Design of Affordable Greenhouses for East Africa

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Abstract—Reflecting the severity of global food insecurity, over 60% of the East African population is considered malnourished, with many regions in a state of famine. There is broad agreement on the need to help small-scale farmers move from subsistence to sustainable and profitable farming by boosting their agricultural productivity, reducing post-harvest spoilage losses and providing market linkages. Inflation, resulting in high fuel and fertilizer prices, prevents farmers from producing larger harvests. Most countries in East Africa have an agrarian economy with over 80% of the households depending on agriculture for their livelihoods. The climate is characterized by biannual dry seasons where many farmers suffer due to water shortages coupled with poor soil nutrition. While short periods of rain benefit local farmers, heavy rainfall sometimes destroys cash crops. Greenhouses are permanent glass or plastic-covered structures that allow farmers to grow vegetables and fruits year-round through mechanically-controlled temperature and irrigation systems. Greenhouses can help farmers in East Africa grow and protect crops in both wet and dry seasons. Large commercial farms, many of them owned by multi-national corporations, employ greenhouses that span several acres of land to produce high-value cash crops including fruits, vegetables and flowers for the export market. East African companies import and sell greenhouses priced at over US $2,000 to commercial farmers. While greenhouses can significantly increase smallholder productivity and improve livelihoods, current designs are inappropriate and too expensive. The adoption of affordable and context-appropriate greenhouses can lead to improved livelihoods for farmers and entrepreneurs while fostering food security. This paper describes the constraints and design tenets for low-cost (~$200 bill of materials) greenhouses and discusses results from three years of field-testing such greenhouses in Kenya, Tanzania and the United States. Currently, the field-tested prototypes excel in affordability, maintenance, and crop protection. This paper strives to blur the boundary between context-driven design, applied research and development by seeking collaborators to refine and localize the technology with the ultimate objective of disseminating it broadly.

Index Terms—food security, greenhouses, subsistence farming, east Africa

I. INTRODUCTION

East Africa is facing the worst food crisis of the 21st Century. Hundreds of lives are being lost each day and the crisis is projected to worsen over the coming months and years. The 2007-2008 riots over food prices in thirty countries across the developing world, most of them in Sub-Saharan Africa, bear testimony to the enormity and scope of the challenge. Over 200 million people in Sub-Saharan Africa have insufficient food while one-third of them are grossly malnourished. Over 60% of the East African population is considered malnourished with many regions classified as being in a state of famine [1]. Food security issues have escalated in recent years due to drought and high levels of poverty among farmers [2, 3]. Humanitarian efforts led by the World Food Program and other organizations provide food and save lives, but are expensive, ineffective, and, in the long term, unsustainable [4].

Recent efforts to address food insecurity are exemplified by the Vision 2030 program developed by the Kenyan government. This ambitious program proposes a multi-pronged approach for fostering food security involving agricultural policy reforms, creation of publicly accessible land registries and branding Kenyan farm produce. It also emphasizes increasing the productivity of small farms, reducing food spoilage with appropriate post-harvest technologies and providing market linkages for farmers [5]. Technologies that improve agricultural production and lower the cost of food to the poor can help developing countries fulfill their vision to ameliorate food insecurity [6]. East African nations, including Kenya and Tanzania, experience relatively long dry seasons followed by periods of rain. The climate in these countries is characterized by a long-rain season from March to May and a short-rain season from October to December [7]. During the dry months, many farmers suffer due to water shortages coupled with poor soil nutrition [8]. While short periods of rain benefit local farmers, heavy rainfall often destroys crops like tomatoes [9]. For a farmer in East Africa, a greenhouse can potentially protect crops in both wet and dry seasons [10].

Greenhouses are glass or plastic-covered structures that allow farmers to grow vegetables and fruits year-round through automatic or manual climate control systems [11]. While greenhouses can significantly increase productivity and improve farmers’ livelihoods, current designs are inappropriate and too expensive for small-scale, subsistence farmers. In Kenya, for example, several companies sell greenhouses for approximately US $2,000. These greenhouses are largely out of reach for subsistence farmers [10]. For farmers in East Africa to be able to grow crops year round at an affordable price, a new design is needed. A related technology, known as a high tunnel, is a structure with a single layer of glazing that relies on a manual ventilation system. This term best describes the structures highlighted in this
paper. Although high tunnels only provide intermediate climate protection and are fundamentally different from greenhouses, the term “greenhouse” is in common usage and, consequently, the prototypes discussed in this paper are referred to as “affordable greenhouses”.

