

# A System Dynamics Model for Subsistence Farmers' Food Security Resilience in Sub-Saharan Africa

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## ABSTRACT

Food security at subsistence farmers' level in sub-Saharan Africa has become an issue of concern due to increasing vulnerability caused by a number of factors such as: changing climate, resource scarcity (e.g. land and inputs), environmental degradation (e.g. declining soil fertility, deforestation, and surface water eutrophication), market failures and weak public/donor support initiatives. In light of these challenges, farmers must be prepared to survive by self-provisioning. To pursue the fastest and most practical route to improved food security, focus should be on resilience based initiatives at household and community levels. In this paper, the authors investigate the factors that have enabled subsistence farmers to succeed despite the previous shocks and stresses, and develop a system dynamics model for sustainable food security based on initiatives exclusive to the farmers. The model is used to examine the question: how can innovative subsistence farmers engage in better livelihood and market orientated production irrespective of external public or donor support?

## KEYWORDS

Food Security, Livelihood, Resilience, Sub-Saharan Africa, System Dynamics Model

## 1. INTRODUCTION

Worldwide, over 850 million people do not have regular access to the minimum calories they require on a regular basis, and most of those are in Asia and sub-Saharan Africa (Hammond & Dub, 2012). At the same time, the subsistence farmers are most vulnerable to any shocks to their agricultural system which is the sole source of their livelihoods. These farmers are not only isolated and deprived of access to safety nets but are frequently exposed to pest and disease outbreaks and extreme weather events, which cause significant crop and income losses and aggravate food insecurity (Chauvin et al., 2012; Oyo, 2013). While agricultural growth has been the precursor to the acceleration of industrial

growth in a number of emerging economies such as China, Brazil, and India, for sub-Saharan Africa, current agricultural productivity is low and there have been numerous failures in getting agriculture moving (Chauvin et al., 2012).

In contrast, the literature is rich with case studies where productivity led agricultural transformation is playing a significant role in economic transformation in general and making agriculture an important driver of growth in Africa (Thompson et al., 2007; Baiphethi & Jacobs, 2009; Haggblade, 2010; Africa Progress Panel Policy Brief 2010; Settle & Garba, 2011; Chauvin et al., 2012; Oyo, 2013). Studies have found that agriculture has been the engine of growth in most developing countries with causality running from agricultural growth to economy-wide growth in most cases, and that even small variations in agricultural productivity have had strong implications for the rate and pattern of economy wide growth (Chauvin et al., 2012). Furthermore, agricultural growth can provide the economy with much needed stimuli such as capital, labor, and foreign exchange to finance and fuel growth in non-agricultural sectors (Fan et al., 2013; Stave & Kopainsky, 2014).

In order to articulate the key issues in this paper, we provide definitions of key terms as outlined in Table 1.

### 1.1. Problem

Agricultural growth rate and food security in Africa has been volatile since the 1980s. This largely was caused by negligence by most governments and donors in the 1980s and 1990s (Chauvin et al., 2012). Renewed commitment to agriculture over that last decade, e.g., through the Comprehensive Africa Agricultural Development Programme (CAADP) and the Maputo declaration of 2003 in which African heads of state pledged to devote at least 10% of their national budgets to agriculture

Table 1. Definitions of key terms

Terminology	Definition
Resilience	The Resilience Africa Network (RAN) defines resilience as the capacity of people and systems to mitigate, adapt to, recover and learn from shocks and stresses in a manner that reduces vulnerability and increases well-being (RAN Report 2014). From a more systemic perspective, Walker et al. (2006) define resilience as the capacity of a system to experience shocks while retaining essentially the same function, structure, feedbacks, and therefore identity. The key issue of interest in these definitions that ties with food security at subsistence farmer level is ability to recover from shocks and hence being less vulnerable to stressors.
Food security	Food security has generally been defined as the access by all people at all times to enough food for an active healthy life (Anderson, 1990). According to the World Food Summit organized in Rome in 1996, food security exists when all people, at all times, have physical and economic access to sufficient, safe, nutritious food to meet their dietary needs and food preferences for an active life (FAO, 2011). At household level, food security refers to the availability of food in one's home which one has access to. In this case, a household is regarded as food secure when the members of the family do not live in hunger or fear of starvation.
Subsistence farming	Subsistence farming has been defined by Morton (2007) as self-sufficiency farming and a livelihood strategy where the main output is consumed directly, with a minor proportion of output marketed. It is also frequently and more generally used to describe rural producers, predominantly in developing countries, who farm using mainly family labor and for whom the farm provides the principal source of income (Fan et al., 2013).
System dynamics model	A model of a system is a tool used to study the behavior of a system without having to experiment on the real system. As such, a system dynamics model is a tool used to study the behavior of a system by describing the system and understanding how information feedback govern its behavior, and designing robust information feedback structures and control policies through simulation and optimization (Coyle, 1996). Since simulation and optimization are underpinned by mathematical equations, a model can also be defined as a collection of mathematical equations which represent behavior/characteristic of real system (Azar, 2012).

