A GROWING CULTURE

Environmental Benefits Toolkit

DOCUMENTING AND QUANTIFYING THE BENEFITS OF SMALLHOLDER FARMING

COLUMBIA UNIVERSITY
MASTER OF SCIENCE IN SUSTAINABILITY MANAGEMENT
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EXECUTIVE SUMMARY

The Columbia University Spring 2017 Capstone Team is pleased to present the following report, composed of two sections. The first is a set of recommendations for establishing a baseline for, and documenting the progress of, smallholder farming communities; it bears the title ‘Environmental Benefits Toolkit.' The Toolkit in its current form focuses on specific aspects of the environmental benefits accruing to smallholder farmers, but its approach could be expanded to other sustainability benefits. The second section details the in-field work done in Kasejjere, Uganda to test the application of the Toolkit and the interviews conducted with community members. Referred to as the ‘Test Case,' it is a first attempt at creating a baseline for environmental practices using an approach that works to link the experiences of a smallholder farming community with the information demanded by actors in the sustainable agriculture community. This second section includes interview transcripts; methods for testing water and soil, and the results of those tests; a GPS-generated map of Kasejjere that locates the fields tested; and a photo database.

This project’s objective had two aims. First, it hoped to develop a clear method for establishing a baseline for the environmental practices related to smallholder farmers, and for documenting their progress over time. Second, it attempted to translate and correlate local empirical knowledge to the conventional metrics recognized by the international agricultural community. The goal was to enable A Growing Culture to expand upon the knowledge sharing it has pioneered: in addition to facilitating the way farmers can communicate with each other, it might also be possible to allow farmers to speak directly to actors in the sustainable agriculture community. If they can speak on their own terms to the larger sustainable agriculture community, farmers can benefit from what they know as well as what they harvest. This kind of knowledge sharing can increase recognition and appreciation for smallholder farmers, solidifying their social positions and preserving their traditions even as they establish their role in new opportunities through physical crops and the value of the knowledge they offer.

This paper and the associated resources are intended for use by A Growing Culture, its field coordinators, and the communities in which they work. The way the information is presented will have to be phrased differently based on the context of each community. This paper does not yet do that work but recognizes that this is still to be accomplished. What this paper seeks to do is provide the foundations for A Growing Culture to build on.

Thank you,

2017 Columbia Capstone Team

DEFINITION OF KEY TERMS

Agroecology: "Agroecology is a scientific discipline, a set of practices and a social movement. As a science, it studies how different components of the agroecosystem interact. As a set of practices, it seeks sustainable farming systems that optimize and stabilize yields. As a social movement, it pursues multifunctional roles for agriculture, promotes social justice, nurtures identity and culture, and strengthens the economic viability of rural areas. Family farmers are the people who hold the tools for practicing Agroecology. They are the real keepers of the knowledge and wisdom needed for this agenda. Therefore, family farmers around the world are the keys elements for producing food in an agroecological way." (FAO)

Industrial (or Conventional) Agriculture: "Industrial-style agriculture is characterized by 'farms [that] are often very large, highly specialized, and run like factories with large inputs of fossil fuels, pesticides and other chemicals, and synthetic fertilizers derived from oil.'" (Union of Concerned Scientists)

Key Indicator: A measurable value that can be used to express some degree of progress.

Metric: A measurement tool that offers a sense of scale, describes the scope, identifies the data source, and/or provides other context-specific insight to ascertain progress and guide decision-making.

Metric Category: A theme for evaluating the aggregate records found through the data collection process appropriate for each metric.

Smallholder Farmer: The term 'smallholder' refers to their limited resources or farm size relative to other farmers in the sector. Thus, the definition of smallholders differs between countries and between regions. In favorable areas with high population densities, smallholders often cultivate less than one ha of land, whereas they may cultivate 10 ha or more in semi-arid areas, or manage 10 head of livestock. (Adapted from FAO)

Sustainable Agriculture: The management and conservation of the natural resource base, and the orientation of technological and institutional change, in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such a practice conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable. (FAO)

Sustainable Agriculture Community: A geographically dispersed group of individual farmers and supportive organizations, including nongovernmental organizations, governments, investors, and companies that share a common vision for their practices and their intents.

