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Supply Chains in Sub-Saharan Africa: A Decision Support System for Small-Scale Seed Entrepreneurs

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Abstract

It is necessary to infuse a consistent supply of improved seed varieties into local sub-Saharan African crop production to improve low crop yields. The best distribution channel for the improved seed varieties may be small-scale commercial seed companies, but local entrepreneurs struggle to determine whether such businesses are viable. Using a multi-echelon supply chain approach, a decision support system (DSS) was designed to help African seed entrepreneurs make informed decisions about small-scale seed chain businesses. Specifically, entrepreneurs make decisions about where to locate seed enterprises, with which farmers to contract, and where to store seed. Optimization and simulation modeling are used to evaluate infrastructure variables such as distance, transportation cost, and storage loss and cost in three development level areas. Currently, the decision tool is used in Mozambique, Malawi, Kenya, and Tanzania. The model has supported the start-up of at least 17 small seed companies that are now introducing improved seed varieties into villages and farms. The DSS applies decision science research in a humanitarian application and offers important managerial implications about supply chain infrastructure to nongovernmental organizations and humanitarian groups. Such applications are vital as groups such as USAID, the Gates Foundation, and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) continue to move toward micro-enterprise, value chain, and market-oriented development programs.

Keywords

Africa, Decision Support Systems, Entrepreneur, Seed, Supply Chain Modeling

Disciplines

Agricultural Science | Entrepreneurial and Small Business Operations | Operations and Supply Chain Management | Strategic Management Policy | Technology and Innovation

Comments

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Supply Chains in Sub-Saharan Africa: A Decision Support System for Small-Scale Seed Entrepreneurs*

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ABSTRACT

It is necessary to infuse a consistent supply of improved seed varieties into local sub-Saharan African crop production to improve low crop yields. The best distribution channel for the improved seed varieties may be small scale commercial seed companies, but local entrepreneurs struggle to determine whether such businesses are viable. Using a multi-echelon supply chain approach, a decision support system (DSS) was designed to help African seed entrepreneurs make informed decisions about small-scale seed chain businesses. Specifically, entrepreneurs make decisions about where to locate seed enterprises, with which farmers to contract, and where to store seed. Optimization and simulation modeling are used to evaluate infrastructure variables such as distance, transportation cost, and storage loss and cost in three development level areas. Currently, the decision tool is used in Mozambique, Malawi, Kenya, and Tanzania. The model has supported the start-up of at least 17 small seed companies that are now introducing improved seed varieties into villages and farms. The DSS applies decision science research in a humanitarian application and offers important managerial implications about supply chain infrastructure to non-governmental organizations and humanitarian groups. Such applications are vital as groups such as USAID, the Gates Foundation, and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) continue to move toward micro-enterprise, value chain, and market-oriented development programs. [Submitted: September 17, 2010. Revised: May 2, 2011; November 8, 2011; February 19, 2012. Accepted: February 27, 2012.]

Subject Areas: Africa, Decision Support Systems, Entrepreneur, Seed, Supply Chain Modeling.

INTRODUCTION

Many sub-Saharan African countries struggle to meet the basic food and nutritional needs of their people. Perhaps the most troubling trend in sub-Saharan African agriculture is that per capita grain production is more than 10% below the pre-Green Revolution level (FAO, 2005). In contrast, per capita grain production has doubled in East Asia and the Pacific over the same period (Minot, Smale, Eicher, Jayne, Kling, Horna, & Myers, 2007). There are many reasons for this stark difference (e.g., cost of fertilizer, lack of water, crop mix, lack of infrastructure, extremely low population densities), but one important contributing factor is the lack of a formal seed supply chain capable of infusing a consistent supply of improved genetics and crop varieties into local crop production (Minot et al., 2007; Brown & Funk, 2008).

The application of decision sciences in humanitarian efforts is gaining interest in the research community. OR/MS research has been sparsely applied to humanitarian efforts compared to research in the social sciences and humanities, necessitating the call for greater research (Altay & Green III, 2006). Some have responded by applying logistics and supply chain management to disaster relief (Van Wassenhove, 2006; Gyöngyi & Karen, 2007; Mustafa, Nebil, & Manuel, 2010). Indeed, the June, 2011 *Interfaces* issue was devoted entirely to humanitarian applications of OR/MS.

Although evidence suggests that commercial seed demand has been underestimated, formal seed supply chains capable of sourcing, conditioning, and distributing seed to meet the needs of African farmers are lacking (Tripp & Rohrbach, 2001; Tripp, 2006). In some regions, a complex informal seed supply chain does exist at the village-level, but this system of seed lending only distributes unmodified seed saved from previous harvests and perpetuates the low-yield problems plaguing the region (Rohrbach, 1997; Almekinders & Louwaars, 2002). Formal seed systems are absent for several institutional reasons including highly regulated local markets that inhibit commercial development and government donor programs that discourage commercial seed supply chains by offering free or subsidized seed (Tripp & Rohrbach, 2001).

In addition to the many institutional blocks to formal commercial seed supply chain development, profit margins for commercial seed companies are small. “If the full costs of source seed, seed inspections, and advisory services are included, the probability of maintaining a financially viable enterprise…is very low” (Tripp & Rohrbach, 2001, pp. 158). Examples of successful small-scale commercial seed production do exist. For instance, an experimental program in Zimbabwe sold seed, priced at full commercial levels, and virtually all the seed was sold during the 1998/1999 planting season (Tripp & Rohrbach, 2001). In Ghana, seed growers have contracted farmers to raise foundation seed, which is conditioned and sold to seed dealers (Lyon & Afikorah-Danquah, 1998). In Uganda, “case studies confirmed that small-scale African farmers can be organized and motivated to produce and sell good quality bean seed” (Soniia, 2004, pp. 396). Although the success rates of such projects are low, the concept may offer the best development solution for viable seed supply chains capable of introducing improved crop varieties and genetics into sub-Saharan African countries.

The future success of small-scale commercial seed production depends partially on understanding and operating supply chains, from foundation seed inputs through distribution and sales of seed. This includes identifying local markets which have the highest probability of success based on supply chain factors such as transportation rates and local infrastructure, seed proliferation and conditioning costs, and storage and distribution costs. Potential market issues and market penetration rates are also critical factors (Dorward, Kydd, & Poulton, 1998). In Africa, these supply chain factors are extremely dynamic between different markets, and the geographic market sizes are limited because of infrastructure issues (Ghosh & Craig, 1984).

Furthermore, environmental, institutional, and cultural contexts are key drivers in developing economies (Brouthers, 2002; Cavusgil, Chan, & Zhang, 2003). Finally, a framework used to identify parameters causing behavior patterns by crop and region suggests that farm density and farmer attitudes towards innovation influence the effectiveness of retail seed networks (Kopainsky & Derwisch, 2009). Local entrepreneurs have the most complete understanding of the stark differences that exist between the small geographical markets within the African seed industry and the need to explore small-scale seed operations.

