A Decision Support Tool For Greenhouse Farmers in Low-Resource Settings

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Abstract— **Affordable greenhouses have been proven to substantially increase crop yields by allowing farmers to grow year-round while, at the same time, decreasing water consumption. These benefits translate to improved livelihoods and food security for urban farmers and improved nutrition for their rural counterparts in resource-constrained areas. Accordingly, affordable greenhouses have been introduced to experienced and novice farmers in Kenya, Rwanda, Cameroon, Mozambique, Zambia, and Sierra Leone. Across these countries with different horticultural traditions, educational infrastructure and agricultural extension systems, there is a distinct knowledge gap on the basics of greenhouse farming. Even those who have previous farming experience need to rethink their strategies in order to transition more efficiently from conventional open-air farming to greenhouse farming. This problem has created the need for a comprehensive and context-appropriate decision-support tool to guide farmers through a series of questions across four phases of greenhouse operations: preparation, planting, nurturing, and harvesting. This article describes a highly visual decision support tool that educates farmers about important considerations and helps them make informed horticultural decisions. It also provides case studies for commonly grown produce like tomatoes, bell peppers and greens. This tool can be deployed on a computer, a tablet, or even a three-ring binder, and has been co-developed with, and validated by, farmer groups in Zambia.**

Keywords—Greenhouses; food security; smallholder farmers; knowledge gap

I. Introduction

With a population of 9 billion people expected by 2050, the earth is facing an unavoidable increase in demand for food. In order for the population to continue to prosper, this increase in demand must be met through the sustainable intensification of agriculture. The capability to produce more food on less land, while also reducing negative environmental impacts, is crucial to the populations' well being and survival [1]. In an effort to combat these challenges, greenhouse technology serves as a simple, yet practical, solution.

In addition to helping address system-wide concerns over food security, greenhouse technology can facilitate improved livelihoods for many smallholder farmers. The low initial investment and rapid rate of return makes greenhouses extremely attractive [2]. Many farmers have adopted the technology due to its ability to bring higher economic returns in comparison to open-air agriculture [5]. In locations such as China, greenhouse adoption has boomed, making up over 90% of all global greenhouse vegetable cultivation in the world [2]. These greenhouses have doubled crop yields by extending growing seasons and increased the income of many farmers. Greenhouses also provide ecosystem benefits such as lower water consumption and improved soil protection [2]. These benefits, however, are harder to realize in countries in Sub-Saharan Africa, where such technology is unique and previously out of reach to many farmers. In Zambia, many rural farmers interviewed about the potential use of greenhouses, found the idea of farming in a greenhouse irrational.

The successful diffusion of greenhouse technology and its adoption depends heavily on overcoming a broader educational barrier. Watering, crop spacing, and time till harvest all differ in greenhouse farming when compared to open-air farming. The failure to address the distinction between greenhouse and open-air farming has created a knowledge gap. With many current and potential users lacking a basic understanding of how greenhouses address their specific needs. Farmers must obtain such knowledge in order to utilize this technology to its utmost potential. A study conducted in Kenya revealed that educational levels, experience with greenhouse farming, and number of extension staff farm visits, all had a significant effect on greenhouse performance [7].

Users of greenhouse technology vary from those with substantial experiences with open-air farming to those who have had very little. The overall success of greenhouse users is largely dependent on the outcome of the learning process. What is missing across the board is a framework that integrates both greenhouse and open-air farming knowledge, and successfully transitions users towards greenhouse horticulture practices.

A method to understand, aggregate, and standardize a process of greenhouse farming should utilize a comprehensive and context-specific approach. Understanding the current horticultural practices, or indigenous practices, of varying locales is vital. By engaging smallholder farmers and observing their current farming techniques, greater adoption rates of greenhouses and higher chances of success can be obtained [7]. Integration of indigenous practices will help bridge the knowledge gap of farmers who are transitioning to greenhouse farming.

A decision support tool can facilitate a successful translation process. The decision support tool proposed in this paper provides a series of questions that spans the four phases of greenhouse farming operations in one harvest cycle: preparation, planting, nurturing, and harvesting. It is a highly visual guide that lays out case studies for many different commonly grown produce such as tomatoes, bell peppers, and greens. This tool allows farmers to move through the agricultural process of greenhouse farming with ability to make more informed decisions. This tool will be disseminated simultaneously through two methods: a paper copy and a PDF version that can be downloaded and read on a computer, smartphone, and e-reader.