in an effort to raise agricultural growth to 6% a year, have had negligible impact. For instance, the benchmark for Maputo declaration with regard to 10% national budgets expenditure on agriculture has not been realized by majority of the signatory countries (Chauvin et al., 2012; Harvey et al., 2014). During the previous periods of declining public/donor intervention and unmet pledges, subsistence farmers developed resilience to shocks and stresses thus ushering in new trends of self-reliance/self-provisioning. What seems viable at this point is to pursue other alternatives to food security based resilience strategies developed over the years, with less expectation from government and donor intervention.

## 1.2. Objective

The dynamics of food production and hence food security and livelihoods are interlinked, and need to be studied as a whole. The interactional effects for food production at subsistence farmers' level needs to be studied in order to investigate appropriate strategies that could improve their production and hence livelihoods. Furthermore, food security and livelihood issues are complex and a thorough understanding of the underlying relationships is necessary. To help generate this understanding, conceptual and simulation models are necessary. In this paper, we investigate the factors that have enabled subsistence farmers to succeed despite the previous shocks and stresses, and develop a system dynamics model for sustainable food security based on initiatives exclusive to the subsistence farmers. Most importantly, the model examines possible successful interventions tailored to different types of subsistence farms and specific contexts in which they operate. Ultimately, the paper provides a plausible answer to the question: how can innovative subsistence farmers engage in better livelihood and market orientated production irrespective of external public or donor support?

## 2. EXISTING FOOD SECURITY INTERVENTIONS

A number of successful food security interventions in sub-Saharan Africa have been reported in the literature. For the purpose of the discussion in this paper, three approaches are emphasized, namely: sustainable production intensification, organic green revolution for Africa, and seed banking.

### 2.1. Sustainable Production Intensification

Sustainable production intensification (SPI) goal is to produce more from the same area of land while conserving resources, e.g., through the application of conservation agriculture practices, the use of good seeds of high yielding varieties, integrated pest management, plant nutrition based on healthy soils, efficient water management, and the integration of crops, pastures, trees and livestock (FAO, 2011; Settle & Garba, 2011). One of the key success cases of SPI is in diversifying smallholder farms which can provide farmers opportunities for rebuilding soil fertility by enhancing nutrient flows and efficiencies while introducing new sources of food and nutrition for local populations (Settle & Garba, 2011). This in return gives farmers a greater choice in what they can sell, trade, eat or feed to animals, which in the long run would lead to greater economic and ecological resilience. The SPI intervention is knowledge intensive and hence thrives in an environment of functional extension services.

Settle and Garba (2011) report of successful implementation of SPI through farmer field schools in which 116,000 rice, vegetable, cotton and other farmers were involved in four West African countries. According to Settle and Garba (2011), the programme resulted in improved yields and incomes and at the same time, substantially reduced the use of chemical pesticides while improving the use of fertilizers and organic amendments. As a long-term sustainability measure, the programme was successfully integrated into local, provincial and national structures.