Although local entrepreneurs are willing and able to identify factors that determine the viability of small-scale seed chains, understanding the effect of such factors is difficult for even the savviest entrepreneur. Still, successful integration of supply chains requires both access to and use of supply chain information and models to make decisions (Min & Zhou, 2002). While some supply chain management models exist that evaluate seed systems in Africa (e.g., Cunningham, 2001; Almekinders & Louwaars, 2002; Melnyk, Lummus, Vokurka, Burns, & Sandor, 2009; de Boef, Dempewolf, Byakweli, & Engels, 2010; Sperling & McGuire, 2010), many research and practitioner opportunities remain unexplored.

In this paper, a supply chain, spreadsheet-based decision support system (DSS) model is presented that helps African seed entrepreneurs understand and manage small-scale seed chains. Often, researchers from multiple disciplines must collaborate in order to offer methods for developing multi-stage supply chain models (Carter & Narasimhan, 1996; Carr & Smeltzer, 1999; Giunipero, Handfield, & Eltantawy, 2006) and to discuss decision variables and performance metrics associated with the problems the models are intended to solve (e.g., Beamon, 1998; Swaminathan, Smith, & Sadeh, 1998; Min & Zhou, 2002; Manuj, Metzer, &

Bowers, 2009). Our model relies heavily on the methods and variables offered by these researchers and the application of a supply chain mapping exercise.

To help African seed entrepreneurs understand and make business decisions regarding purchasing and distribution of seed, we construct a DSS that allows users to simulate high levels of variability in several factors influencing seed-related business decisions. Users choose how many tons of seed to store at different types of storage facilities and locations, while incorporating demand and production characteristics such as location, yield, transportation distances, and storage loss into their decisions. Because spreadsheets are readily available and conceptually attainable by African seed entrepreneurs, the DSS was developed using a spreadsheet platform, thus increasing potential adoption. Azad, Erdem, and Saleem (1998) describe the challenges in bringing information technology to developing countries in terms of selecting appropriate technology based on environmental factors unique to the developing country. A DSS using spreadsheets is appropriate for African seed entrepreneurs because they are familiar with both the seed environment and the technology.

The goal of this research is two-fold. First, the research project provides local African entrepreneurs a DSS to make better-informed decisions using local data available at the village level. Second, we demonstrate how the DSS can be used to model highly variable supply chain infrastructure parameters and conditions that exist in Africa. The model results offer insight for non-governmental organizations (NGOs) and other humanitarian based organizations as they allocate their resources.

The following section describes the specific requirements of this model and links the model to supply chain principles. The DSS model for African seed chains is then presented and described with emphasis on the model's functionality, usability, and deployment. Next, simulation and optimization are incorporated into the model, offering insight into the effects of supply chain infrastructure on seed enterprise development. Finally, the implications and conclusions section describes the DSS impact and discusses its implications.

REQUIREMENTS AND SUPPLY CHAIN MAPPING

A DSS for assisting African seed entrepreneurs to understand and manage small-scale commercial seed companies requires the practical application of supply chain principles and modeling techniques. We use a supply chain approach, which includes concepts related to location analysis, operations, transportation, inventory and storage, and distribution. The model was developed with input from several agricultural development experts. These experts have over 80 years combined experience working in developing country seed research and related projects. The experts on sub-Saharan African seed were instrumental in describing basic requirements of the spreadsheet model. Based upon the direction of the expert advisors, the end users were defined as seed entrepreneurs or seed alliance officials who advise potential seed entrepreneurs. In both cases, the spreadsheet model needed to be simple, accessible, and useful to entrepreneurs with a limited degree of education.

A group of African seed practitioners and experts met for a three day conference during which a formal group process mapping procedure was employed. From the supply chain mapping exercise and literature, important design features and specific needs were identified, resulting in a detailed supply chain flow map of a small scale African seed supply chain. As the supply chain mapping process developed, the group of experts identified complex supply chain relationships and issues, key variables, product flows, risks, and various players.

For example, the group quickly recognized that a theoretical trade-off exists between the size of a seed conditioning plant and potential market size limited by high transportation costs.

On one hand, a larger seed conditioning plant offers operational economies of scale and can even improve the quality of the conditioned seed. On the other hand, larger plants mean that more seed would need to be shipped greater distances, becoming cost prohibitive because of transportation expenses (the section “Analysis Using DSS” contains a more complete discussion of this tradeoff). The group also found that it was difficult to quantify basic input variables such as transportation rates and distances, crop yield, demand, and inventory costs including storage, loss and damage, and pest control. Empirical data needed to populate the variables gleaned from the process mapping activity were unknown, highly variable, and dependent on each small market location and crop. Therefore, the effective application of this DSS must be finely granular because only at the local level do people possess the knowledge needed to make informed decisions about their seed supply chains. Until now, those with the local knowledge did not have the decision tools available to use the data they possess.

Four major supply chain echelons were identified using the supply chain mapping exercise (Figure 1). First, plant breeding occurs and varieties are released through a “variety release system,” which is unique by country. In most sub-Saharan African countries, governments mandate the release of the varieties, because they attempt to control the type and condition of seed sold and grown (e.g., non-GMO seed). Additionally, each country’s requirements for release are unique, so large scale production between countries is rare. The government’s control over the release of varieties may relate to concerns about general crop genetics, such as genetically modified organisms and intellectual property rights, or may result from political issues. Newly released varieties are called foundation seed. Activities in this first echelon (known as the Foundation Seed and Variety Release Program) are largely out of the control of local seed entrepreneurs, so the process mapping activities focused on echelons 2, 3, and 4. Each of these major echelons became inter-connected process flow maps, providing the framework for the seed chain DSS spreadsheet model. The following sub-sections (by echelon) describe the process used to develop the model.

Insert Figure 1 about here

Foundation Seed and Contract Growers

Procuring and proliferating the foundation seed occurs in echelon 2, which is the first major echelon controlled by the entrepreneurs. Plant breeding and varietal release are highly regulated in most sub-Saharan African countries, so foundation seed is usually available at a set price through local governments. Once foundation seed is purchased, local farmers (contract growers) raise a crop, proliferating the seed under contracted terms. Most sub-Saharan African farms are small (less than 2 hectares), so each small scale commercial seed entrepreneur contracts with multiple growers to meet minimum scale requirements. At the conclusion of echelon 2, the entrepreneur owns proliferated seed, referred to as “green seed,” in storage facilities or at a seed conditioning facility. Figure 2 provides a high-level process map of echelon 2.