This article outlines the context and challenges of addressing educational barriers, a description of the tool, its validation process, its sample-use scenarios and its limitations.

II. Context and Challenges

Greenhouse technology has not been successfully adopted on a wider scale in Sub-Sahara Africa, causing many farmers to miss the opportunity and practicality of greenhouses. This reflects a largely neglected opportunity to address the knowledge gap. In the Gusii highlands of Southwest Kenya, farmers have abandoned greenhouse farming after the first crop cycle, despite having initially invested in the technology [6]. This abandonment of greenhouses is becoming a larger trend. In Nigeria, a survey was conducted to assess the barriers that caused greenhouse abandonment in many parts of the country [8]. Nigeria housed many greenhouses exclusively for research purposes. The attempt to encourage locals to transition to using greenhouses as a means of augmenting their income was unsuccessful. Merely introducing previously out-of-reach technology to farmers is not sufficient to guaranteeing proper understanding and utilization.

The lack of initial effort to understand both the existing practices and the needs of farmers prevented many in Nigeria and Kenya from transitioning to greenhouse farming. Greenhouses in many of these contexts are unaffordable and unfamiliar to the local community. If these issues are not successfully addressed, they can act as barriers that perpetuate an even larger knowledge gap between farmers and greenhouse technology. The process of knowledge transfer should be geared towards the farmer and farming practices, rather than the just the technology itself, in order to overcome abandonment [5]. Indeed, additional knowledge and skills that greenhouses require in the agricultural process may act as an opportunity for a scalable solution to address local needs.

In Tajikistan, a woman's cooperative in an area with natural disasters, built and farmed small-scale greenhouses. These greenhouses served as a mechanism for women to gain skills such as first aid and disaster management. Truly understanding the livelihood dynamics will allow for the contribution of a particular technology to aid changes desired by the farmer [5]. Both disaster management, which was a distinct need of the community, and food security, were simultaneously addressed through the utilization of greenhouses. As a result, many women became fully prepared and capable of handling disaster-related situations such as landslides and earthquakes [9]. Leaders in the community maintained a cyclical transfer of knowledge as these women taught other women—a justifiably more sustainable method of integrating indigenous and greenhouse farming practices. The design of such knowledge management practices lead to project success.

A system of knowledge transfer between the designers of greenhouses and the individual farmer can ensure higher rates of adoption. Agricultural technology succeeds in accordance to the extent of the farmer's involvement in the process [5]. When treated as experts of their own techniques, farmers enable multiple pathways for dissemination. Non-formal educational systems such as night schools, radio, television, print media, and mobile phone applications are all ways to translate these new techniques [10]. These pathways ensure that the technology incorporates the needs of farmers by delivering a more context-specific approach. Restructuring the learning process, from merely giving farmers greenhouses to taking the initial time and effort to enable greater understanding of the technology, is much more conducive to greenhouse user success. Through these methods, the capability of farmers is expanded.

The ways in which extension agents have been communicating with farmers is currently being revolutionized with technologies that increase ease of promoting various informational networks. Many applications and services have been created for this sole purpose, allowing extension agents to have multiple ways to communicate and interact with farmers. An example of the potential success of the impact of these methods of dissemination is the success of the organization Digital Green. That provides information through a mobile platform, which has been proven to be 10 times more effective than traditional extension service practices. They have currently produced over 3,700 videos in 20 languages, and reached over 640,000 community members. Their services can be accessed through smartphones, tablets and computer [4]. This organization has proven the success of such dissemination methods, validating the method of using e-readers and publishing the tool on the website. This method of dissemination can enhance communication, and improve the delivery information system.

Many of these communities with experienced farmers have survived thousands of years through indigenous farming techniques. Greenhouses should be utilized as a means to safeguarding such knowledge. This technology can act to preserve indigenous crops. A system of knowledge transfer should not disregard such practices, but provide additional knowledge of greenhouse horticultural practices. Applicable and context-specific techniques must be recommended to the farmer in place of predetermined and general techniques [5]. An extension agent is typically hired by the government to travel to farms and provide support for their agricultural needs. Such actors are an integral part of the knowledge process. Farmers, through systems of knowledge transfer, can act as development partners in conjunction with extension agents, who simply act as catalysts of the transition process. This distinct approach equips farmers with the skills and knowledge required to make decisions on their own production of resources, ultimately aiding in profitable and sustainable results [10].