II. GREENHOUSE TECHNOLOGY BASICS

There are two parts of a greenhouse: the framework and the glazing (plastic covering). Typically, the glazing covering the greenhouse is replaced many times before the framework fails due to corrosion and mechanical loading [12]. The greenhouse frame is typically designed as the gable, hoop, or a mix of the two, each design with its own strengths and weaknesses. The gable design incorporates a steel frame and glass roof panes. While it is sturdy, the initial construction and maintenance costs are often too high for the developing country context – with capital costs for one 24’ x 96’ section being well over US $10,000 not counting the climate control systems [13]. Some variations of the hoop and gable designs are constructed of wood or galvanized steel [14]. While these designs tend to be inexpensive alternatives to the gable designs, wooden frames are not practical for the East African context due to high levels of humidity that cause rapid deterioration. Hoop houses are often made by hobbyists in the U.S. and are constructed mainly from schedule 40 PVC piping [15]. Plastic hoop houses are much weaker than the steel gable designs. For use in developing countries, the plastic frame requires further research in terms of durability [16].

The glazing material used in greenhouses includes glass, polyvinyl chloride (PVC), polypropylene (PP), or polyethylene (PE). The durability of the plastic glazing ranges between one to eight years or more depending on the type of plastic and its thickness. The durability is contingent upon various factors including temperatures exceeding 70°C and pesticide exposure that can damage PE sheeting [16]. Most greenhouse-grade plastics are coated for protection against ultraviolet light and are designed for specific crops. Currently, all greenhouse-grade plastic available in East Africa is imported from Israel, Europe or the US, and is very expensive. A greenhouse is at the mercy of its surroundings. Weather conditions and soil types impact the foundation as well as the structural support system. Areas with heavy rainfall require extra support for the hoops so that the greenhouse can withstand stormy weather. The structure must also be adapted for the insects and animals like moles, rats, and other pests that will interact with it. Above ground, common pests such as grasshoppers and whiteflies endanger greenhouse crops if the structure is not free of crevices between the plastic connections. However, it is imperative for the user to introduce beneficial insects to make sure the crops are pollinated and kept free from insects that carry disease. The greenhouse itself must be environmentally benign and should require minimal maintenance. While these design constraints apply generally to most user groups, diverse customer segments in East Africa have their own needs and it is essential to understand and integrate their use preferences.

III. AFFORDABLE GREENHOUSES

The high startup cost of greenhouses led the Children and Youth Empowerment Center (CYEC) in Nyeri, Kenya to partner with the Humanitarian Engineering and Social Entrepreneurship (HESE) program at The Pennsylvania State University to design and build affordable greenhouses for the center. HESE also partnered with the Tropical Pesticide Research Institute (TPRI) in Tanzania to field-test prototype greenhouses and with the United Nations Industrial Development Organization (UNIDO) to further develop the affordable greenhouse technology and dissemination strategy. The US-Kenyan team spent the 2008-09 academic year studying, validating and articulating the context of use and design needs for affordable greenhouses in east Africa. The team engaged in research, design and early-stage prototyping followed by three weeks of intense fieldwork in Kenya. During this period, the team interviewed over fifty small-scale farmers and over twenty agro-businesses about their needs and use preferences. The team also studied the competitive landscape that presently includes two providers for the entire East African market. These companies are essentially importers and integrators and are focused primarily on the needs of large-scale, commercial farmers. The final affordable greenhouse design constraints and requirements for small-scale businesses and subsistence farmers emerged from the myriad discussions and were synthesized by the US-Kenyan design team. They are:

- **Material Costs:** Less than US $200 for an affordable greenhouse with a minimum planting area of 360 square feet.
- **Ease of Assembly:** Two individuals with minimal training should be able to assemble the greenhouse from the ground-up in two days.
- **Lifespan:** Minimal lifespan of ten years for the greenhouse structure and five years for the glazing; only limited maintenance should be required by the farmer.
- **Modularity/Scalability:** More sections can be added as a farmer is able to afford additional units.
- **Portability:** The entire structure can be moved when crops no longer require greenhouse protection.

