002). Native cassava pests in Asia have not caused serious crop losses, although the cassava mealybug has recently reached Southeast Asia and may spread to the high-risk area of Karnataka in India (Parsa et al., 2012).

Cassava pests feed on the leaves or stems of the plant, reducing its photosynthetic capacity and leading to stunted plant growth and reduced root yields (Lebot, 2009). Yield losses are greatest during the dry season, as the plant can regrow a new leaf canopy more easily in a wet season, and some pests are more prevalent or more likely to attack cassava in the dry season. Yield losses from mealybugs and mites in Africa were especially severe shortly after their introduction in the 1970s. Yield loss estimates from mites are 13-80% (Bellotti, 2002).

Adaptations to Crop Pests

Adaptions to crops pests for cassava include the following:

- *Biological control:* Pests are sometimes controlled through the introduction of natural enemies. For instance, *P. manihoti* mealybug, one of the most severe cassava pests in the world, was controlled in Africa through the introduction of the parasitoid *Anagyrus lopezi* in the 1980s, a natural enemy from the mealybug's native South America. Afterwards, high infestations of *P. manihoti* were reduced by 90% (Parsa et al., 2012). The introduction of a

Phytoseiid mite species, *Typhlodromalus aripo*, has also helped control the green mite in Africa (Lebot, 2009).

➢ *Chemical control:* Pesticide use for cassava is minimal, due to the high costs and long crop cycle of cassava, which means several applications may be needed (Bellotti, 2002). No estimates of pesticide use specific to cassava in SSA and SA were available, but in a survey of 150 farming households in Nigeria, commonly used pesticides included lindane, monocrotophos, and 'Apron star' (metalaxy + difenoconazole + thiamethoxam) (Oluwole & Cheke, 2009).

➢ *Improved varieties:* Improved cassava varieties with resistance to pests have been used successfully. For instance, the International Center for Tropical Agriculture (CIAT) has developed and released cassava varieties with moderate resistance to mites (Bellotti, 2002).

➢ *Intercropping:* Intercropping cassava can reduce the spread of whiteflies, depending on the intercropped species. Gold (1990) found that cassava intercropped with cowpea experienced reduced egg populations of two species of whitefly, with yield losses of 12% compared to approximately 60% for cassava monoculture, cassava/maize intercropping, and mixed cultivar systems. However, farmers may be uninterested in this method if the intercropped species has little commercial value.

Environmental Impacts of Pest Management

The use of pesticides for cassava is low in SSA and SA, and estimates of pesticide impact specific to cassava were not found through this review, but overall are unlikely to be substantial. When used, pesticides can have adverse effects on beneficial insect populations or non-target bird and fish species (Bellotti, 2002). Their use can also lead to pesticide resistance among pest species. Pesticides also carry health risks to farmers and consumers, although the level of risk varies widely by pesticide type, usage, and environmental factors (Damalas & Eleftherohorinos, 2011).

Good Practices for Pest Management

➢ *Quarantine:* Because most cassava pests are geographically isolated, with many of the most damaging in the Americas, better information on geographic distribution, and careful quarantine measures restricting transfer of infected germplasm are important in preventing the spread of pests and diseases to new areas (Campo et al., 2011; Lebot, 2009; Bellotti, 2002).

➢ *Biological control:* In addition to the biological controls that have already been introduced, other natural enemies of cassava mites, mealybugs, whiteflies, and other pests have been identified that could potentially be used as biological control agents (Bellotti, 2002). For instance, recent progress has been made identifying the natural predators of whitefly, with potential implications for whitefly biological control (Wyckhuys et al., 2013).

➢ *Improved varieties:* Although adequate host plant resistance in cassava is not available for mealybugs, the development and use of resistant varieties has proven successful for mites and whiteflies (Bellotti, 2002).

<u>Weeds</u>

Weeds constrain cassava production by competing for water, sunlight, nutrients, and space. This competition leads to reduced canopy development and reduced root number and weight, and decreases yield by approximately 40% in early branching varieties and nearly 70% in late or non-branching varieties (Agahiu et al., 2011). Weeds can also pierce cassava roots, leading to infection, and can harbor pests and disease. Uncontrolled weed growth can lead to yield losses as high as 95% (Melifonwu, 1994). Farmers typically manage yield losses from weed competition usually through hand and mechanical weeding, so that actual losses are much less. Nevertheless, weed competition is reported as one of the most widespread severe constraints to cassava production in SSA (Waddington et al., 2010). Manual weed control accounts for a high proportion (around 60%) of the large amount of labor used in cassava production in East Africa (Fermont 2010a).