Yield: Some count number, whether individual or bundled, of a crop harvest per unit measure of cultivated land area.

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1 | INTRODUCTION

Smallholder farmers are providing up to 70 percent of the world's food[1] using traditional methods that may have been passed down for generations. However, the conditions that today's farmers have inherited bear little resemblance to those of their parents and grandparents. Climate change is altering the volume and frequency of rain, flooding and droughts are becoming more pronounced and prolonged, and temperatures are rising[2]. Subsistence farmers must adapt to these conditions to protect their livelihood and way of life.

Farmers are responding to climate change with agroecological innovation, tailoring traditional methods and testing crop varieties to counter the effects of climate change in sustainable ways[3]. For instance, they are improving the health of depleted soil by mulching in green and animal manure, planting nitrogen-enriching plants and trees to boost crop production, and reforesting areas of land to create biodiverse microenvironments. These methods improve growing conditions and aid in carbon sequestration, critical to the global effort to reduce greenhouse gases. Agroecological farmers do not use commercially produced inputs, due to resource constraints or by personal choice, which decreases capital requirements while protecting their ecosystem.

Preserving farmer knowledge and sharing agricultural innovation is at the heart of A Growing Culture's mission. They have been gathering stories and farmer-led documentation to cross-pollinate between communities and sharing it with a broader audience online[4]. Our project needed to stay true to their bottom-up approach of farmer-led knowledge sharing. The Capstone Team began by asking a series of interrelated questions:

1. Is there a discernible relationship between the understanding and experience of smallholder farmers and the terminology used by sustainable agriculture and the broader community?
2. How can local farming knowledge be translated across the geographic and cultural boundaries that separate small farming communities with resources that can aid in their development?
3. Is the proposed approach to documenting and translating local farmer knowledge valid and replicable?

1.1 | Problem Statement

Due to several overlapping factors, such as resource and time constraints, smallholder farmers do not commonly document their performance nor basic environmental measurements such as soil health, water usage, or amount of crops harvested per acre (yield). Smallholder farmers may not place a high value on tracking these measurements[5], but the sustainable and industrial agriculture communities do, to demonstrate progress over time[6]. Smallholder and subsistence farmers rely on memory for historical data, such as the volume of rain, crop production, or climate conditions[7]. Without collecting this information over time, smallholder farmers are unable to counter claims from industrial agriculture that industrial farms are more productive[8]; smallholder farmers may produce higher yields with less environmental damage but are largely left out of the discussion around solutions for feeding their countries' growing populations[9].

Farmer innovations, knowledge, and experience often have a limited reach. This information is typically communicated orally farmer-to-farmer, within the family or village[10]. This vital information needs to be preserved and exchanged with other communities and the broader sustainable agriculture community. This knowledge also needs to be saved for the future, as the younger generation is leaving the labor-intensive work of the farm for employment in the city[11]. In exchange, farmers need to be able to tap into resources and knowledge they may lack access to, from their remote locations.

Additionally, smallholder farmers often apply their empirical knowledge via trial and error to crop cultivation[12]. While their experience has significant value, this approach can take vital resources and time in failed attempts. These failures may become more frequent due to climate change.

Finally, the Capstone Team's research has provided case studies indicating that smallholder farmers are hesitant to modify their method of farming, relying on their traditional methods even when they become less productive[13]. To spread the adoption of agroecological practices, a response to this trepidation must be considered.

Conventional versus empirical approach to agriculture

Large-scale farmers, whether they take an industrial or sustainable approach to agriculture, may have the means to afford scientific testing and analysis to determine components of the soil and adjust them or the crops they grow as needed[14]. This method encourages tracking and documenting inputs and outputs over time. Smallholder farmers may rely solely on experience, observation, and trial and error to take the same measurements. Soil fertility can be measured by look, feel, and color of the soil, as well as by the success or failure of certain crops or weeds[15]. While this method may contain a lot of guesswork on behalf of the farmer, it may be the only viable method due to time and resource constraints.