Over the last three years, affordable greenhouses targeting small enterprises and smallholder farmers have been designed and field-tested based on these constraints. The greenhouse materials cost approximately US $200 and the structure can be assembled by two people in two days. The capital costs can be recovered in two or three crop cycles. This technological innovation is the result of field-testing several different design concepts, materials and construction processes in the US, Kenya and Tanzania. The key tenets, design decisions and preliminary testing results are provided in this paper. While the technology is at the heart of this venture, the challenge lies in the successful synthesis of engineering design, business strategy and the implementation process. The competitive and collaborative advantage is based on integrated design, community-driven approach and strong partnerships with
clearly defined roles, responsibilities and returns for all entities.

IV. GREENHOUSE STRUCTURE

The defining innovations that have led to the success of the greenhouse designs include the rebar connectors (Figure 1), bamboo connectors and scalable sections. Rebar connectors are simple welded steel rods that allow the user to easily replace a broken rib in the greenhouse when needed. Tee connectors are used for the two ends of the greenhouse whereas the cross connectors are used in between the tees to connect each vertical wood post (Figure 1). For both the tee and cross connectors, the shorter ends (6”) are the connections for the ribs whereas the long ends (1’) connect each vertical wood post to each other.

![Fig. 1: a) Greenhouse foundation b) Finished greenhouse frame with PPR plastic pipes](image)

To fix the glazing in place, bamboo connectors bolt down the glazing in between the plastic pipe and a piece of bamboo with a piece of tire strip to prevent tear (Figure 2). One of the defining characteristics of these affordable greenhouses lies in its ability to be mobile and flexible in design. The bamboo connectors allow for the greenhouses to be expandable over time by the addition of more sections.

![Fig. 2: Bamboo connector - 3” long bolt with ¼” nut and washer. 6” bamboo piece with 6” tire strip](image)

pipes have very recently entered the East African market and are affordable, strong, light-weight and durable. They also have a 50-year lifespan and are recyclable. PPR piping has been repurposed to build the affordable greenhouse frame. The current design uses greenhouse-grade plastic for glazing. Experimentation with lower-cost substitutes such as processed rice bags is in progress.

**Design**

The affordable greenhouse uses a hoop design and is at the mercy of harsh environmental conditions including wide temperature variations and occasional rainstorms accompanied by high winds. Since PPR piping that holds up the structure can fail due to mechanical creep in the hot summer months, vertical beams are inserted after every other hoop to provide additional structural support (Figure 1). Metal clips to hold the glazing in place are expensive and not locally available. Instead, bamboo connectors were created to keep the glazing on the pipe frame (Figure 2). Easy-to-use roll-up bars located on the side of the structure were also added to serve as a ventilation system during the hot weather.

**Scalability**

While typical greenhouses are permanent structures, this greenhouse design is a modular, expandable structure. The return on investment is typically two crop cycles, which is generally six months, but can be as short as four months depending on the crop. Increased profits obtained through the use of the greenhouse can be used to expand the initial structure by adding additional sections or to install accessories such as drip irrigation systems.

**Construction Process**

The greenhouse construction process has three phases: 1. preparing the ground, 2. setting up the framework, and 3. installing the glazing. The greenhouses can be readily constructed in two eight-hour days by two adults who have...
little or no formal education. A visual construction manual has been developed and refined based on feedback received in Kenya. Since all the connections in the framework are bolted, it is important to make sure that the drilled holes line up in order for the pipe grid to stand straight without having to rotate any pipes. Careful drilling can prevent shear stress from developing in the frame. A remark by one Kenyan community member to another captures the simplicity of construction: “The greenhouse is like a big safari tent. You pitch it the same way you set up your tent on safari”.

V. FAILURE MODE ANALYSIS

The greenhouse has several immediate and time dependent failure modes. Greenhouses are subject to gusts of wind that can sometimes exceed 25 m/s. These gusts can result in significant lift forces that must be countered with a strong foundation. Our structure is designed to tolerate wind speeds of 10 to 25 m/s. Another imminent failure mode includes yielding of the PPR pipes that are preloaded with a bending stress during installation to create the hoop shape. All other factors are time dependent in that materials will lose their structural integrity over time. For instance, the PPR pipes will tend to experience stress relaxation from the preloaded bending stress and the rebar will experience a mix of corrosion and fatigue from the surrounding environment. While there is not enough data to calculate how the PPR pipes will creep, the corrosion rate and time to failure of the rebar can be estimated.