Adaptations to Weeds

➢ *Hand weeding:* Weeding by hand, commonly with the help of a hoe, shovel, or machete, is the most widely used means of controlling cassava weeds in SSA and SA (Lebot, 2009; Howeler, 2000). It is also the most labor-intensive (Agahiu et al., 2011) and in practice is rarely completely effective since the weeding is often insufficiently frequent, some weeds are left, and so some damage still occurs.

➢ *Chemical control:* Herbicides are an effective means of weed control, but the level of effectiveness varies with weed type, cassava cultivar, quantity of herbicide used, and the other crop management practices in use (Melifonwu, 1994). Studies in Nigeria found that herbicide use increased the mean yield for cassava from 7.0 to 8.2 t/ha (Agahiu et al., 2011) and from 9.3 to 11.9 t/ha (Olorunmaiye, 2010a). In the latter study, herbicide was combined with hand-weeding and control crops. A survey of 450 farmers in Nigeria found that 30% were using herbicide, and of those that did not, 73% did not use it because of the high cost (Agahiu et al., 2012). Study results from another site in Nigeria found that plots receiving glyphosate yielded 28% more than plots hand-weeded five times, and 45% more root than plots weeded twice (Chikoye et al., 2002). Herbicide damage to some intercropped plants also complicates effective use of herbicide in cassava systems.

➢ *Intercropping and cover crops:* Intercropping with other food crops, such as with indeterminate (spreading) cowpea, groundnut, melon, maize, or rice, can also help control weeds and increase cassava yields (Melifonwu et al., 2000; Chikoye et al., 2002). Non-food cover crops planted with cassava can also be used to suppress weeds by creating shade that denies the weeds sunlight, as well as contributing to soil maintenance. A study in Nigeria found that twelve months after planting, plots with cover crops (including velvet bean and tropical *kudzu)* had 52-66% lower weed biomass than plots without cover crops (Chikoye et al., 2001).

Environmental Impacts of Weed Management

Estimates of the environmental impacts of weed control specific to cassava in SSA and SA were not found, but these impacts are fairly well understood in reference to other crops. Hand weeding can contribute to soil erosion (Melifonwu, 1994) and is likely to be a significant cause of soil loss in cassava systems. Herbicides, meanwhile, potentially have the largest environmental impact of weed control methods, as they can contaminate groundwater or top soil and harm microorganisms, plants, wildlife, and humans (Ayansina & Oso, 2006). Overuse of herbicides for weed control can also lead to an increase in herbicide-tolerant weed varieties (Powles, 2008). Nevertheless, at present for cassava in SSA, herbicides have only local environmental impacts since they are rarely used.

Good Practices for Weed Management

- *Timing and frequency:* The timing of weeding is important, as weeds are most destructive during the early stages of crop growth. Onochie (1975) tested the effect of different start times for weeding on cassava yield, and found that the first three months were the most crucial for weeding. In West African systems, weeding is recommended 3-4 weeks after planting, 7-8 weeks after planting, and again 12 weeks after planting (Melifonwu et al., 2000). After four months, weeds have little impact on yield and weeding becomes less essential, although weeds may still impact the quality of the stakes of the future crop. The frequency and intensity of weeding can also be reduced if land is cleared immediately before the start of a rainy season (Melifonwu et al., 2000).
- *Improved varieties:* Some improved varieties of cassava are less susceptible to weeds because they grow low-hanging branches at an early stage, which forms a canopy that denies weeds sunlight (Melifonwu et al., 2000). These improved varieties also require less frequent hand weeding and lower rates of herbicide (Akobundu, 1980). Although herbicide resistant cassava is not in use, CIAT is currently conducting research to identify herbicide resistance in cassava (Ceballos et al., 2011).
- *Mulching and intercrops/cover crops:* Mulching with harvested leguminous plant remains, rice husks, and other crop and weed residues can suppress weeds, along with providing benefits for the soil. Intercropping of some food crops and non-food cover crops with cassava can be used to reduce the weed burden, manage soil fertility and diversify food production.

<u>Drought</u>

Cassava is a drought-resistant crop, giving it an advantage over other staple crops in areas where it is grown, which often have less than 800 mm of annual rainfall, dry air and high temperatures, and/or a dry season of 4-6 months (Alves, 2002; Turyagyenda et al., 2013; El-Sharkawy, 1993). Cassava's drought tolerance is mainly due to its control of water consumption, by closing its stomata (leaf pores that control gas exchange) during periods of drought to prevent excessive water use (FAO, 2001). Cassava also has a deep (more than two meters) root system that can reach underground water when available and extract 20-40% of its total water uptake (El-Sharkawy, 2007).