### 2.2. Organic Green Revolution for Africa

The organic green revolution for Africa was proposed by Otsuka and Yamano (2005) as an extension of the very successful and well reported Asia's green revolution. The organic

green revolution for Africa is a seed-livestock-agroforestry farming system meant for Africa whereby the use manure from cattle and leaves from agroforestry trees with nitrogen fixation capacity would increase soil fertility and hence yields. Initial adoption of this farming system in the Kenyan highlands area was successful. In practice, a typical farmer who employs this farming system cultivates feed crops and grows fodder trees with the capacity to fix nitrogen (i.e., agroforestry trees) on the farm, feeds the cattle in stalls, obtains manure from the stalls, and applies the manure or compost on crops such as maize or banana. When combined with improved maize varieties, the potential for doubling maize yield is high (Otsuka & Yamano, 2005). Another advantage of using manures on crops is that it facilitates retaining moisture on soil longer, which to a certain extent is an appropriate technology for the areas with less rainfall and irrigation facilities.

### **2.3. Seed Banking Initiative**

Seed banking is a holistic approach for empowerment of smallholder farmers through preserving seeds for future planting, diversifying into higher value crops and saving money from sale of surplus crops concurrently (Oyo, 2013). Accordingly, seed banking ensures that smallholder farmers do not lack the quantity and quality of seeds they need during planting seasons as well as access their savings to invest in necessary farm inputs for higher productivity (Oyo et al., 2012; Oyo, 2013). In effect, seed banking services are provided by a seed bank which is a community based organization that also offers agro-processing, agricultural produce marketing and extension services. As such, the seed bank buys harvested crops from farmers at competitive prices, processes them and sells the processed crops for profit, while maintaining a threshold amount of money that is converted into improved seeds and other farm inputs which farmers access during the planting season.

According to Oyo (2013), results from initial implementation of seed banking confirmed that supporting smallholder farmers in production, processing, produce marketing and preservation of seeds for future planning through seed banking initiatives strengthens subsistence farming, making it more profitable. Using available data from initial roll-out of seed banking and simulating over a period of five years, Oyo (2013) found that seed banking can transform the subsistence farmers' population into a prosperous people with a two hundred per cent (200%) rise in earnings. Moreover, the improved income is possible in parallel with abundance of food for consumption and excess seeds preserved for future planting.

Evidence from the three cases discussed here suggest that food security is sustainable when the interventions are pursued by the farmers themselves with basic external support especially on infrastructural development and input subsidies. We examine this insight further in the next section.

## **3. THE CASE FOR RESILIENCE IN FOOD SECURITY INTERVENTIONS**

Most food security programmes have been designed to increase productivity through technology driven intensification, while productivity is important, other related objectives must also be considered, especially by increasing resilience of the farmers themselves. Subsistence farming has always been a vulnerable enterprise due to a number of known factors that will not be reiterated here. As these factors escalate, farmers tend to endure because of their resilience through a variety of risk-coping strategies. Most importantly, successful subsistence farming occurs when external support from government, donors and NGOs complement farmers' self-provisioning initiatives. As such, the kind of external support varies from one farming community to another.

A deeper reflection on the effect of resilience and external support on food security reveals several unique conceptual behaviors as show in Figure 1.

The nature of external support implied in Figure 1 include the following:

- Subsidizing expensive farm inputs;
- Providing access to affordable fertilizers;
- Extension services intensification such as farmer field schools on better farming methods, soil conservation methods and post-harvest handling techniques;
- Infrastructure development through improved road network, small-scale irrigation schemes, and provision of small and medium size food processors;
- Providing access to farm improvement finances/loans;
- Structuring of food/produce markets to ensure that farmers sell processed food and not raw food.

As depicted by Figure 1, four unique food security behaviors are possible when the nature of external support and resilience are considered simultaneously. The issues of concern for each behavior are as follows:

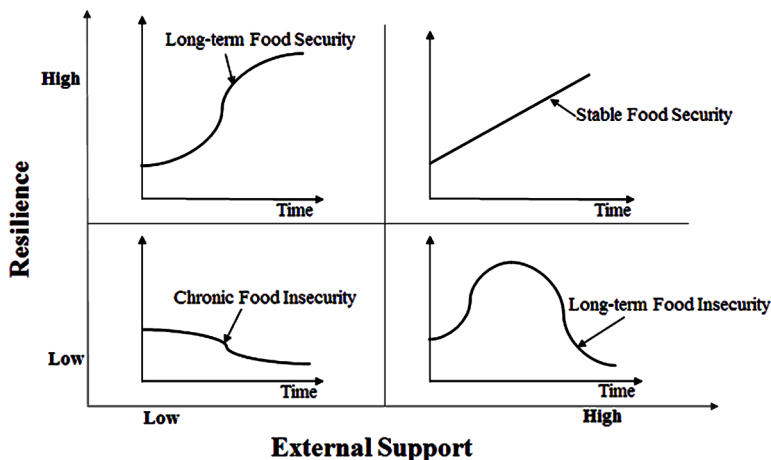
### 3.1. Chronic Food Insecurity

Chronic food insecurity in the context of Figure 1 would occur when both resilience and external support are low. In this case, the farmers are unable to meet their minimum food production requirements over a sustained period of time. As such, the farmers resort to copying strategies that further escalate their vulnerability such as: eating less food, reducing the number of meals per day, purchasing food, changing diet, selling assets to buy food, borrowing money for food, receiving food from relatives or the community, increasing consumption of wild plants and animals, leasing land to other farmers, taking children out of school, and receiving food aid from government/charity organizations. From our experience on livelihood projects involving farmers with the aforementioned copying strategies, increasing external support may alleviate the problem only for a short period of time, but cannot provide a long term solution unless their resilience is improved simultaneously.

### 3.2. Long-Term Food Insecurity

Over dependence on external intervention without self-supporting initiatives leads to short lived food security but long term food insecurity as shown in Figure 1. This category of farmers believe in constant flow of seeds for planting and other basic inputs without which their production capacity falls

Figure 1. The effects of resilience and external intervention on food security



below minimum levels required for provision of household food needs. Again due to low resilience towards self-provisioning, external interventions cannot yield significant impact, resulting into food insecurity in the long-term or rather a better-before-worse behavior.

### 3.3. Long-Term Food Security

This is the category of self-reliant farmers with the following characteristics:

- Preserving seeds for future planting seasons;
- Storing food for future household needs in case of turbulences in projected production;
- Using soil conservation methods like mulching, contour farming;
- Applying small-scale irrigation initiatives;
- Invest in agriculture through improved seeds, fertilizers, pesticides, ox plough, and extension services;
- Focusing on selling processed produce whenever applicable;
- Using diversified farming practices by integrating livestock with crop production;
- Having access to adequate land and water.

The above characteristics apply to people who practice farming both as a business and for their livelihoods and therefore are able to thrive with minimal external intervention.

### 3.4. Stable Food Security

Stable food security is an ideal scenario whereby farmers' initiatives are complimented by external intervention in such a way that the net effect is a food secure community. In effect the farmers are self-reliant as in previous case and the external services provided, strengthens environmental resilience leading to stable food security.

In real-life, the achievable scenario given previous volatile external support to agriculture and food security in sub-Saharan Africa is the long-term food security that is based on farmers self-provisioning. We pursue this further in the next section.

## 4. SELF-PROVISIONING FOR LONG-TERM FOOD SECURITY

Most investments in subsistence agriculture and food security are realized by subsistence farmers themselves. This occurs through different modalities but mostly through labor investments to enlarge and improve the resource base, and to a lesser extent through personal savings and remittances from family members which are used for the acquisition of new/additional resources. However, these investments are limited since domestic needs receive priority when food, health or education expenditures are at risk. Innovative initiatives are thus needed to empower households into self-provisioning and long-term food security. We demonstrate these initiatives in Table 2.

The insights from Table 2 and Figure 1 further inform the system dynamics model discussed in the next section.

## 5. THE SYSTEM DYNAMICS MODEL PERSPECTIVE

In system dynamics terms, we might characterize the practices leading to the subsistence farmers' food security resilience in terms of identifiable stocks. As pointed out by Hassanien et al. (2015), any given stock might be sustainable if the flows in are greater or equal to the flows out of the stock, the agricultural production cycle from planting, harvesting, post harvesting, consumption and sale of surplus food, consists of several stocks that can be maintained by managing the inflows and outflows. Resilience in this cycle is achievable by considering adaptation strategies that would minimize any