III. Description of Tool

The goal of the decision support tool is to overcome the knowledge gap that both novice and practiced farmers commonly face with greenhouse technology, specifically in the African context. Through the provision of a comprehensive and context appropriate decision-support tool, farmers will be guided through over 40 decisions formulated as questions. These questions span four general stages of faming: preparation, planting, nurturing, and harvesting.

A user-friendly and context specific approach is taken to meet the needs of new greenhouse users. The tool acts as a master layout of all the decisions farmers consider as they move through each stage. Information will be available to the farmer, regardless of the decision he or she makes. Those greenhouse users, who have access to soil testing for example, have a different decision to make, than those who do not have access to such recourses.

Two types of questions can be found: those that are general to farming, and those that are specific to the plants chosen to grow. Information is provided on three major crops that farmers in that region tend to grow: tomatoes, greens, and peppers. The design process of the tool prioritized adaptability and scalability. Adaptability allows this tool to encompass differing needs and resources available to users. Scalability allows more crops to be added in the future when deemed beneficial.

A. Preparation

The first stage farmers need to consider is preparation. In this phase 17 questions are asked to help farmers properly prepare their soil for planting. Preparation is a vital phase in farming, and without proper attention to important nutrients there is an increased risk that plants will not flourish and be productive.

One of the first decisions farmers need to make is what plant they intend to grow. Different plants and varieties will dictate the length of growing seasons, the amount of water and nutrients needed, and differing nurturing techniques. Once this is decided, farmers must determine what types of plant beds they will utilize. In-ground beds involve making elevated soil rows, and usually are the best option to utilizing space inside the greenhouse. The choice however remains with the user, and the information is presented in a table that differentiates the benefits and the costs of each bed type.

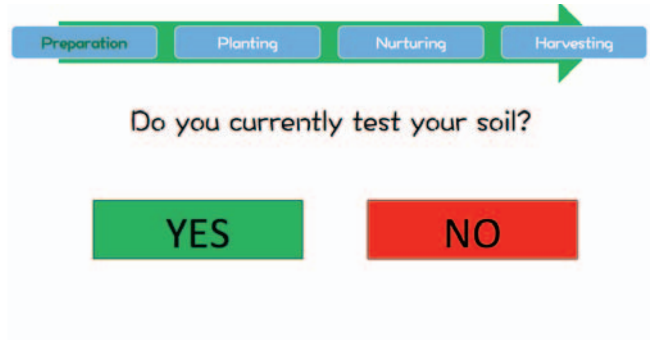

Fig. 1 Preparation Slide Directing Users Towards Relevant Soil Testing Methods

Greenhouse spacing is one of the crucial differences in comparison to open- air farming. Greenhouses allow a greater amount of crops to be grown in a defined area compared to traditional farming, as the crops can be spaced closer together. With many open-air farmers unfamiliar to the new spacing requirement, they remain unable to utilize such a distinct benefit. A convenient layout is presented, showcasing the number of crops and the spacing between each of those crops in a 6-meter by 5.5-meter area. Once farmers make these decision it is time for them to begin cultivating the land to ensure proper nutrients are added to the soil. Adding the correct nutrients based on plant needs will greatly increase odds of success. In areas in Zambia, the soil can be more clay-like, while in other locations it is grainy and sandy. These differing soil types require the farmer to respond in a different manner; for instance, sandy soils require more organic matter compared to soil composed of more clay.

With many rural farmers unable to access affordable soil testing equipment, it becomes difficult to identify what nutrients must be added. To circumvent this problem, the decision-support tool supplies information on plant characteristics that act as potential indicators of nutrient deficiencies, this can be seen in figure 4.