However, long dry periods reduce cassava growth and yield. The severity of this reduced growth is dependent on the length and magnitude of drought, the cultivar type, and the stage of development of the crop when drought occurs (Omonona & Akinpelu, 2010). Cassava is particularly vulnerable to drought from 1-5 months after planting, the stage of root initiation and root swelling, when water deficits of two months or more reduce yield by 32-60% (Omonona & Akinpelu, 2010; Okogbenin et al., 2011; Lebot, 2009). Under experimental conditions, root and shoot biomass have been reduced by as much as 70% in water-stressed cassava plants (Burns et al., 2010). Recovery from drought is more likely in areas with more than one rainy season per year or a short dry season (Burns et al., 2010).

The concentration of cyanogens also increases in water-stressed cassava, and instances of acute cyanide poisoning in cassava-dependent communities have been observed to be higher in drought years (Burns et al., 2010). Estimates of the increase of cyanogens from drought vary by cultivar and the nature of the drought. Research in Mozambique found that cyanide concentration from cassava flour in drought years was 120 ppm, compared to 40 ppm in non-drought years (Ernest et al., 2002). El-Sharkawy (1993) found an average cyanide increase of 40%, while Bokanga et al. (1994) found that cyanide content in roots in the driest conditions exceeded that of roots in the wettest conditions by five times. Roots with higher toxicity require more post harvest processing, further straining farmer resources.

Adaptations to Drought Constraints

- *Irrigation:* One method of preventing water stress is through irrigation, although successful water management requires a sure supply of water, some investment and careful planning, and formal irrigation for cassava is rarely used in SSA (Burns et al., 2010; Schlenker & Lobell, 2010). In SA, irrigation of commercial cassava fields is only practiced in Tamil Nadu, India, and is recommended whenever available soil moisture content drops below 75-80% (Howeler, 2000).
- *Drought-tolerant varieties:* One of the most frequently recommended strategies for improving drought management is the use of cassava genotypes that are tolerant to early drought stress (Fermont, 2009a; El-

Sharkawy, 1993). However, no quantified estimates of the use of drought-tolerant cassava in SSA or SA were found.

- *Mulching, crop residues, reduced tillage:* Reduced tillage and the retention of crop residues on the soil surface can increase moisture retention and reduce moisture loss from soil, raising cassava productivity and sustainability.

Environmental Impacts of Drought Management

No estimates of the environmental impact of drought management specific to cassava were found. Throughout much of SSA, water resources have not yet been fully exploited for irrigation, meaning that there may be scope to increase water use (perhaps reducing the pressure to expand land for cassava), but water depletion could become a greater concern if irrigation is expanded in the future.

Good Practices for Drought Management

- *Drought-tolerant varieties:* Research on drought-tolerant cassava at CIAT and other research centers is ongoing (El-Sharkawy, 2012). For instance, there is great variation in stomatal conductance (the rate at which CO_2 enters and water vapor exits the stomata of a leaf) among cassava cultivars, with implications for breeding for drought-resistance (Okogbenin et al., 2011). More research is also needed on the genetic diversity in cassava's photosynthetic rates (El-Sharkawy, 2007). It will likely be some time before such technologies can be deployed sufficiently to make any difference in SSA.
- *Management practices:* In contrast, preventative management strategies are already available that can decrease the impact of drought, although many of them require additional labor at the onset of the rains, a peak period in labor demand. Such strategies include early planting at the beginning of the rains and improving soil coverage with organic materials, which leads to reduced evaporation and improved rainfall infiltration. Soil coverage can be improved through weed control, mulching, or conservation tillage (Stroosnijder, 2009 in Fermont, 2009a).

<u>Soil Fertility Constraints</u>

Cassava has a high tolerance for acidic soils (that are common in many tropical environments) and can grow relatively well on soils with low levels of phosphorus (P) compared to other crops, and is often grown under these conditions (Howeler, 2002b). Unlike most other crops, cassava forms a strong association with the mycorrhizal fungi that are present in soils. This symbiotic relationship increases cassava's nutrient acquisition, especially of P, which is why cassava tolerates soil with low P levels (Fermont, 2009b; Burns et al., 2010).