1.2 | Project Context

Organizations like A Growing Culture are aiding communities by capturing farmer knowledge in an exchange of ideas, which is shared within the community as well as more broadly via the Internet[16]. For example, they sponsor farmer-led workshops, which may be documented via digital video, to share skills and ideas[17]. Successful initiatives, in the communities that A Growing Culture works with, focus on knowledge sharing, however, there are currently no comparable methods of measuring their environmental benefits over time. Quantifying environmental progress can help farmers in two ways.

The first is a means of communicating the success of their work to promote practices and participation in a “knowledge economy.” For community leaders who are promoting sustainable and local practices, or striving to meet environmental objectives, quantified progress provides evidence to support their claims[18]. Focusing on supply chain or yield to improve farmers’ lives is good, but A Growing Culture recognizes that what farmers have in their minds is also extremely valuable. Assisting farmers to improve their livelihoods using their knowledge and valued by others, but not directly linked to their physical harvests, is part of what we envision. There is no reason that farmers should be excluded from an economy that trades in ideas. AGC’s work supports this implicitly, through sharing knowledge. By extending that support to sharing the value of farmers’ work in regards to their environment, A Growing Culture can support the further development of community self-sufficiency and stability.

Second, the ability to demonstrate progressive benefits to the environment through recordkeeping could create additional opportunities in the form of investments, subsidies, and grants. This approach is valuable for farmers who are looking to expand to new markets to sell crops, join corporate supply contracts, or diversify their income. Studies on smallholder farmers and recordkeeping (i.e. crops harvested, the cost of inputs, and income) show that maintaining written records opens up access to credit and other investments including sustainability certifications[19]. Across the global sustainable agriculture community, major actors including governments, investors, companies, and non-governmental organizations (NGOs) are looking to demonstrate progress towards environmental objectives[20]. Companies are facing increased public scrutiny to deliver more transparent supply chains and support farmers with sustainability certifications[21]. Similarly, companies and investors have growing interests in demonstrating social and environmental progress as well as financial returns[22]. Numerous grants exist to support smallholders, but the NGOs that distribute them need to demonstrate progress to their donors[23]. A growing number of organizations are required to show results-based performance to their investors or sponsors to validate funds are being spent with positive impact; results need to be collected and reported[24].

The growing interest in sustainable agriculture is partially driven by the United Nation's Sustainable Development Goals, which are a set of 17 global goals that focus on reducing poverty, improving education, and sustainable development, among others. Each goal has individual targets, 169 in total, that are relevant to smallholder farmers, including protecting biodiversity, access to clean water, and food security; all of these targets are challenged by climate change[25].

Sustainable Agriculture and the SDGs

The following Sustainable Development Goals are particularly relevant to the overarching themes of this project:

- Goal 2: Zero Hunger | Target: Double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment[26].
- Goal 2: Responsible Consumption and Production | Target: Encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle[27].

The emphasis on sustainable development is aimed at reducing poverty without compromising environmental ecosystems[28]. Smallholder farmers who can demonstrate the environmental benefits of their sustainable farming practices may have an increased opportunity to participate in this solution. However, to participate, farmers will need to measure their benefits and track them over the course of years in a systematic way; without this data, they may not be able to access resources offered to those aiding in this global effort[29].

1.2.1 | Challenges

Governments, investors, and non-governmental organizations (NGOs) involved in the sustainable agriculture and sustainable development space have individually and collectively sought to standardize means for quantifying benefits from sustainable practices, per their specific interests and concerns. The result is a large set of metric categories and indicators designed to help demonstrate trends (See Section 8.2).

However, these metrics and key indicators often do not account for the context and capacities of smallholder farmers in developing countries. Rather, the approach creates some barriers that make smallholder participation in these efforts challenging. These barriers can be separated into two categories: Documentation and Transportability.