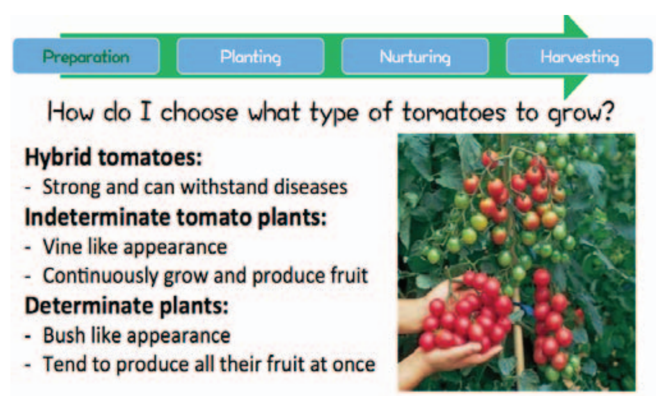

Fig. 2. Preparation Slide Giving Advice on Choosing Tomatoes

Regardless of whether or not soil testing is utilized, specific nutrients need to be optimized for the plants farmers intend to grow. Farmers need to be aware of the nutrients plants require at their different stages of development. For instance, a starter fertilizer high in phosphorous is recommended at the time of planting to promote proper root development. If fertilizers are not accessible, local materials can suffice. Manure, compost, and wood ash are low-cost available remedies for altering nutrient contents. In spite of unavailable fertilizer, these are still viable, true and tested methods of improving soil quality. Aged manure and/or compost have been proven to provide adequate nutrients for most plants.

B. Planting

Once important nutrients are added to the soil and the land is tilled, farmers are ready for the planting stage. In this phase farmers are guided through six questions to help them maximize the potential use of their land by teaching proper spacing and planting techniques.

At this point farmers need to consider the benefits of a nursery bed. Nursery beds are created to germinate seedlings, which will then be transplanted to their final destination. The nursery bed helps ensure that proper nutrients are supplied to the vulnerable seedlings. This saves water and other materials because they only need to be applied to the small seedbed areas. Additionally, planting approximately 20% more seeds than necessary, farmers can choose the best seedlings to transplant. Instructions and advice are supplied for farmers who are unfamiliar with the spacing needed for seeds and plants. Spacing can affect the quantity and size of the fruits produced by plants and needs to be considered.

Fig. 3 Planting Slide Teaching Proper Method Of Transplanting Seedlings

C. Nurturing

After planting, farmers are guided through an additional five questions to help them properly nurture their plants to further limit the potential of pests and diseases from infecting their crops. Farmers need to pay utmost attention to the plants in the early stages of growth and continue to monitor until harvesting. Farmers should check their plants weekly for possible pest and disease damages. White flies, for instance, tend to live on the bottom of tomato leaves and can devastate tomato plants if not promptly identified and treated. Proper weeding and disposing of plant material can prevent white flies, as well as other pests. Old plant debris can serve as a breeding ground for these pests.

In the nurturing phase farmers should also consider the benefits of de-suckering and de-foliage. Suckers are side-shoots that grow in the crotch between the stem and branch of certain plants. It is recommended to remove the suckers from indeterminate tomato plants because excess foliage can burden the plants. De-foliage is a technique that serves a very similar purpose. De-foliating plants involves removing leaves below fruits in order to decrease foliage. Excess foliage can promote wet conditions that lead to fungal diseases. Furthermore, suckers and foliage use up nutrients that could be going to fruits, resulting in smaller yields. Watering is another critical aspect throughout all stages of plant development and needs to be reconsidered for the context of greenhouses. Recommendations are provided for traditional watering techniques and drip-line irrigation. Recommendations take into account water savings to limit the burden on farmers in resource-constrained settings.

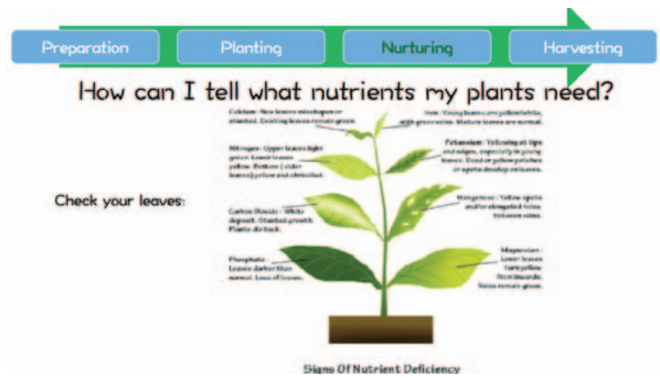

Fig. 4. Nurturing Slide Depicting How To Tell What Nutrients Plants Need Based On Appearance Of Leaves

D. Harvesting

Once plants are getting close to the end of their crop cycle, farmers need to be equipped with proper knowledge of harvesting and post-harvesting knowledge in order to limit spoilage before crops are either sold or consumed. This section provides the final five questions to ensure crops are harvested at the correct time. It is necessary that farmers know the difference between maturity and ripeness so they can properly harvest their crop. Maturity precedes ripeness and it is at this time that fruits should be taken off the plant and stored.