The major nodes in echelon 2 include purchasing foundation seed, grower transaction costs (i.e., contracting with, inspecting, and educating the growers), seed certification (i.e., government inspections needed to certify the seed), and green seed harvest (yield). The transaction activities and the seed certification nodes between the contract grower and the green seed harvest nodes are connected by links. Therefore, green seed cannot be harvested before transaction activities and seed certification activities occur. Also, two other links are important to this echelon. First, foundation seed is transported from its source to each contract grower. Second, harvested green seed is transported from each contract grower to storage and/or to the conditioning plant. Several supply chain input and decision variables related to location, operations, transportation, inventory and storage, and distribution were identified. These variables will be discussed in the section on the DSS spreadsheet model and its deployment.

Insert Figure 2 about here

The process mapping exercise highlights the need to evaluate each contract grower independently, because each represents a separate supplier relationship with unique terms and trust levels. For example, transportation costs are quite high in many locations due to poor infrastructure, and transaction costs vary greatly between growers. Therefore, the landed costs of seed to a storage facility or to the conditioning plant may be substantially different from one grower to another. The model also must allow for multiple types of contracts, storage, and transportation.

Seed Storage and Conditioning

The third echelon, Seed Storage and Conditioning, begins where the Foundation Seed and Contract Growers echelon finishes. After leaving the contract grower farms, the green seed is either delivered to a storage facility or directly to a conditioning facility. Here, the green seed is not associated with individual farms. The seed passes through pre-conditioning storage, conditioning, and post-conditioning storage nodes. Due to conditions such as weather, theft, pests, and poor storage facilities, high storage losses are considered normal in many areas of sub-Saharan Africa. Once again, the links represent seed transportation between farms (echelon 2), storage (owned and rented) and the conditioning plant. These transportation costs are extremely important because they are highly variable and can represent a high proportion of the final costs of goods sold.

Figure 3 is a high level process map of the Seed Storage and Conditioning echelon. "Discards" are the eliminated material sold by the entrepreneur to the conditioning plant (re-sold by the plant as livestock feed), but the value is minimal. Good green seed is treated with chemicals to help maintain quality. Finally, the seed is certified for germination and variety, labeled, and bagged. Because of storage loss and conditioning discards, the quantity of conditioned seed is less than the quantity of green seed harvested.

Insert Figure 3 about here

The Seed Storage and Conditioning echelon (echelon 3) is completed when the seed, stored either at the plant or at rented or owned storage facilities, is loaded for transport to a distributor. At this point, the total cost per ton of conditioned seed is known, and is based on the variable inputs estimated by local entrepreneurs. The cost per ton of conditioned seed is not the final cost of goods sold; this is due to transportation costs to the distributer.

Distribution and Marketing

Distribution and Marketing comprises the fourth and final echelon in the seed chain mapping process. The conditioned seed is transported to multiple distributors, each located in different villages of varying distance from the conditioning facility. In this echelon, supply chain principles inform the inclusion of several important input variables that must be estimated by the entrepreneurs. First, the seed distributors must be chosen based on trustworthiness, sales potential, and profit margin. Next, the entrepreneurs must set prices and estimate demand. While estimating demand and market share has been the topic of much research, it is not our focus. Rather, our objective is to develop a DSS to assist African seed entrepreneurs in making decisions regarding small-scale seed chain businesses based on their estimated input parameters, especially those related to supply chain infrastructure.

The input variables in echelon 4 affect decisions and outcomes in the other echelons. In fact, decisions in the Distribution and Marketing echelon must be made before decisions in the Foundation Seed and Contract Growers echelon (echelon 2). This highlights the need for an iterative decision model that allows the users to experiment with various demand and supply parameters. Echelon 4 also highlights the need to evaluate each distributor independently. Transportation costs, sales, and the profitability of one distributor might be extremely different from the profitability of another.

DSS SPREADSHEET MODEL AND DEPLOYMENT

We developed the seed chain DSS model using a spreadsheet framework based on the strengths and weaknesses of spreadsheet models, objectives, requirements, and results from the supply chain mapping exercise. Spreadsheet packages are ubiquitious, and users have become quite comfortable with their operations (Ragsdale, 2001). Applications of spreadsheet based DSS's are numerous, ranging from water resource planning in China (Weng & Chai, 1992), to inventory control (Sobotka, 1998), to creating golf teams (Ragsdale, Scheibe, & Trick, 2008). However, simply developing a spreadsheet DSS is insufficient for complex decision criteria. Designers of DSS are called to integrate appropriate decision analysis tools for robust systems (Bhargava, Sridhar, & Herrick, 1999). Novak and Ragsdale (2003) used spreadsheets to solve stochastic multi-criteria linear programming (LP) problems, and Zhong (1991) used simulation to plan water supply systems. Scheibe et al. (Scheibe, Carstensen, Rakes, & Rees, 2006) used geographic information systems (GIS) and integer linear programming (ILP) to plan broadband wireless networks. While many models focus on a single part of larger supply chains (i.e., inventory control, operations, or transportation), we used a comprehensive supply chain approach to model the African seed supply chain. The expected users have limited spreadsheet knowledge and are not familiar with advanced modeling or mathematical concepts. Moreover, user adoption depends upon confidence in the spreadsheet results, so the modeling techniques must be understandable to an audience that is less sophisticated than the traditional OR/MS academic.

The supply chain mapping framework discussed in the previous section provided the general framework for the model. The model was developed in four spreadsheet sections. The first section is an input section for major variables including the company name, owned storage capacity, and currency. Also, the names of up to five types of crops can be entered in this section; this allows seed entrepreneurs producing and marketing multiple crops (i.e., maize, ground nuts, rice and sorghum) to use a single spreadsheet model to manage all crops. Finally, the names of up to eight contract farmers and eight seed distributors can be included in this section.

Next, tabs were added with names corresponding to the echelons discussed in the previous sections: “Foundation Seed and Contract Growers,” “Storage and Conditioning,” and “Distribution and Marketing.” The input variables and calculated cells for these tabs follow the logical flow of a seed supply chain, which helps meet our requirement for a simplistic model that will be trusted by users with limited spreadsheet modeling skills. Together, the four tabs form a single model. However, because each entrepreneur may market multiple crops, multiple tabs were added for each echelon, based on the user’s input on the setup tab. For example, “Foundation Seed and Contract Growers” tabs are available for any five crops named by the entrepreneur (e.g., maize, sorghum, ground nuts, cotton, peas).

The model maximizes expected profit. Revenue is available by selling seed at distributors and from selling discards to the conditioning facility. Major costs include foundation seed, the contracted price of green seed purchased from the farmers, and transaction and certification costs. Next, pre- and post-conditioning storage and maintenance costs are considered, as well as conditioning costs. Finally, transportation costs between the nodes are considered. Important model constraints ensure that enough conditioned seed is grown and conditioned to meet demand and that storage limitations are considered.

Mathematical Model

We first define the notation for the seed entrepreneur's profit maximization problem in Table 1.