During cassava cultivation, the soil nutrients that have been absorbed by the plant are removed along with the plant during harvest, contributing to soil degradation. The amount of nutrient removal is dependent on soil fertility, yield, and whether other plant parts besides the roots are removed from the field. Soil nutrient degradation increases when yields are higher, because the plant absorbs a higher amount of nutrients (Lebot, 2009). However, at low yields (less than 15 t/ha) cassava removes much less nitrogen (N), P, and potassium (K) than other crops, and even at high yields nutrient removal is comparable to or lower than other crops. This is because the majority of nutrients such as N, P, Calcium (Ca), and Magnesium (Mg), and 40-50% of K are contained in the leaves and stems of cassava plants, so few nutrients are removed if these are returned to the soil (FAO, 2001). In contrast many other food crops are grain crops; nutrients tend to accumulate in the grain of these crops and are removed from the field for consumption.

Because of its adaptation to poor soil conditions cassava is increasingly often grown on marginal soils in drought-prone regions without the use of fertilizer and other chemical inputs, and frequently farmers plant it as a 'last resort' sole crop on otherwise exhausted fields in West and East Africa to help regenerate some soil fertility (e.g. Adjei-Nsiah et al., 2007; Fermont et al., 2008). Depletion of soil fertility is an ongoing challenge for the sustainable production of cassava, as it is with other crops in SSA. Soil fertility depletion, N deficiency and inadequate fertilizer management were reported as severe and widespread in the most important cassava farming systems in SSA (Waddington et al., 2010).

Adaptations to Soil Fertility Constraints

Common adaptations to soil fertility constraints in SSA and SA include the following:

- *Traditional methods:* Farmers in SSA rely on a number of traditional methods to restore soil fertility. In sparsely populated areas with sufficient land availability, slash and burn agriculture continues to be practiced for cassava. However, higher human population densities result in insufficiently long fallow periods for the sustainable use of slash and burn, leading to decreasing nutrient stocks and productivity (Pypers et al., 2012). Increasing population pressure often shortens the fallow period to one or two years, which is insufficient time for bush re-growth and soil fertility to recover, leading to a downward spiral of decreasing fertility (FAO, 2001). In these more densely populated areas with a longer history of cropping, crop rotation, intercropping and short fallowing are practiced.
- *Fertilizer use:* In SSA, there is little use of synthetic fertilizers in cassava production, as they are not readily available or too costly (Fermont, 2009b; FAO, 2001). Fertilizer is sometimes used on a crop intercropped with cassava, such as maize, and some of this fertilizer may in practice be used by the cassava. Farmers in SSA sometimes apply organic manures or compost to cassava. Worldwide, animal manure rates for cassava vary from 5 to 10 t/ha, but optimum rates and application methods have not been tested experimentally (Lebot, 2009; Howeler, 2002b).

Fertilizer is also infrequently used in Kerala, India, but fertilizer is applied at high and sometimes excessive rates in Tamil Nadu (FAO, 2001; Howeler, 2000).

- *Crop residue management:* As long as the leaves and stems are returned to the soil, few nutrients are removed, and low yields of cassava are sustainable for many years without the use of fertilizer. However, farmers in India harvest the leaves for animal feed and the stems for fuel wood, increasing nutrient removal by two to three times (FAO, 2013). Howeler (2001) calculated an average removal per t of fresh roots of 2.53 kg/ha of N, 0.37 kg of P, 2.75 kg of K, 0.44 kg of Ca and 0.26 kg of Mg if only roots are removed, but 6.68 kg/ha of N, 0.76 kg of P, 4.87 kg of K, 2.78 kg of Ca and 0.87 kg of Mg if the whole plants are removed.
- *Intercropping:* Intercropping with crops such as maize and legumes is commonly practiced in SSA and SA. Studies in Nigeria and other regions have shown that intercropping often decreases cassava yields slightly, but diversifies food supply, makes more efficient use of the land and increases farmer income (FAO, 2001). With intercropping, incorporating the intercrop residue after harvest may improve soil fertility without drastically reducing yields, particularly if the intercrops are fertilized (Howeler, 2002b). No quantified estimates of the effect of cassava intercropping on soil fertility were found.

Environmental Impacts of Nutrient Management

Runoff or leaching from excessive or inappropriate use of synthetic fertilizers can lead to surface water contamination, algal blooms, and contamination of wells and drinking water (Burns et al., 2010). No studies were found that documented these environmental impacts of nutrient management specific to cassava, although past studies in East Africa's Lake Victoria region, a major agricultural area where cassava is grown, have shown that agricultural activity has led to nutrient loading, deoxygenation of the lake water, and fish-kills (Lindenschmidt et al., 1998).