Barriers to Documentation

The knowledge base of smallholder farmers is dependent on their individual experiences, and the highly variable social and environmental contexts in which they live. This provides challenges to capturing environmental progress resulting from sustainable and local practices.

Challenges	Description
Limited Time and Capacity	Starting and sustaining records requires considerable time and effort, which may not be available in smallholder communities[30].
Literacy	Low literacy and limited mathematics skills have been found to be the key reasons why farmers do not keep records[31].
Access to Technology and Connectivity	Differing access to technology including hardware such as cell phones and computers, as well as services including cell and internet[32].
Perceived Value	Surveys show the primary reason smallholder farmers do not keep records is they do not see a use for such records nor find them beneficial[33].

Barriers for Transferability

A smallholder farmer's experience, education, location, and income have a significant impact on their understanding and value of basic metrics, such as farm size, water usage, crop yield or soil health. The sustainable agriculture community uses standardized metrics to measure impact. Although these two groups are working toward the same goal, they are speaking different languages, even in a literal sense. How each group represents their information, including word choice can influence the interpretation. Linguists have theorized that individuals speaking in different languages perceive the world differently[34].

Based on a comprehensive literature review, key sustainable agriculture community actors collect information in two distinct ways:

- Qualitative information on what is happening on the ground through audits and surveys. This method of information collection includes types of practices employed, whether fertilizer or pesticides are used, etc.[35]

- Quantitative data collected from conventional testing techniques and comprehensive studies. Studies show that top-down approaches that impose technologies are not sustainable over time, due to the need for continued external support and resources[36].

Because of this barrier, farmer knowledge is not always transferable from the individual to international actors. As such, farmers can be prevented from adequately accessing external resources or communicating the benefits of their practices. A lack of available, consistent data exacerbates these disconnects[37].

1.2.2 | Solution

This Capstone project sought a way to augment A Growing Culture's existing farmer-led initiatives. There is an opportunity to document the environmental benefits of farmer innovations over time. The Team researched basic measurements that have value to smallholder farmers through research and one-on-one interviews with farmers. Through this, process an approach was designed and field-tested in a farming village that A Growing Culture is currently partnered with, Kasejjere in central Uganda.

The approach starts with establishing a baseline with some basic measurements to determine the state of the farmer's ecosystem, such as soil health, water quality, and biodiversity. An emphasis is placed on taking periodic snapshots over time to track the progress of farmer initiatives. It is the intent of this project to validate empirical farmer knowledge with affordable conventional methods. This approach will not only establish a track record to confirm the benefits of agroecology for the farmer and their community, but this will also be accomplished using metrics that have been established by the sustainable agriculture community. Smallholder farmers demonstrate a need and an opportunity for A Growing Culture to help capture and promote this kind of information, just as A Growing Culture already does with their local practices and knowledge.

Measurements are not intended to add additional labor to smallholder farmers. But given the global sustainable agriculture focus on metrics, communities need to capture progress to secure access to opportunities within the broader sustainability community. This Capstone Project identified potential resources to collect this information and a framework on what might be collected. A Growing Culture is uniquely positioned to support this type of information collection, as well as share and advocate on behalf of their partner communities, just as they already do with their current knowledge-sharing network. The Environmental Benefit Toolkit addresses this opportunity.

2 | THE ENVIRONMENTAL BENEFITS TOOLKIT

The Environmental Benefits Toolkit is a collection of resources that can be shared with field coordinators or community leaders that A Growing Culture partners within farming communities. The Toolkit presents a scalable approach to collect, aggregate, and track the environmental benefits of agroecological farming practices. An emphasis is placed on gathering and preserving local knowledge through informational interviews with farmers and documenting basic environmental trends over time.

Documenting measurements' benefits requires two components. After establishing a baseline for components of the soil, water sources, biodiversity, and productivity, farmers can track their successes after adopting agroecological farming practices. Capturing their experience will confirm which practices are working and will encourage these practices by validating the farmers' efforts. Additionally, A Growing Culture will benefit by having reportable data to reflect improvements for the community. These results can be shared with other communities who are interested in sharing knowledge and potential investors who may require results-based performance as criteria for their funding.