Table 2. Strategies for self-provisioning and long-term food security

Strategies	Description	Implications to Subsistence Farming
Investment in inputs	All agricultural activities are investments and farmers need to cost their investment in farming and determine profit/loss	Every cost ranging from land, labor and inputs (seeds, fertilizers, pesticides, etc) to post harvest handling must be computed. In cases where the farmer uses own land, labor and seeds, then local market rates for these should be used. In doing so, a new perspective of farming as a business and means of livelihood becomes the foundation of subsistence practice.
Seeking appropriate extension services	Extension programmes can be unique to a community and in some cases applicable to several communities	For profitable farming, farmers should stick to better crop varieties that offer higher yields, but use less water, fertilizer or other inputs and are more resistant to drought, heat, submersion, and pests and diseases. Extension services should address specific and general needs of a farming community.
Ensuring access to better markets	The need for direct links between producers and consumers is necessary in ensuring that the producers sell higher value processed goods	Smallholder organizations and collective action are crucial for penetration into the domestic, national, and regional markets for higher returns. Higher returns becomes the goal seeking behavior for higher production.
Re-designing community self-empowerment programmes	Focus on community programmes initiated by the community for self-empowerment	Farmer groups need to pull resources for self-empowerment through improved seeds, small scale field machinery, and small scale food processing.
Preserving food and seeds for future consumption and future planting	Households are food secure when they can preserve food for future consumption and seeds for future seasons	It is increasingly becoming difficult for subsistence households to preserve food and seeds for future needs, except for resilient households. These exceptional households could be benchmarked by the rest in achieving holistic community culture of food and seeds preservation.
Diversifying livelihoods	Integration of livestock in the farming system	Livestock and crop farming complement each other. It has been found that most progressive subsistence farmers are engaged in crop and livestock production (Fan et al., 2013; Otsuka & Yamano, 2005).
Increasing saving from agricultural income	Formation of community saving schemes, e.g., saving clubs or saving societies to minimize shocks due to market failures	The community saving schemes are a necessary source for faster loans for investment in farming to increase production and income. Existing saving schemes focus on end of year celebrations only and these could be diversified.

disturbances arising from sudden large changes to the outflows. For example, extended rains beyond the harvesting period would limit sunshine that is needed for drying the harvested crops and the farmers' response would be to process the raw food itself.

### 5.1. Related System Dynamics Models

Oyo (2013) analyses system dynamics models for food security over the period 2001-2011 and finds that these models are more qualitative than quantitative based. Interestingly, none of the models reviewed focused on Africa's situations. Between 2011 and 2015, however, system dynamics models for agricultural development and food security in sub-Saharan Africa have been studied at an impressive rate. The remainder of this section focuses on these recent studies. Kopainsky et al. (2012) examine sustainable food security policies in sub-Saharan African countries from social dynamics perspective, maintaining that social dynamics override adoption of effective food security policies. In the same study area scope, Saldarriaga et al. (2013) explore stakeholders' views on dynamic complexity of climate change, agriculture and food security. Other studies have focused on individual sub-Saharan

African countries such as: Oyo (2013) on system dynamics model for food security and livelihood at subsistence farmer level in the Uganda; and, Ayenew and Kopainsky (2014) on food insecurity issues using system dynamics simulation model for the effects of population, food production and markets in Ethiopia.