Proper storage is crucial in order to not spoil the crop. Food waste is an ongoing problem and improper storage techniques are the leading cause of this problem. Sustainable post-harvesting techniques are often expensive. Indigenous knowledge and techniques farmers have adopted can increase time before spoilage.

IV. Validation

In Zambia, field research was conducted to further understand the current practices of farmers. Greenhouses are not as common in Zambia, compared to other African

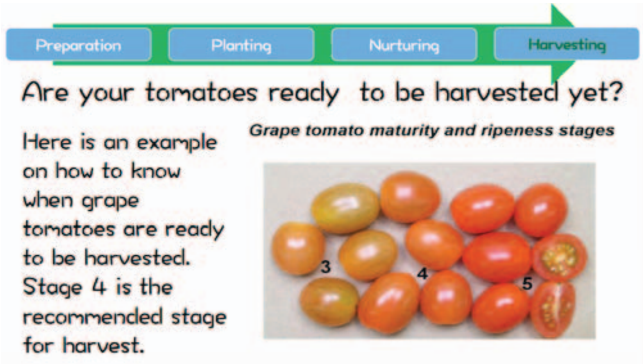

Fig. 5. Harvesting Slide Showing When To Harvest Tomatoes Based On Color

countries. Interviews with smallholder farmers in Zambia offered insight to existing indigenous horticulture practices, and their ability to translate into greenhouse farming. Through interviews with over 30 farmers, in three various rural areas in Zambia, the Decision Support Tool was validated. It was validated in three major areas, the need, the concept, and the technology.

E. Need

The need for the Decision Support Tool was gauged by validating each of the questions and decisions that had been outlined. Previous research had already been done on more Western and modern horticultural practices, in order to compare such practices to ones currently used. In Zambia it was clear that although various methods were similar between farmers, many techniques were unique. Despite the various techniques employed, there was a lack of farmer-to-farmer collaboration. Many would express challenges they faced, that their neighbor would have overcome. An example is one farmer growing cabbage, using anthill soil, to overcome problems of their cabbage being too small.

The tool was then modified to aggregate horticultural techniques that will allow farmers to succeed, after seeing what has worked and what has not. The different levels of success farmers directly relate to what horticulture practices they adopt. From techniques as seemingly insignificant as spacing of crops, which had enormous impacts on the farmers yield. The tool acts as a space, where the agricultural process is standardized, to ensure that farmers are capable of accessing all the information, at any given time. Adding to the tool context-specific techniques allows the farmer to directly apply these practices.

F. Concept

Similar to a student being guided through the educational system by an advisor, the tool is meant to guide the farmer. The series of questions that the tool includes was validated with each interview. No question regarding plant beds, fertilizer, composting, transplanting was unfamiliar to the farmers. Each one of them had already thought through the process, and understood their capacity to undertake each of the various techniques. Older women, and those with smaller farms, were unable to preform crop rotation, even though they knew it would erode the soil. The length of the crop cycle was the determining factor for many of these women. They expressed that rape, a leafy green similar to kale, is their preferred crop. In comparison to tomatoes and cabbage, it's much easier to tend to, needing less water, and a mere two weeks to mature.

The process of farming vegetables such as tomatoes, cabbage, and greens was validated through the experiences of more experienced farmers, who described the process with ease. However, when asked technical details, such as how soil is tested,, the distance between plants, and amount of manure or fertilizer used, ambiguous answers were given. Farmers did not have a uniform method of measuring, which affected how large their plants would become. The aggregation of such experiences allowed us to add to what many farmers were missing, by structuring those experiences into a detailed list of questions.

Changes were made to the original tool through the addition of practical solutions, such as ensuring farmers read their seed packets. Measurements in the form of centimeters or meters were substituted by using the length of a finger, or a hand to ensure their adoption in the farming process. The only farmer, who adopted any kind of measurement system, was advised by an extension agent to measure fertilizer with one bottle cap per cabbage plant. The inclusion of such practical advice would provide a more uniform measurement process in a practical manner.