Supplemental materials will be provided to A Growing Culture as additional support, including a literature review, and an image database and copies of interviews with farmers taken during the Team's visit to Kasejjere.

2.1 | How to Use the Toolkit

The Toolkit can be tailored or adjusted to the needs of a community. It is organized into four sections:

1. The Case for Environmental Benefits Documentation: Outlines the reasons for documenting and communicating the environmental benefits of agroecology for smallholder farmers.
2. Implementation Guide: Details the steps for planning and implementing an Environmental Benefits Documentation project in a new community.
3. Field Guide: Contains inexpensive and low-resource tests to validate smallholder farmer knowledge.
4. Test Case: Narrates the trial and results of the above approaches in the farming village of Kasejjere, Uganda.

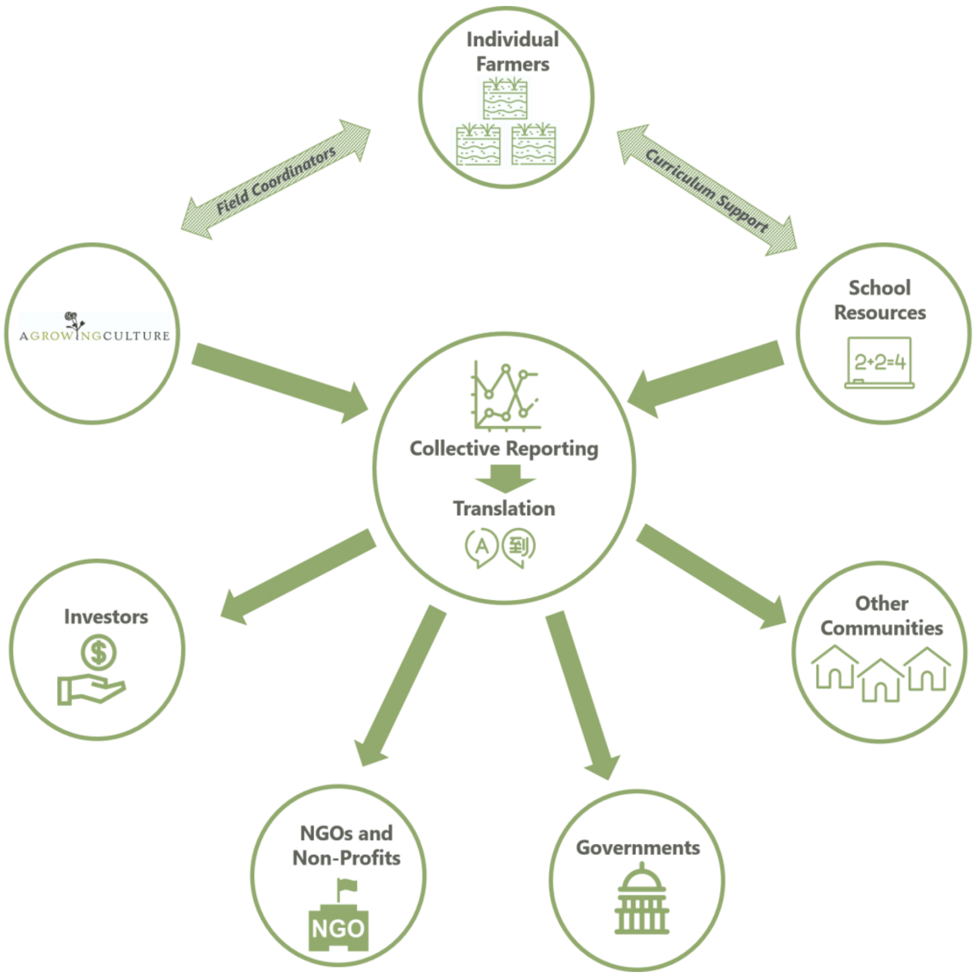
2.2 | Intended Outcomes of the Toolkit

The Toolkit is intended to augment the knowledge-sharing practices at the heart of A Growing Culture's mission. The goal is to take a practical approach to preserving farmer knowledge and quantify it in simple terms that should not demand additional labor for the farmers. The documentation process is one approach to validating community success stories that can provide substance and context to the farmers, other communities, and potential investors in funding A Growing Culture's outreach.