Wind loading

With typical gusts reaching between 10 to 25 m/s in rural Kenya, the greenhouse must be able to withstand the lift force generated from the winds ranging between 1902.3 - 7171.5 N. Assuming that the weight of the greenhouse is about 1800 N, the winds create a large enough lift force to lift the structure if the foundation is not properly anchored down. Fig. 3 lays out a pressure map generated due to wind loading under standard atmospheric conditions. The analysis was done with Flow Simulation on SolidWorks. The computer model of a greenhouse below is designed with a radius of 2.74 m and a depth of 6.09 m (9 ft radius, 20 ft depth), which matches the proposed design illustrated in Fig. 1. In this simulation, the model greenhouse is exposed to lateral wind with a constant velocity of 25 m/s. This simulation has shown that the foundation must compensate for the force that is beyond the weight of the structure. Varying design parameters may be used to prevent the structure from lifting via heavy vertical support columns and/or using concrete to anchor down the foundation posts. In Kenya and Tanzania, the foundation posts were reinforced with sand and rock mixture, which has proven to be effective thus far.

Two years of field testing has shown that the PPR pipes are prone to deform in the direction of the prevailing winds. Extra vertical support columns may be needed to prevent deformation of the PPR piping. Furthermore, as the model above shows greatest stress concentrations on the foundation posts, the rebar stakes may need to be grounded with concrete to prevent shifting.

Yielding

Under maximum shear stress and distortion energy theories, assuming that the rebar is under uniaxial tension, the maximum bending stress that is equal or greater than the material’s yield strength will be a mode of failure. Initial results show that taking the radius of the pipes to be 2.74 m, E = 4.3 GPa, outer diameter of the pipe = 25.4 mm:

\[
M = -\sigma c
\]

\[
1 = \frac{E}{\rho}
\]

\[
\sigma_{yield} = \frac{E}{\rho} = \frac{0.0127}{2.74} (4.3 \times 10^5) = 19.9 \text{ MPa}
\]

Where M is the moment about the neutral axis, I is the moment of inertia, c is the perpendicular distance from the neutral axis, \( \rho \) is the radius of the hoops, E is the elastic modulus, and \( \sigma \) is the maximum bending stress respectively [17]. Taking the yield strength of PVC to be 31 - 60 MPa [18], the pipes are projected to withstand the bending stress that is preloaded during the installation phase. Based on the calculation above, the applied bending stress is insufficiently large to cause short-term damage to the rebar connectors. However, under corrosive environments, the degradation of the rebar will eventually cause the connectors to fail.
Corrosion

With atmospheric corrosion, the rebar connectors are projected to last for years without failure.

\[ \text{Corrosion Penetration Rate} = \frac{KW}{\rho At} \]

Where \( K \) is a constant and \( W \) is the weight loss after exposure time \( t \); \( \rho \) and \( A \) are the density and the exposed specimen area. Assuming the modulus of the rebar to be that of mild steel (\( E = 210 \text{ GPa} \)):

\[ \sigma_{\text{rebar, yield}} = \frac{c}{\rho} = \frac{0.003175}{2.74} \left( 210 \times 10^9 \right) = 243.3 \text{ MPa} \]

To find how long it would take for the rebar to fail under atmospheric corrosion, \( \sigma_{\text{PVC}} \) is set equal to \( \sigma_{\text{rebar, yield}} \), where the decreased “c” will show the volumetric loss of the material, which corresponds to the weight loss. The rebar is projected to fail when the maximum bending stress on the rebar is equal to the preloaded bending stress applied by the PPR pipes. Atmospheric corrosion rates in rural areas range from 5 μm/year to 10 μm/year [19]. Therefore, for a corrosion rate of 0.005 mm/yr:

\[ \sigma_{\text{rebar}} = \sigma_{\text{PVC}} = 19.9 \text{ MPa} = \frac{c}{2.74} \left( 210 \times 10^9 \right) \]

\[ c = 259 \mu \text{m} \]

For this value of “c” the weight loss:

\[ W = \pi \left( 0.00026 \right)^2 \times (0.1524) \times 7850 = 254 \text{ mg} \]

\[ t_{\text{failure}} = \frac{KW}{\rho A(CPR)} = \frac{87.6 \times 254}{(7.85)(0.048)(0.005)} = 1348.2 \text{ years} \]

Thus, time to failure for the corrosion rate of 0.01 mm/yr would be around 674 yrs. Even if the corrosion rate were to be multiple times greater, rates less than 0.5 mm/yr are acceptable where the time to failure would then be about 13.5 years or less [20]. One factor that contributes to the degradation of the rebar is the corrosive nature of acidic soils where the posts in soil may have a value that is greater than 0.5 mm/yr. Acidic soils can be addressed by replacing the rebar with a non-corrosive Polypropylene Random Copolymer Type 3 (PPR) pipe posts.