N is also a key component of cyanide, and it is possible that changes in N content due to fertilizer application may impact cyanogen production in cassava. Studies to date have been contradictory on whether N fertilizer can increase cassava's cyanogen production, and if so by how much (Burns et al, 2010).

Good Practices for Nutrient Management

- *Fertilizer use:* Fertilizer application for cassava leads to increased yields, plant biomass, root quantity, and nutritional content (Burns et al., 2010; Fermont, 2009b). Fertilizers high in N and K but low in P are best suited for cassava. Studies have recommended applying approximately 80 kg N/ha, 10-20 kg/ha P, and 50 kg/ha K for a yield of 15 t/ha, or 150 kg N/ha, 20-30 kg/ha P, and 150 kg/ha K for a yield of 30 t/ha (FAO, 2001; Howeler, 2001). Animal manure is also recommended in addition to or in place of chemical fertilizers. However, Howeler (2000) cautions that manures contain low and unpredictable amounts of N, P, and K, with just 50 kg of a 15-15-15 synthetic fertilizer equivalent to one metric t of wet pig manure (although synthetic fertilizers are lacking in micronutrients present in manure). Sometimes transport and application costs for manure may also be higher than the cost of synthetic fertilizer in the event that manure is not locally available, although in SSA it is usually the manure or compost that is more readily available.
- *Green manure:* Green manuring, the incorporation of cut or uprooted legumes and other crops into the soil to add nutrients, is another means to improve cassava yield and soil fertility, especially in cases where fertilizer is not available. When there is a long wet season, green manures are usually planted early in the wet season and then mulched or incorporated into the soil before planting cassava (FAO, 2001). In Nigeria, Hahn et al. (1993, in FAO, 2001) demonstrated that yearly rotations of cassava with green manure or weed fallow were able to sustain yields of 20 t/ha for an improved variety and 11 t/ha for a local variety for 18 years without the use of fertilizer. Pypers et al. (2012) found that green manure increased cassava yields by 36 to 158% in the DR Congo without fertilizer, and that yield increases using both green manure and fertilizer together were additive.
- *Returning leaves and stems to the soil:* Because so many of the nutrients in cassava are contained in the leaves and stems, returning them to the soil is an essential step in maintaining soil fertility (FAO, 2001), so farmer practices that routinely incorporate crop residues or composts or retain them on the soil surface are encouraged.

Soil fertility varies by field, but there is a lack of well-functioning soil testing services for farmers. Farmers could improve the efficiency of their fertilizer use and reduce their costs and environmental impacts by using a soil testing service that also made fertilizer recommendations (Burns et al., 2010; Howeler, 2000).

Post-production of Cassava

Cassava roots require processing before they are fit for human consumption. Processing techniques vary by end use, across regions and with different varieties, however they often require the heavy resource use. Many are very labor intensive and need important amounts of water, wood and other fuels.

Storage Constraints

Cassava deteriorates much more rapidly than other tuber and tuberous root crops such as yam and sweet potato. Physiological deterioration occurs two to three days after harvesting, followed by microbial deterioration three to five days after that (Karim & Fasasi, 2009). This process, known as post-harvest physiological deterioration (PPD), begins at the wounded root terminal and is influenced by the cultivar as well as environmental conditions (Salcedo et al, 2010). Symptoms include blue/black vascular streaking, brownish occlusions, and chemical deposits from wound sites, followed by discoloration of the storage tissues and an unpleasant flavor and odor (Reilly et al, 2007). Significant quantities of cassava root are also damaged or rot during transportation to markets or processing facilities (Wenham, 1995).

Adaptations to Storage Constraints

Adaptations to cassava storage constraints include:

- *Traditional storage:* There are a number of traditional storage methods for cassava, including use of pits in shaded areas. Cassava stored in boxes lined with sawdust or coconut husks can last up to four weeks in areas with temperatures of 22-24 °C. In India, cassava can be stored in clamps for as long as two months. Clamps are created by placing 300-500 kg of fresh roots on a bed of straw or grass and covering them with soil and more straw. Dried cassava is easier to store than fresh cassava, but is vulnerable to losses from fungi, bacteria, insects, and rodents (Lebot, 2009).
- *Late harvesting:* Cassava is sometimes harvested late or buried immediately after harvest as a means of storage (Karim & Fasasi, 2009; Wenham, 1995). However, leaving cassava in the ground past maturity can lead to loss of starch content and an increase in cooking time due to increased fiber content (Salcedo et al., 2010). Depending on the cultivar, leaving cassava in the ground also leads to a loss in weight and quality after a certain length of time (Lebot, 2009).