Insert Table 1 about here

The general simulation-optimization model follows.

$$\begin{aligned} \text{Max } \pi &= sv * \sum_{s=1}^{3} L_s * g_s(1-gl_s) + \sum_{d=1}^{n_d} p_d * d_d - \sum_{f=1}^{n_f} (h_f (p_x * r_f + p_f * y_f) + t_f) \\ &- \sum_{s=1}^{3} (g_s (gsc_s + gmc_s) + g_s(1-gl_s) * cc) + c_s (\mathrm{csc}_s + cmc_s) \\ &- rk\left(\sum_{f=1}^{n_f} \sum_{s=1}^{3} km_{f,s} * g_{f,s} + \sum_{s=1}^{3} \sum_{d=1}^{n} km_{s,d} * CS_{s,d} \right) \end{aligned} \quad (1)$$

st:

$$h_f * y_f \geq \sum_{s=1}^{3} \mathrm{g}_{\mathrm{f,s}} \quad \text{for } f = \{1 \ldots n_f\} \quad (2)$$

$$\sum_{f=1}^{n_f} g_{f,s} \leq K_s \quad \text{for } s = \{1 \ldots 3\} \quad (3)$$

$$g_s(1-gl_s)(1-L_s)(1-cl_s) = \sum_{\mathrm{d=1}}^{\mathrm{n_d}} \mathrm{CS_{s,d}} \quad \text{for } s = \{1 \ldots 3\} \quad (4)$$

$$d_d = \sum_{s=1}^{3} CS_{s,d} \quad \text{for } d = \{1 \ldots n_d\} \quad (5)$$

The objective function (Equation (1)) maximizes profit (π) for the seed entrepreneur. The decision variables are hectares contracted for each farm (h_f), tons of green seed stored at each storage location (g_s), and tons of conditioned seed stored at each storage location (c_s). The revenue component includes sales of discards and sales of conditioned seed. Discards are the percent seed discarded (L_s) of the total green seed after green seed storage loss (g_s*(1-gl_s)). Discards are sold at price sv. Seed (d_d) is sold at distributors for price p_d. Costs associated with echelon 2 include the price of purchasing foundation seed (p_x*r_f) and the price of purchasing the green seed from the farmers (p_f*y_f). These costs must be paid for each hectare (h_f) contracted with each farmer. The final costs associated with echelon 2 are transactions costs (t_f). Costs associated with echelon 3 include green seed storage (gsc_s) and maintenance costs (gmc_s) per ton of green seed (g_s), conditioning costs (cc) per ton of green seed after green seed storage loss (g_s*(1-gl_s)), and conditioned seed storage (csc_s) and maintenance costs (csm_s) per ton of conditioned seed (c_s). Finally, transportation costs are added. Tons of green seed ($g_{f,s}$) shipped from each farm to each storage location, and tons of conditioned seed ($CS_{s,d}$) shipped from each storage location to each distributor, are moved $km_{f,s}$ and $km_{s,d}$ kilometers, respectively. The resulting ton-kilometers are charged a rate of rk (per kilometer per ton).

Four constraints are imposed on the model. First, Equation (2) is a constraint set for green seed production and seed departure from farms to storage facilities. The total seed produced at each farm (h_f*y_f) must be greater than or equal to the total seed shipped from each farm to the storage facilities ($\sum_{s=1}^{3} g_{f,s}$). Next, Equation (3) is the constraint set for green seed arrivals. Green seed shipped to each storage facility must be aggregated ($\sum_{f=1}^{n_f} g_{f,s}$), and total arrivals cannot exceed the storage capacity at each storage facility (K_s). Based on input from the African seed experts and seed entrepreneurs, rented storage was not constrained, but owned and plant storage capacity is constrained. Equation (4) is the constraint set for inventory shrinkage, inspection losses, and departures from storage facilities to distributors. The green seed (g_s) remaining after green seed storage loss ($1\text{-}gl_s$), after discards are removed ($1\text{-}L_s$), and after conditioned seed storage loss ($1\text{-}cl_s$) at each storage facility is the amount of seed that can be shipped from each storage facility s to each distributor d, ($\sum_{fd=1}^{n_d} CS_{s,d}$). This constraint ensures that seed must be available before it can be shipped to distributors. Finally, Equation (5) is the constrain set for conditioned seed arrivals from storage facilities at distributors. This constraint requires combined departures from the storage facilities to each distributor ($\sum_{s=1}^{3} CS_{s,d}$) to be equal to the demand at each distributor (d_d).

The model is designed to help entrepreneurs both understand the interactions within the seed supply chain and make decisions. To accomplish this objective, costs and activities associated with each farm (contract grower) are listed separately (i.e., $1\ldots n_f$). Therefore, it is possible to evaluate the important variables (i.e., transportation expense and hectares contracted) affecting the cost of green seed on a farm-by-farm basis. Next, cost and benefit information is made obvious to inform decisions about storage alternatives (i.e., 1…3 where 1 = plant, 2 = rented, 3 = owned). Finally, landed cost and profit (π) estimates are detailed by distributor (i.e, $1\ldots n_d$).

The DSS was validated for functionality by experts on African seed, and entrepreneur users, and minor changes were made based on their feedback. However, the model continues to improve based on user feedback and change requests needed to accommodate new or evolving seed chain scenarios. Since the model's inception, several versions have been released. Prior to releasing new versions, all change requests are logged and updated ideas are discussed. A business development coordinator from the International Crops Research Institute for the Semi-

Arid Tropics (ICRISAT) determines which upgrades are made for each version. Final upgrade decisions are based on user needs and on the original intent and purpose of the spreadsheet. The new versions are sent to current users along with documentation describing the changes.

Training and Deployment

To implement the DSS, a week long train-the-trainer program was developed and taught to ICRISAT country representatives and personnel from the West African Seed Alliance (WASA) and the East African Seed Alliance (EASA), as well as to a small group of seed entrepreneurs. The program, held in Accra, Ghana, was attended by participants from the African countries of Ghana, Niger, Nigeria, Malawi, Tanzania, Benin, and Mozambique. As a group, we mapped the processes of the entire seed supply chain to highlight key relationships and to build confidence in our modeling approach. Using the spreadsheet DSS, participants were trained to assess risk on key variables and to evaluate market size based on distributor specific landed costs and expected demand-sales price relationships. These training exercises directly link theory related to location and operations with a practical application. The users were also trained to use the tool to identify markets with the greatest profit potential.

ANALYSIS USING DSS

The previous sections describe specific requirements of the DSS and the model used by African seed entrepreneurs. Functionality, usability, and deployment were emphasized in those sections. Our goal was to offer a humanitarian focused DSS to help entrepreneurs develop seed enterprises. In this section, the DSS model is used to analyze development and humanitarian efforts under various supply chain infrastructure conditions that exist in Africa. To accomplish this, simulation and optimization techniques are incorporated into the original model.