Other Time Dependent Factors

PVC typically can last for years if there is no direct sunlight, however, the material is prone to get damaged by UV rays within weeks if left unprotected. The prototype built at the CYEC in Nyeri, Kenya in 2009 failed due to stress relaxation at the joints. In 2010, the greenhouse was rebuilt on top of the existing foundation where vertical support columns were installed to minimize creep in the PVC pipes. Current designs use PPR instead of PVC. PPR piping has a typical lifespan of about 50 years. The greenhouse built in 2010 is built out of 60% PPR pipes that were used in conjunction with PVC pipes. As this prototype is approaching its second year since construction, fieldwork has shown that the vertical support columns are a key feature to prevent stress relaxation in the hoop structure. The current design is 100% PPR.

In terms of corrosion in the couplers that act as the tent stakes connecting the pipe framework to the ground, the rebar naturally degrades faster at these points than the tee and cross connections at the top. Factors such as porosity, electrical conductivity, dissolved salts, moisture, and acidity or alkalinity all play a role in corrosion of the couplers in the soil [21]. However, the amount of time it takes for rebar to degrade in soil is largely contingent upon the location and the agronomics. In any case, we estimate a lifespan of at least ten years. When the rebar connectors fail, they can be replaced very easily with new connectors.

VI. FIELD TESTING RESULTS

In Nyeri, Kenya, the first greenhouse prototype was built in May 2010 and has undergone five successful tomato growing cycles. In Tanzania, two different affordable greenhouse designs have been field-tested. Two more prototypes have been constructed in Nairobi in April 2012 specifically for the purpose of long-term testing. Another prototype will be built by high-school students under the supervision of their teachers in Nairobi in June 2012 following instructions provided in the construction manual. An intelligent fast-failure strategy has been employed to rapidly test multiple design concepts, various materials and different construction techniques; the prototypes currently under testing represent the product of several design sprints as shown in Fig 4.
Makumira campus in Tanzania held their shape perfectly until they had to be taken down due to space issues five months after construction. Excluding the building tools and drip irrigation system, a larger greenhouse was built for approximately US $200 in both Kenya and Tanzania. Since 360 square foot greenhouses (the intended starter size) cost considerably less than US $200 to construct, it may be beneficial for farmers to start with a section larger than 360 square feet; adding additional modular sections to the initial greenhouse in the future as they make and save more money.

Environmental Protection

With the 6th harvest of tomatoes pending, the greenhouse at the CYEC has protected the plants from both inclement weather and pests. Although the drip irrigation system has had problems with clogging, the greenhouse itself has successfully shielded the plants from extreme weather as well as from pests such as white flies that often devastate tomato plants.

Ease of Maintenance

The simplicity of the rebar connector coupled with the durable yet flexible PPR pipes has kept the greenhouses structurally sound. The primary benefit of having a grid structure was that the grid simplified the initial setup process and made changing damaged ribs relatively simple. The initial prototype was the only greenhouse to have a weak frame whereas subsequent frames were not a source of failure. Exposure of plants to the sun significantly decreases when the greenhouse glazing is not cleaned regularly. Cleaning of the glazing is a vital part of the maintenance regimen.

VII. BUSINESS STRATEGY

The affordable greenhouse technology is ready for broader field-testing and a beta launch in East Africa. Our technology team continues to streamline the design for easier assembly and is researching low-cost substitutes for greenhouse-grade plastic. An “Affordable Greenhouse Kit” that contains all the required construction materials and the simple tools needed to assemble the greenhouse is being developed. An optimal way to produce the more complex elements (like the various joints, door frame, etc.) needs to be explored. The cost of the frame is approximately US $100 with the imported glazing material accounting for an additional US $100. Since the glazing material is imported and one company in Kenya currently controls the lion’s share of the market, the plastic is expensive and the prices are volatile due to foreign exchange rate fluctuations. Stitched rice bags (durable, woven plastic bags used to store 20-100 kilograms of rice) coated with waterproofing and strengthening agents are being explored as an inexpensive substitute for glazing. This substitute for plastic sheeting can reduce the glazing cost from US $100 to US $45, reducing the total cost of the affordable greenhouse to US $145.