Technology

After showing the tool to many of the farmers through an e-reader, modifications were made. The majority of space on each slide was taken up by text. Going through such slides with the farmers, brought about the realization that for many who do not speak proficient English, pictures were much more effective.. The tool was then further reviewed to use simpler, more precise language . Diagrams that showed crop rotations, and intercropping included crops that many of the farmers were unfamiliar with. All diagrams and pictures were then reviewed to ensure that they were context-specific. Soil testing using a jar and water was deemed impractical to include in the tool, due to the confusion it caused among farmers. Many of the farmers needed direct, and simple methods. As a substitute, checking the plant leaves for missing nutrients in the soil was a more practical approach. Many of the farmers appreciated this additional knowledge.

The use of an e-reader in certain contexts where many do not have access to smartphones, is both unpractical and unsustainable. This was realized when many of them were unable to use the device. Multiple methods of disseminating this tool had to be created in order to ensure a practical approach, such as giving a paper-copy to extension agents to personally disseminate to farmers in their districts.

V. Sample Use Scenarios

A successful user experience will require the extension agent to ensure the user has the opportunity to access this information. This will be carried out through the provision of a paper-version of the tool, which can be accessed at any time. The importance of building trust between the extension agent and the farmer is necessary for success. The user will depend on the extension agent to maneuver the obstacles to success, fruitfully. It is also essential to note that the user still retain their own knowledge, and use the extension agent, and the tool itself, as a way to reach a positive outcome. This attempts to avoid unsustainable relationships of dependency between the two actors. Especially for new greenhouse users, the application of this tool will become a vital aspect of their success.

The factors of accessibility and affordability are crucial to the success of the tool, as they ultimately determine the extent of the impact. Although this tool was designed with the African context in mind, it is applicable to all areas where greenhouse farming is occurring. Extension agents will be a vital component in the implementation of this tool in the greenhouse adoption process. This decision-support tool can be used through two methods, a paper cop or through a PDF version, which can be read on an e-reader, tablet, computer, and smartphones. These two methods will carry the same information, with the same processes.

A. Paper Copy

The paper copy will include laminated slides inside of a binder. In addition to a table of contents, this will allow them to easily locate the question they are looking to answer, and all the related informational slides the tool encompasses. The paper copy has the ability to be mass-produced at a cost-effective rate, in comparison to the e-reader method, where only those with the necessary capital can access the information.

B. PDF

The PDF method version allows users to access this tool on a wide variety of devices. Devices such as smartphones, tablets, e-readers, and computers all have the capability of displaying PDF's. In order to display effectively on a smartphone, the decision-tool must be optimized to fit on a much smaller screen. For any device used to view the PDF version, the user will be capable of viewing the tool in a way that will allow a greater degree of user interaction improving the experience. The user can physically press on stages that he or she wishes to be taken to, and then click on specific crops to gain more detailed information relating to their plants of interest. The use of hyperlinks allows this level of interaction between the tool and the user. The limits of this method remain to be the accessibility of users to smart devices.

VI. Shortcomings of the Decision Tool

The decision support tool is still in its prototype stage. With only three major crops as options, it is limited in it ability to provide valuable information to farmers who are interested in growing more exotic plants. Further testing is necessary in order to validate this tool's impact. Farmers who have a limited experience with farming or farmers who only need specific information may be more inclined to find this useful than those with minimal to no experience.

The shortcomings of the tool also coincide with the way any instruction document is treated. Often time's guidelines and recommendations are disregarded as generic information, as some of the techniques are common knowledge to many experienced farmers. The challenge lies in ensuring that this tool is useful, even to those who know how to farm. Ideally, a greater number of farmers would be interviewed to identify the gaps they face, in order to validate how successfully the tool will allow farmers to transition to greenhouse farming.

With a greater amount of a time, studies spanning a longer period of time can be done to reveal just how successful the tool was in this transition process. Such data would add vital information to the tool, which could help farmers.

VII. Conclusion

This decision support tool is an initial step for increasing the access that greenhouse users have to vital information that will guide them through relevant decisions. Additionally it will add to the successful and sustainable adoption of greenhouse technology, as it mitigates the risk smallholder, and novice farmers inherently face. In the future this tool could encompass a greater variety of crops, supporting the most popular crops being grown. This will include features that promote greater potential for lateral knowledge sharing. Seeking to promote greater farmer-to-farmer interaction. This would create a wider community of greenhouse users that will act as a support system to help them succeed. With the availability and accessibility of a decision support tool greenhouses can be widely adopted, with greater support and less risk. To combat imperative issues of food security that our world faces as the population continues to grow.

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