We also retain our objective of profit maximization for the seed entrepreneur. The expected profit maximization objective function is useful to show where seed supply chains are more and less viable, based on local infrastructure conditions and other selected input parameters. One could argue that focusing on profit maximization is not truly humanitarian in the sense of directly saving lives, supplying food to starving people, or providing safe drinking water (to name a few). However, the profit maximization objective function will allow NGOs or other humanitarian decision makers to consider the effects of infrastructure conditions on seed chain profitability when choosing where to expend resources. Research has shown that microloans offered to poor entrepreneurs for the establishment of profitable business have brought benefit not only to businesses but also to the poor households (Eversole, 2000; Dalglish & Tonelli, 2011;). The model presented in this research should be particularly interesting to organizations allocating resources based on USAID's "microenterprise development" concept, the Gates Foundation's "value chain" approach to development, or ICRISAT's "market-oriented development" strategy (USAID, 2006). If profitability is not possible, the profit maximization framework still identifies infrastructure conditions which enable seed enterprises to be relatively more or less profitable. For example, if infrastructure conditions prohibit profitability, humanitarian agencies may choose to invest in fixed cost assets, such as a seed conditioning facility or improved storage, to enable entrepreneurs to develop seed enterprises. Although such enterprises would not be economically viable on their own, the enterprise could become viable if fixed cost investments were made in improved storage or a conditioning plant.

For the simulation-optimization models, three development areas were chosen representing differing infrastructure conditions in Africa. The goal was to represent three vastly different scenarios in African development. The three areas of development were identified as “highly developed,” “moderately developed,” and “least developed,” based on factors such as agricultural practices, infrastructure, and knowledge diffusion. The terms are not strict development definitions defined by the World Bank or development researchers. Rather, the terms simply define areas used to discuss base-line differences in development. Accordingly, these terms must be understood in relation to sub-Saharan Africa, where “highly developed” has a different meaning than it does in an industrialized nation.

Parameters for the three development areas used in this paper represent possible scenarios based on input from African seed system experts and trainers from the train-the-trainer session. In addition to the African seed experts and the trainers, three entrepreneurs using the DSS to develop seed enterprises offered insight into the model parameters.

The uncertain supply chain infrastructure variables which the African seed system experts and trainers from the train-the-trainer session chose to be most salient, were transportation cost (rk), distance from farms to storage ($km_{f,s}$), storage fees (gsc_s, csc_s), pre- and post-processing seed loss (gl_s, cl_s), and distance from storage to distributors ($km_{s,d}$). Triangular distributions of these uncertainties were used to populate the model across each index ($f=1,\ldots8$, $s=1,\ldots3$, and $d=1,\ldots8$) in each of the three development areas (high, moderate, least). Table 2 shows the triangular distributions used to parameterize the stochastic variables and values used for the deterministic variables.

Insert Table 2 about here

Seed demand and yield are highly variable. However, the focus of this research is to evaluate the effect of supply chain infrastructure on seed enterprise viability. Therefore, in this model both demand and yield are treated as deterministic. (Note that in the user model, entrepreneurs may vary yield and demand.) Clearly, demand and yield variation will have large effects on profitability, but we control these variables to observe the effects of infrastructure conditions on seed enterprise profitability. Throughout this research, the African seed experts and those attending the train-the-trainer sessions were interested in how infrastructure (transportation costs, distance, and storage) influenced profitability. These experts understand how demand and yield variation affect success (both are critical), but understanding the effect of infrastructure is more elusive. Therefore, after careful consideration, we focused our model on the evaluation of supply chain infrastructure.

The model accounts for market density. Regions are assumed to have differing market densities, so the distance traveled to distribute seed for a constant level of demand is different between regions. Distance is also a stochastic variable within regions, so the same relationship between market density and distance to distribute a constant level of demand is captured within each region. Simply stated, more sparsely populated areas will require greater travel distance to match the quantity demanded in the more densely populated regions. Consequently, transportation cost, a function of infrastructure and distance, limits the profitable market size. In turn, a trade-off exists between market size and the size of a seed conditioning plant. Larger conditioning plants may benefit from economies of scale, but no matter their size, output for a profit maximizing plant will not exceed demand, because additional output would decrease profit. Ultimately, transportation costs limit market size (demand). For this reason, supply chain infrastructure and distance to markets become extremely important when considering the economic viability of seed enterprises.

The objective function for the Monte Carlo simulation-optimization remained expected gross profit (loss), so the general model remains as shown in Equation (1). The existing constraints remain, but a new constraint is added for the optimization model. The farm size constraint limits the maximum farm size to ten hectares and imposes a non-negativity condition (Equation (4)). In the original user model, this constraint was not needed; entrepreneurs would not enter a farm size greater than 10 hectares because such farms do not exist. In the simulation-optimization model, the constraint becomes necessary. Note that the variable hectares (h_f) is not new, but the constraint is new.

$$\begin{aligned} &\text{subject to:} \\ &\text{farm size: } 0 \le h_f \le 10 \quad \text{for each } f \end{aligned} \tag{8}$$

This spreadsheet DSS uses Frontline's Risk Solver Platform to perform the simulation and optimization functions (Frontline, 2010). The results of each level of development are interesting and shed light into the factors that most affect success (expected profitability) for developing seed enterprises.

Results

The results of the simulation-optimization analysis offer important supply chain infrastructure opportunities for humanitarian based organizations. The results for each of the three areas of development are presented in Table 3 and discussed below. Country names are given only to represent the three distinct levels of development modeled. Actual levels of development vary between and within countries, which we capture through simulation analysis.

Insert Table 3 about here

Highly developed areas

South Africa serves as a general representation of a highly developed agricultural area. After performing a Monte Carlo simulation and optimization, the model objective suggests that infrastructure conditions are sufficient for seed enterprises to be economically viable in the highly developed areas. The results show a mean profit of $15,413 (all currency has been converted to US dollars for general comparison purposes) and an expected minimum profit of $12,093 (Table 3). Note that 17.5 hectares were contracted in varying quantities with all eight farmers. All available plant storage was utilized, but none of the owned storage was used because of the higher level of storage loss associated with owned storage. The stochastic variables that have the greatest influence are (moment correlations are shown in parentheses) the cost of plant storage after conditioning (-0.700), the cost of rented storage after conditioning (-0.441), transportation rate per kilometer per ton (-0.415), and the distance to each of the distributors (average -0.103). Therefore, storage of conditioned seed at the plant and at rented storage both have a greater impact on profitability than market density (i.e., distance to distributors) or transportation costs.

Moderately developed areas

Both Kenya and Ghana generally represent areas considered moderately developed in terms of African agriculture. The DSS objective function once again has a mean positive value of $8,066 but ranges from a profit of $3,138 to a profit of $12,189 (Table 3). The number of contracted hectares increased from 17.5 in the highly developed areas to 20.0 in the moderately developed areas, due to greater storage loss in the moderately developed areas. Once again, all the plant storage was utilized, and none of the owned storage was used. The stochastic variables with the greatest influence on the objective function are the cost of rental storage for conditioned seed (-

0.716) and the cost of plant storage for conditioned seed (-0.465). The transportation rate per kilometer per ton (-0.374) and distances to distributors were the next most important variables, but their moment correlation values were relatively low.