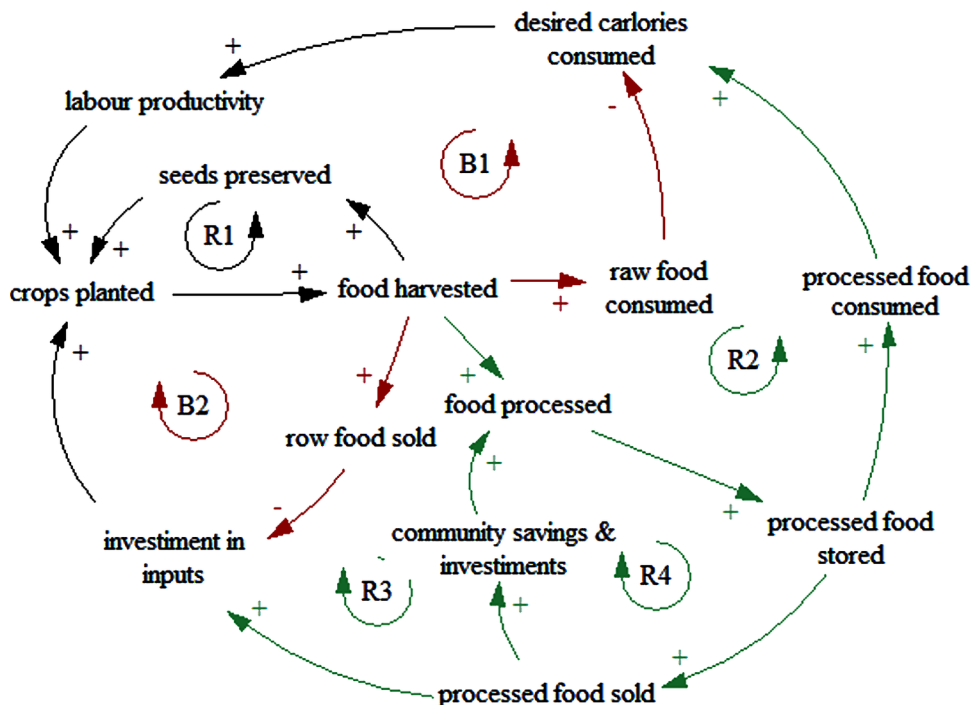
From the previous chapter, it is clear that research on food security issues in sub-Saharan Africa using system dynamics modeling is still at its infancy with the first published work dating 2012. This study therefore extends previous work by providing a generic system dynamics model using stocks and flows for sub-Saharan Africa's subsistence farmers' situations, leaving room for adaptation to specific environments with actual data.

## 5.2. Model Scope

The issues discussed in relation to Figure 1 formed the basis for the model scope. The focus of the model therefore is to experiment scenarios for the four unique food security behaviors categorized as: stable food security, long-term food security, long-term food insecurity and chronic food insecurity. These behaviors take place at household level and hence the model should be tested using household data. Since the model is meant for sub-Saharan Africa's subsistence farmers' situations, we present the generic stocks and flows in this first version, leaving room for adaptation to specific environments and subsequent simulation and analysis. These stocks and flows are based on underlying feedback for food security and food insecurity scenarios at subsistence farmers' levels as shown in Figure 2.

Figure 2 is the basic feedback loops depicting food security scenarios (green labeled loops, R2, R3 and R4) and food insecurity scenarios (red labeled loops, B1 and B2). The black labeled loop R1 is cross-cutting. In the context of this research, Figure 2 covers all the four unique food security behaviors, i.e, chronic food insecurity is depicted by loop B1 and loop B2; long-term food insecurity differs from chronic food insecurity by additional loop, R1. Similarly, long-term food security is

Figure 2. Underlying feedbacks for food security/insecurity scenarios



represented by loops R1, R2 and R3 while stable food security is depicted by loop R4 on addition to long-term food security representative loops.

From the basic feedbacks in Figure 2, six important scenarios at subsistence farmers' level can be studied. These include:

- Producing different types of food for domestic and commercial purposes;
- Resilience to shocks and stresses caused by climate change, soil fertility change, food production land change, and changes in food prices;
- Minimizing food losses in the garden, at harvest, and during post-harvest handling and storage;
- Maximizing income from food sales;
- Avoiding gaps in seeds for planting and basic inputs;
- Collective investment in extension services.