The greenhouse addresses the needs of two types of target customers categorized as the market penetration segment and the post-penetration social impact segment. The market penetration segment includes small-scale commercial farmers and “weekend farmers”. Weekend farmers are people who are not economically dependent on agriculture, but farm as a pastime. The market penetration segment also includes educational institutions and boarding schools interested in using greenhouses to teach about farming as a business enterprise or to grow food for school consumption. Small commercial farming operations can increase their profits with affordable greenhouses and recover their capital investment comfortably in just two growing cycles. The “weekend farmers” are an important market in East Africa, since a significant number of people in urban areas maintain farms (shambas) at their rural homes that they may visit each weekend. These city dwellers have disposable income and are interested in boosting their agricultural production primarily to be able to consume produce grown on “their own farm” all year round. An affordable greenhouse is expected to decrease the growing time of most fruits and vegetables by one-third (for example, tomato plants mature in 8 weeks instead of 12) [22]. In a region that has a dry season lasting approximately 6 months, a reduction in cultivation time of one month translates to a net income increase of 50% over a single growing season for tomato farmers. More importantly, the greenhouse can support agricultural production in arid and semi-arid regions where it is impossible to farm during most months of the year. The affordable greenhouse can be a successful venture for small businesses and weekend farmers, but ultimately it is important to reach subsistence farmers to amplify the social impact of the technology.

The social impact target segment consists of subsistence farmers, many of whom are women, living on a household income of US $2/day or less. These farmers would like to increase their agricultural production to have surplus produce to sell, but they can take few risks and need evidence of the value of a greenhouse (provided by the market penetration segment) before they will accept the investment risk. For example, farmers in yearlong arable areas could boost their daily income from US $2/day to US $3/day using an affordable greenhouse (analysis based on tomato crops). With 80% of its land area classified as arid or semi-arid, and 3% of its land under forest cover, only 17% of land is cultivable in Kenya. However, only 52% of the cultivable land is actually being farmed. In arid and semi-arid regions, access to water is a major problem that is further compounded by evapotranspiration, the water loss from crops exposed to the environment, resulting in an increase in the total water required for crop production. Greenhouses effectively reduce evapotranspiration by 30% when compared to open-field conditions, and the water use per unit yield can be lowered by up to 50% [23] by installing a controlled irrigation system in the greenhouse. Regions classified as having low potential for cultivation are a difficult market to penetrate since farmers in these regions are unlikely to be able to purchase a greenhouse. This lack of capital necessitates a systemic solution with effective market linkages for agricultural products. Making greenhouses affordable for subsistence farmers paves the road to increased crop yields. Reducing maintenance requirements
to a few steps and allowing farmers to have environmental control over their crops empowers them to grow high market-value cash crops. With the option of expanding the greenhouse size over time, the affordable greenhouses can make an impact on the economy, society and environment in East Africa.

VIII. CONCLUSION

Affordable greenhouses can empower small-scale and subsistence farmers to take control of their farming environment. They can install drip irrigation systems to reduce water requirements by up to 50% compared with open-field conditions. They can create a cool microclimate within the structure during the hottest hours of the day and keep crops safe from winds during the night. Being able to manipulate this microclimate, farmers can extend the local growing season. They can begin planting earlier in the season in colder regions or extend crop growth into dry seasons in hotter regions. Greenhouses provide protection from detrimental insects and small animals as well. Essentially, the greatest benefit of greenhouses to poor farmers is that they can increase their crop productivity in a cost-effective manner.

The success or failure of the greenhouses hinges on their functional life and commercial potential. The unique features of expandability of the greenhouse, the use of the PPR pipe framework and the bolted bamboo connectors are proving to be successful so far. Further research over a 3-5 year time frame will validate the effectiveness of each feature. Whether or not small-scale farmers will employ the expandability feature will depend on widespread acceptance of the greenhouses. The actual amount of climate control the affordable greenhouses can provide will become evident with longitudinal studies in the coming years. However, the initial results are encouraging. Our team has raised about $50,000 in grants to refine the technology further and disseminate it in East Africa through a network of distributed micro-enterprises over the next two years. Planning is underway with a Kenyan East Africa through a network of distributed micro-enterprises to the project. Finally, we would like to acknowledge the current greenhouse team with Shruthi Baskaran, Amy Copley, Arianna De Reus, Danielle Lichtliter, Dana Brown and Stephen Suffian who are working hard to take this technology to market.

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