Least developed areas

We use Mali as our example of a country representing the least developed areas in African agriculture. The objective function value in the least developed areas had a mean loss of $11,954 (Table 3), suggesting that infrastructure is a barrier to seed enterprises in the least developed areas. The hectares contracted increased once again to 22.2, the largest area of all of the development levels. This reflects the high level of expected storage loss in the least developed areas. In the least developed areas, the stochastic variable with the highest moment correlation was transportation rate per kilometer per ton (-0.787). The moment correlation for distance to distributors averaged -0.138, which is relatively high compared to the distance to distributors for the moderately and highly developed areas. Conditioned seed storage costs at the plant and rental storage costs were also important variables, but their moment correlation values were relatively low compared to those of the moderately and highly developed areas.

IMPLICATIONS AND CONCLUSIONS

Direct Impact on African Seed Chains

The DSS described in this paper directly impacts African seed chains. To date, the DSS has been translated from English into French and Portuguese and is in use in Mozambique, Ghana, Malawi, Tanzania, and Kenya. In Mozambique, roughly 50 entrepreneurs were trained how use the DSS. At least ten of those entrepreneurs successfully used the DSS to start small-scale seed businesses, and another nine entrepreneurs are using it to develop business plans. In Malawi the

DSS has been used to develop financial projections for a revolving seed fund, and in Kenya the model is used by local seed entrepreneurs hoping to start small-scale seed businesses. The Tanzanian Agricultural Seeds Agency (ASA) uses it to support a business plan for seven farms under their management. The model is helping entrepreneurs start small-scale seed businesses capable of introducing improved crop genetics into local villages and is responsible for helping to launch at least 17 new seed enterprises.

Implications of DSS Optimization–Simulation Model

Results from the DSS distinguish important differences between less and more developed regions in Africa and, thus, give important insight into African seed chain development. Supply chain infrastructure has direct influence on the economic viability of seed supply chains, but the different components of infrastructure (distance, transportation rate per kilometer per ton, storage) have varying levels of impact by region.

In the least developed areas, the transportation rate per kilometer per ton and the distance to distributors prohibits a mean level of profitability. Transportation rates are particularly important in the least developed areas because of the relatively poor infrastructure conditions and greater distances to markets. Infrastructure and market density not only impede profitability by making transportation costs prohibitive, but both are difficult to change. Upgrading transportation infrastructure is expensive and increasing market density is challenging in areas where population density is already relatively low. Governments and NGOs should consider these results when offering seed aid, planning methods to defuse new seed varieties, or locating seed infrastructure (e.g., conditioning plant location decisions). Based on our results, microenterprise development (USAID, 2006) would be difficult to achieve in the least developed areas without substantial investment in the transportation infrastructure.

In the moderately and highly developed areas, the two most sensitive variables relate to seed storage. Infrastructure is sufficient for profitability in the moderately and highly developed areas, but managing storage costs and losses is vital for small-scale seed business. Although transportation costs are still sensitive variables, storage alternatives must be considered by entrepreneurs as they evaluate whether or not to start seed businesses. In addition, the relative ease of and lower cost associated with building quality storage means that governments or NGOs can more easily address storage than transportation infrastructure. By offering additional storage at conditioning plants, cost variability can be further reduced, enhancing entrepreneurs' probability of successfully operating small-scale businesses.

Costs associated with storage are not only per unit costs, but also include storage loss due to theft and spoilage. When storage loss occurs, more green seed is needed, which increases transportation costs and the amount of necessary storage. In this study, costs associated with storage losses are reflected in transportation (rate and distance) and total storage costs (volume and rate).

Interestingly, owned storage was not utilized in any of the development regions, even though no storage costs are associated with owned storage. Because of the relatively high cost of storage loss, all seed was stored at the conditioning plant or in rented storage, both of which have lower storage losses. This would likely go against the intuition of a seed entrepreneur, who would see owned storage as an opportunity to save money, but the actual locations of owned storage are often unsecured and improperly designed to preserve seed. Helping entrepreneurs understand that the cost of seed loss is greater than the cost of renting storage is not obvious, but vitally important. Furthermore, governments and NGOs could consider programs to help better manage storage to reduce loss.

In addition to directly influencing sub-Saharan African seed systems, this paper contributes to the literature by applying decision science methodologies to practical applications used by entrepreneurs to discover variables affecting seed supply chains. Furthermore, in developing countries, connecting theory and practice is a challenging and highly theoretical research which often does not benefit large numbers of people. Specifically, this research encompasses a comprehensive supply chain approach to development, which is consistent with the evolving perspective of enterprise development. This DSS links small-scale entrepreneurs to economic growth opportunities.

As development efforts continue to focus on value chain creation, academics with knowledge of supply chain management and operations research will have much to add. Based on this modeling experience, we offer three suggestions to researchers who may work in development or related research. First, users must have understanding and confidence in the model assumptions, methods, and results. This requires education, well-defined models, and simple but comprehensive modeling techniques. Second, markets and even entire supply chains in sub-Sahara Africa tend to be small and differ greatly between geographical locations. Therefore, care must be exercised in generalizing results. Finally, local residents have a wealth of information about markets, operations, opportunities, and constraints. Their input is essential to research and modeling efforts if the decision models are to be successfully applied. While this last point is obvious, it should stress the necessary importance of taking stakeholder input in model design.

Limitations

Several limitations of this work must be noted. First, we were not able to capture and use actual data from entrepreneurs once the DSS was implemented in Africa. Consequently, the model validation is limited, and we are using estimated parameters in our simulation and optimization. Second, our approach assumes an arbitrary definition of three development areas. Next, this research was developed in conjunction with a humanitarian group whose emphasis was focused on microenterprise development. Together, we sought to help seed entrepreneurs develop viable seed supply chains. Therefore, profit maximization was the central approach to our DSS. This approach, although focused on creating viable enterprises, does not necessarily consider cost minimization and may prioritize the allocation of resources toward the more developed areas of Africa.

Finally, even though demand and yield are truly variable, they were modeled as deterministic variables. This assumption was beneficial to explore the critical role of supply chain infrastructure on seed enterprise development, but future research could explore the price interactions between demand and yield variability. Modeling demand and yield variability would require estimating or simulating price elasticity of demand for each type of seed and cross elasticity of demand for unimproved seed over various growing conditions. The elasticity parameters would be highly dependent on location (market) requiring data collection at the village level.