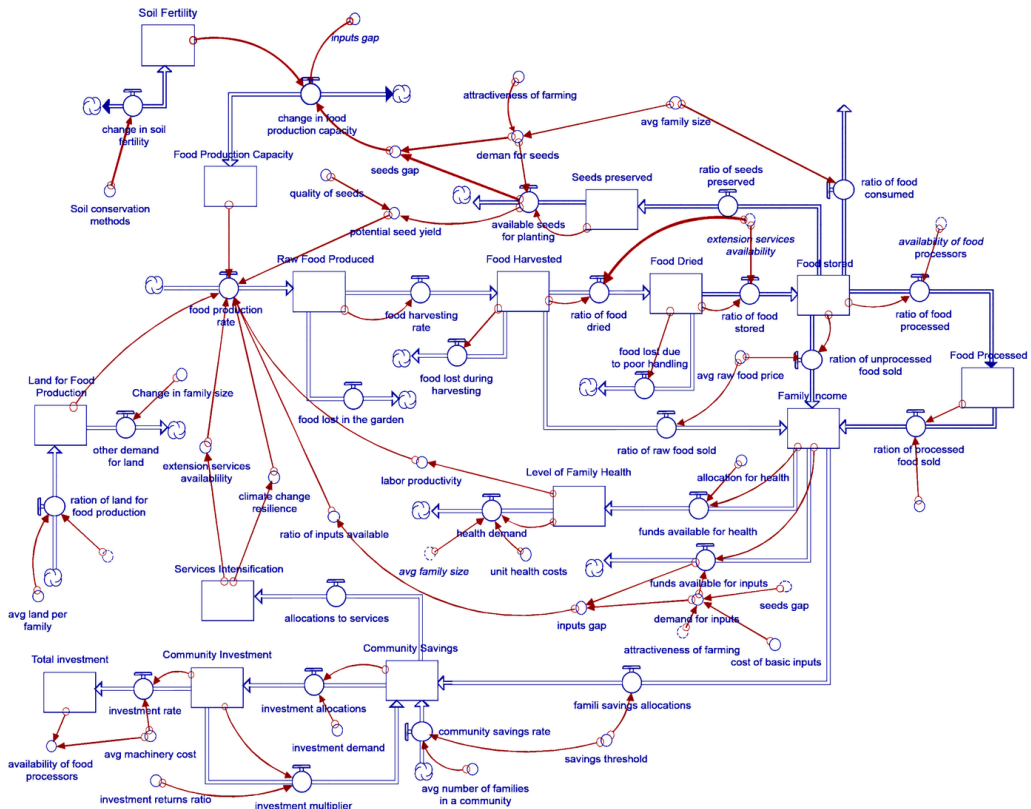
We explore these scenarios using stocks and flows in the next section.

### 5.3. Model Stocks and Flows

Following from Figure 2 and the six important subsistence farmers' scenarios discussed in the previous section, the conceptualized stocks and flows diagram is given in Figure 3.

In discussing the model in Figure 3, we extract a part of Figure 3 in the context of each of the six areas as already outlined, i.e., food production management, promotion of resilience, minimizing food

Figure 3. Stocks and flows diagram exploring livelihood and commercial production



losses, maximizing income from food sales, minimizing gaps in inputs, and collective investment in extension services, and re-construct the underlying feedbacks structure whenever necessary.

### 5.3.1. Goal of Food Production

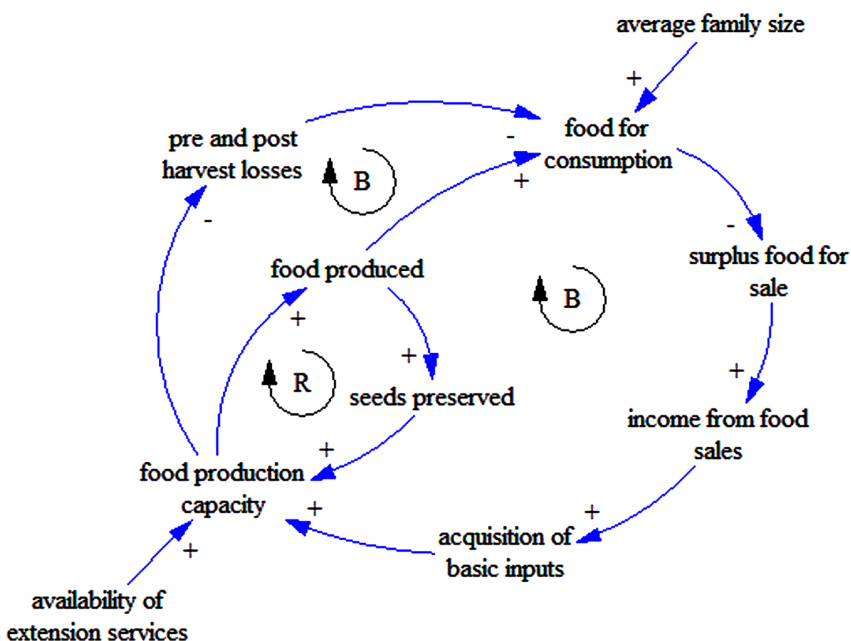
The default reason for subsistence farming is food production for domestic consumption. However, due to overlapping basic needs, subsistence farmers find themselves selling their food and leading lives of severe food shortages. The model in Figure 3 shows that livelihood and commercial production can be achieved concurrently when factors centered on collective action by individual farmers as well as farmers' groups, are emphasized. In addition, the importance of households preserving seeds for future planting while investing in inputs and saving income from food sales, culminate into the general goal for food production. This goal seeks to achieve adequate food for consumption, income from food sales and strengthening of food production capacity. The feedback structure corresponding with this general goal is given in Figure 4.