Environmental Impacts of Post-Harvest Management

No quantified environmental impacts of storage methods were found in the literature. However, reducing post-harvest losses would indirectly reduce the overall environmental burden from cassava production, as there would be decreased pressure for agricultural expansion. There would also be a reduced environmental impact from wasted effort. That is, there would be a reduction in wasted fertilizer, labor, seeds, and other inputs that are used to produce cassava that is lost in the post-harvest stage. Additionally, both traditional and industrial processing of cassava for food may have some appreciable environmental effects from fuel and water use.

Good Practices for Crop Storage

- *Improved varieties:* Early research to improve cassava suggested molecular genetic approaches might suppress cassava's PPD and improve its wound-healing ability to increase cassava's natural shelf life to two weeks or more (Wenham, 1995). Such efforts are still ongoing as researchers seek to identify genetic traits in cassava that make it resistant to PPD (Salcedo et al, 2010).
- *Improved storage techniques:* A variety of storage techniques have been developed for cassava, including packing in moist media, freezing, waxing, canning, and storage of fungicide-treated roots in plastic-bags. However, the technical or financial requirements of these techniques are often out of reach for most smallholder farmers in SSA and SA (Wenham, 1995). Related to this, increased facilities for agro-industrial processing of roots as snack foods, could raise farmer marketing opportunities and livelihoods from cassava.

Climate Change Impacts

Cassava is anticipated to be highly resilient to climate change, in part because cassava is drought tolerant and relatively unaffected by varied climate conditions in comparison to most other crops (Paavola, 2008). Studies that have quantified the impact of climate change on cassava have all found cassava to be the least affected among major crops (including maize, rice, sorghum, and millet) (Jarvis et al., 2012). For instance, Schlenker and Lobell (2010) analyzed historical production and weather data in SSA, and predicted that cassava production would decrease by 8% by mid-century, compared to decreases of 17% for sorghum and millet, 18% for groundnut, and 22% for maize. Liu et al. (2008) used a GIS-based model to predict a negligible change in cassava production of between -2% and +1% by 2030, and Lobell et al. (2008) suggested an average increase in cassava production of 1.1% by 2030. All such studies point out that there is great uncertainty in the climate models they are based on, and do not estimate the effect that increased CO_2 would have on cassava (Jarvis et al., 2012).

In addition to the direct effects that climate change is expected to have on cassava crop growth and production, climate change may also have an indirect influence by affecting some production constraints. For instance, the geographic distribution of cassava pests and disease are likely to change along with the climate, with pest or disease intensity increasing in some areas and decreasing in others. Overall, climate change could lead to increased pest and disease incidence (Jarvis et al., 2012). Climate change could also affect the behavior of natural enemies of cassava pests. For instance, parasitism of mealybugs decreases under drought conditions. However, these behavior changes of natural enemies are complex, and their effectiveness in controlling pests as climate changes could either increase or decrease (Thomson et al., 2010).

Conclusion and Overall Good Practices

Cassava can grow and even thrive in difficult environments, especially those with poor quality soil or limited water availability. This gives cassava an advantage over many other staple crops (especially cereals), and is a major reason that cassava has become increasingly popular with smallholder farmers in Sub-Saharan Africa. It may mean the crop will have an increasing role in mitigating the negative effects of climate change in the region. It also means that farmers may persist with growing cassava as a crop of last resort across degraded lands and that can be a source of widespread damage to the environment.

Nevertheless, cassava still faces a variety of environmental constraints, including major yield losses from pests and disease, competition from weeds, and steadily declining soil fertility. Genetic improvement research on cassava is ongoing, which could potentially lead to varieties with greater resistance to drought, root deterioration, pests, or diseases. Other good practices often revolve around crop management techniques, such as the use of clean planting materials to prevent disease, or improving access to inputs, such as organic and synthetic fertilizers that can raise soil fertility over the longer term.

Methodology

Research for this literature review was conducted through the University of Washington library and Google Scholar as well as websites including the International Center for Tropical Agriculture (CIAT), the International Institute of Tropical Agriculture (IITA), and the FAO. Search terms used include cassava, environment, impact, constraint, land use, intercropping, virus, pest, weed, drought, water stress, fertilizer, green manure, storage, and post-harvest. Lists of works cited from key sources were also reviewed to find additional sources.

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

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