While such research is outside the scope of this project, conjectures can be offered about how demand and yield variability could affect the profitability of seed entrepreneurs. First, yield would fall during drought years, but foundation seed and transactions costs would remain constant. Demand might increase if limited improved seed is available (i.e., drought), but a more likely result would be decreased demand as farmers lack the means to purchase seed. Profit to the seed entrepreneur would likely fall. During years of high production (i.e., favorable growing conditions), demand might increase if farmers have more household income, but, alternatively, farmers might use their abundant (lower valued) unimproved crop as seed, decreasing demand for improved seed. Together, the abundant supply of improved and unimproved seed would likely decrease the price of both improved and unimproved seed. The result in profit for the seed entrepreneurs is unknown.

Another conjecture about demand and yield variability would consider more advanced storage alternatives. At first thought, one might expect a savvy entrepreneur to store seed during times of abundance and sell when supplies are low. However, storing most types of seed for an entire growing season is extremely difficult due to storage losses during the warm growing season and decreased germination over time. Advanced storage alternatives (e.g., climate controlled storage) would be needed to store seed for a complete growing season, and decreased germination would remain a risk. Future research could evaluate the potential risks and rewards associated with such advanced storage systems.

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Figure 1: Basic echelons of the seed supply chain.

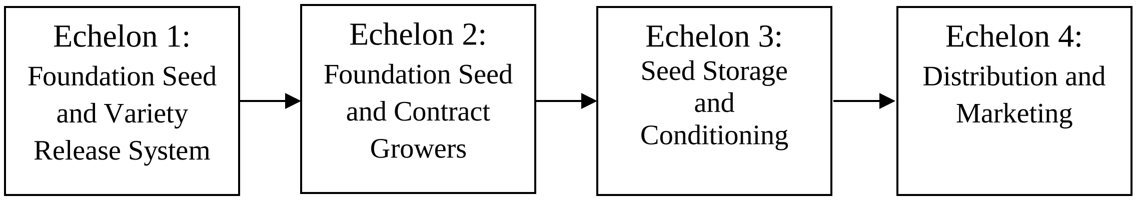

Figure 2: Echelon 2, foundation seed and contract growers.

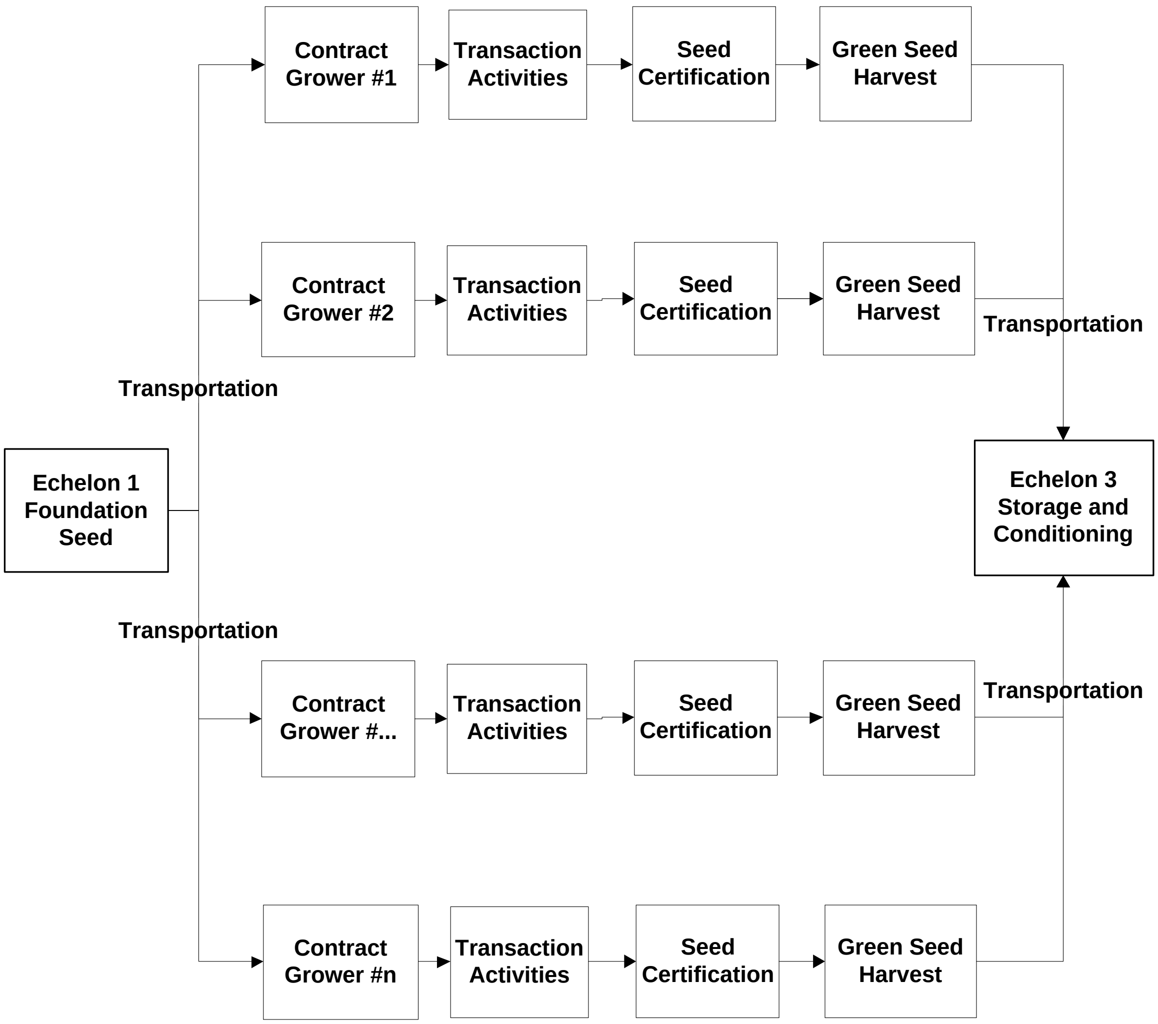

Figure 3: Echelon 3, seed storage and conditioning.