### 5.3.2. Nature of Resilience

In real-life, shocks and stresses are caused by climate change, soil fertility change, food production land change, vulnerability of food allocation for food and for sale. Building resilience to these shocks and stresses stems from advance preparations in anticipation of their occurrence as well as strong public mitigation and recovery mechanisms. Since the focus of the model is on household initiatives for self-provisioning through resilience, the indicators of this goal include: control factors for the *bi-flows* of food production capacity; level of service intensification and community investment stocks; ensuring that the ratio of seeds preserved corresponds with household needs; and ensuring that the ratio of food processed is higher than the combined ratio of raw food sold and unprocessed food sold. The corresponding feedback structure for the resilience strategies as just highlighted is given in Figure 5.

One of the key strategies in attaining resilience is to separate production of food for cash and food for consumption, in order to understand farmers' priorities and design effective support mechanisms.

Figure 4. Feedbacks structure for basic food production goal





## 5.4. Policy Analysis

By convention, simulation experiments inform policy analysis. In the context of the generic model given in Figure 3, we propose some policy directions that can be investigated when the model is adapted to specific environments. These include:

- Separating production of food for cash and food for consumption as these are different goals and in some cases having unique requirements. For cash crops, production and processing need to be addressed concurrently, while for food crops, focus should be placed on production, post-harvest handling and storage;
- Building capacity for crop production at both family level and community level. The basic production requirements such as: access to land, preservation of seeds for future seasons and provision of human labor, should be addressed at family level. Other expensive production inputs such as acquiring high-yielding seed varieties, ensuring integrated pest management, and supporting small-scale irrigation, should be addressed at community level;
- Reducing waste and losses right from crop planting to food consumption. For instance, knowledge of seeds spacing is critical in avoiding planting excess seeds per unit land area. Similarly, families that are prone to food shortages are known to waste food for consumption when their harvests are good;
- Ensuring functional markets for processed food and not raw food.

The policy directions presented here can be examined further and new policies explored when the model is adapted to specific environments.

## 6. CONCLUSION

In this paper we have made and supported the claim that sustainable food security at subsistence farmers' level stems from building resilience, short of which renders the farmers susceptible to chronic food insecurity or at least long-term food insecurity. A conceptual analysis of the effect of resilience and external intervention revealed four unique behaviors categorized as: stable food security, long-term food security, long-term food insecurity and chronic food insecurity. The answer to the question examined in this paper on seeking strategies for which innovative subsistence farmers can engage in better livelihoods and market orientated production irrespective of external public or donor support, was tied to self-provisioning interventions for long-term food security. Eight key strategic issues were discussed to this effect, revealing that when subsistence farming is practiced both for business and livelihood, then, long-term food security is achievable even with minimal external support.

From a more practical perspective, a system dynamics stocks and flows model was developed to further examine how subsistence productions can be more commercial and market oriented. Subsequently, six scenarios for which the subsistence farmers can engage in livelihood and profit productions simultaneously were analyzed. These include: producing different types of food for domestic and commercial purposes; resilience to shocks and stresses caused by climate change, soil fertility change, food production land change, and changes in food prices; minimizing food losses in the garden, at harvest, and during post-harvest handling and storage; maximizing income from food sales; avoiding gaps in seeds for planting and basic inputs; and collective investment in extension services.

What remains to be seen is how the generic model given in Figure 3 can be extended and adapted to specific environments in sub-Saharan Africa using actual data. These case studies would then confirm or disqualify the propositions for achieving long-term food security at household level.

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