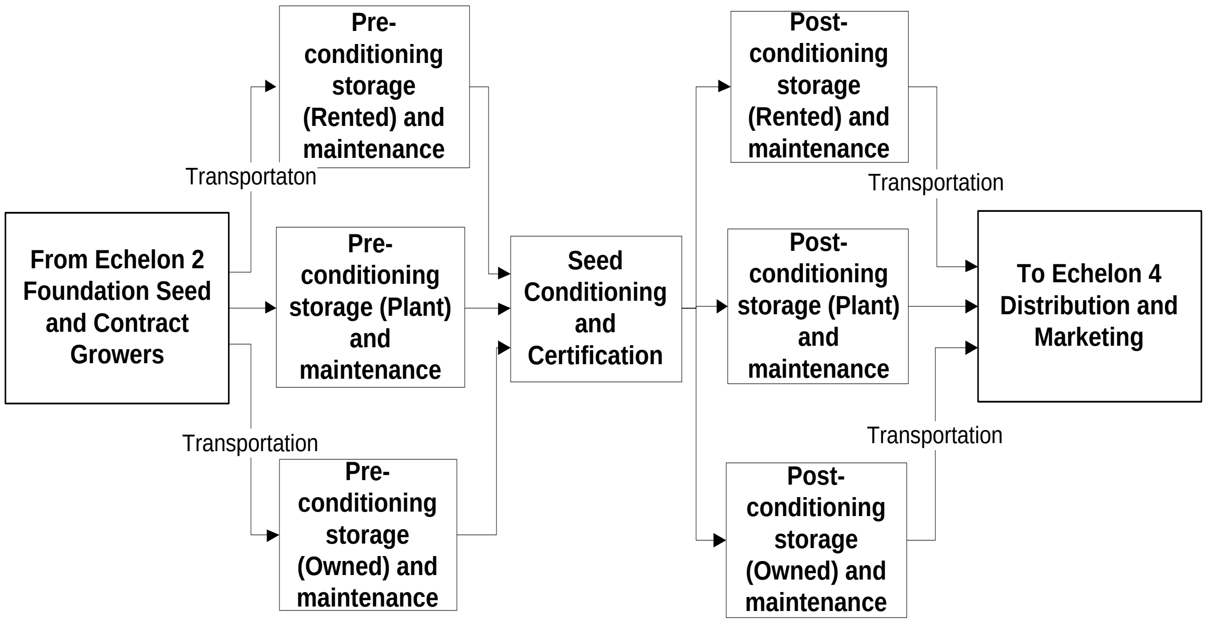

Table 1: Summary of notation.

Objective Function Variable:

π = profit to entrepreneur

Subscripts:

d = indices for distributors 1,…, n_d

f = indices for farm (contract growers) 1,…, n_f

s = indices for storage facilities 1,…, 3, where (1=plant, 2=rented, 3=owned)

Decision Variables:

h_f = hectares contracted with farm f

g_s = tons of green seed stored at storage location s

c_s = tons of conditioned seed stored at storage location s

Exogenous Parameters:

sv = price per ton of discards (revenue to entrepreneur)

L_s = percent of discards (salvageable seed) at storage facility s

gl_s = percent of green seed loss (mold, spoilage, pilferage) at storage facility s

p_d = price per ton of conditioned seed delivered to and sold by distributor d (revenue to entrepreneur)

d_d = tons of seed demanded at distributor d

p_x = price per kg of foundation seed (cost to entrepreneur)

r_f = kg/hectare (application rate of foundation seed) planted at farm f

p_f = price per ton of green seed produced and sold by farm f (cost to entrepreneur)

y_f = yield/hectare of green seed produced and sold by farm f (yield to entrepreneur)

t_f = transactions costs including field visits, training, and inspection cost for farm f

gsc_s = storage cost per ton of green seed at storage location s

gmc_s = green seed maintenance cost per ton (fumigation, germination sampling, etc.) at storage location s

csc_s = the storage cost per ton of conditioned seed at storage location s

cmc_s = conditioned seed maintenance cost per ton (fumigation, germination sampling, etc.) at storage location s

cc = conditioning cost per ton (cleaning, bagging, etc.)

rk = transportation rate per kilometer per ton

$km_{f,s}$ = distance (kilometers) between farm f and storage s

$km_{s,d}$ = distance (kilometers) between storage s and distributor d

K_s = storage capacity in tons at storage facility s

cl_s = percent conditioned seed loss (spoilage, germination) at storage facility s

Endogenous Parameters:

$g_{f,s}$ = tons of green seed shipped from farm f to storage facility s

$CS_{s,d}$ = tons of conditioned seed shipped from storage facility s to distributor d

Table 2: Exogenous parameter values used in model.

	Triangular Distributions								
Stochastic Input Variables	**Least Developed**			**Moderately Developed**			**Highly Developed**		
	min	mode	max	min	mode	max	min	mode	max
$gsc_{s=1\ (plant)}$	$0.06	$0.11	$0.17	$0.06	$0.11	$0.17	$0.06	$0.11	$0.17
$gsc_{s=2\ (rented)}$	$0.17	$0.22	$0.28	$0.10	$0.14	$0.22	$0.06	$0.11	$0.17
$csc_{s=1\ (plant)}$	$1.50	$2.50	$3.50	$1.50	$2.50	$3.50	$1.50	$2.50	$3.50
$csc_{s=2\ (rented)}$	$2.50	$5.00	$7.00	$1.50	$3.00	$5.00	$1.50	$2.50	$3.50
$km_{f,s}$	5	80	200	5	40	100	5	40	100
$km_{s,d}$	10	100	200	10	50	100	10	35	75
rk	$0.381	$0.524	$0.952	$0.286	$0.333	$0.476	$0.190	$0.286	$0.381
$gl_{s=1\ (plant)}$	3%	4%	5%	2%	3%	4%	2%	3%	4%
$gl_{s=2\ (rented)}$	4%	7%	15%	2%	6%	12%	2%	5%	6%
$gl_{s=3\ (owned)}$	4%	12%	20%	3%	9%	15%	2%	7%	12%
$cl_{s=1\ (plant)}$	3%	4%	10%	2%	3%	8%	1%	2%	4%
$cl_{s=2\ (rented)}$	4%	5%	15%	3%	4%	10%	1%	3%	4%
$cl_{s=3\ (owned)}$	4%	10%	20%	3%	8%	15%	2%	5%	10%
Deterministic Input Variables	**Values**								
$gsc_{s=3\ (owned)}$	$0								
$csc_{s=3\ (owned)}$	$0								
p_d	$1,500 for all *d*								
d_d	5.25 tons for all *d*								
p_x	$4.25 per kg for all *f*								
r_f	20 kg/hectare for all *f*								
p_f	$0.44 per kg for all *f*								
y_f	2.5 tons for all *f*								
t_f	$155 for all *f*								
cc	$20.50 per ton								
gmc_s	$2.25 per ton for all *s*								
cmc_s	$3.00 per ton for all *s*								
L_s	1.4% for all *s*								
sv	$5.00 per ton								
$K_{s=1\ (plant)}$	25 tons								
$K_{s=2\ (rented)}$	Unconstrained								
$K_{s=3\ (owned)}$	20 tons								

Table 3: Model results.

	Variables	Least Developed	Moderately Developed	Highly Developed
Objective Function	Mean π	($11,954)	$8,066	$15,413
	Max π	($829)	$12,189	$18,191
	Min π	($27,786)	$3,138	$12,093
Decision Variables	$\sum_{f=1}^{n_f} h_f$	22.2	20.0	17.5
	n_f	8	8	8
	$g_{s=owned}$	0	0	0
	$g_{s=plant}$	25	25	25
	$g_{s=rented}$	30.4	24.8	18.8
	$c_{s=owned}$	0	0	0
	$c_{s=plant}$	25	25	25
	$c_{s=rented}$	24.7	19.7	14.3