The Toolkit is not intended to serve as a definite standard for what farmers are required to measure, nor what practices they should implement. The approach can be tailored to the needs or resources of the community and can be scaled up over time as methods of documentation are discovered. Farmers may not have the resources or time available to document the outlined measurements, however a goal of this paper it to assist in identifying resources within the community who can assist with compiling the data.

Figure 1 outlines the flow of information from farmers to the broader sustainable agriculture community with assistance from field coordinators and local resources.

Figure 1 | Flow of Documented Information



This approach places farmers as the focus, where A Growing Culture and other local assets can support smallholder farmers in collecting and communicating the benefits of their practices to the sustainable agriculture community. Field coordinators can act as the link between A Growing Culture and individual farmers.

3 | THE CASE FOR ENVIRONMENTAL BENEFITS DOCUMENTATION

3.1 | Drivers for Smallholder Farmers

Opportunities to Apply Knowledge

Broad knowledge of a variety of farming practices empowers farmers to respond to different situations, thereby increasing the efficiency of their land, increasing their harvest, and bringing more products to the market[38]. Smallholder farming communities that invest in solutions to protect food, like efficient storage, can improve food security and increase profits by eliminating 30 percent of food loss post-harvest[39].

Opportunities to Share Knowledge

Knowledge sharing provides an opportunity for farmers to understand trends that impact the whole community. Hearing about a neighbor's success with a new farming method is often not enough to convince a farmer to risk their own output to experiment[40]. Documenting the new method with records, photography, and digital video can be more persuasive. Tracking progress over time provides communities with proof, both for themselves and for other communities of the tangible benefits of sustainable agriculture. Sharing knowledge gained over seasons of trial and error allows farmers to advance faster as a community. Value and income is not linked only to physical crops, but also to knowledge.

Increased Community Resilience

Smallholder farming is typically a very individualized undertaking. Success or failure is often tied to the individual farmer's outcomes and the knowledge that has been passed down to them or that they might have acquired from a friend, neighbor, or through trial and error[41]. However, sustainable farming practices benefit not just the individual farmer; they also benefit the local ecosystem[42]. Furthermore, as climate change continues to alter weather patterns (i.e. rainstorm events), building resilience through sustainable agriculture protects the health and potential prosperity of the community[43].

Access to New Resources

The documentation of quantitative knowledge also represents an opportunity to attract resources, not just to sell their products. Knowledge itself is a commodity, and the expression of knowledge and progress can attract grants and investment to support community resources, including but not limited to, education, farmer-to-farmer training, and external partnership opportunities. An example of this type of knowledge commodity is the farmer-to-farmer training and exposure garnered by communities in the *Campesino a Campesino* movement in Latin America, where farmers' skills and sustainability progress has brought international attention and resources[44].

3.2 | Drivers for Broader Sustainable Agriculture Community

While individual metrics may differ, the majority of representatives in the sustainable agriculture community need to demonstrate environmental benefits of their practices. The following drivers fuel demonstration towards progress:

Achieving Sustainable Development Goals

Governments, nonprofits, and companies are voluntarily embracing the Sustainable Development Goals (SDGs). 195 countries ratified the SDGs, and many are serious about their commitments. 22 nations have already started reporting progress on SDG metrics to the High-Level Political Forum, which oversees the management of the SDGs and tracks progress towards the individual targets[45]. Nonprofits are using the SDGs to underscore agendas for social and environmental change[46]. Businesses see the SDGs as opportunities to expand into new markets, or grow existing ones, with food-related SDG initiatives estimated to generate US$2.3 trillion annually for the private sector by 2030[47]. More than 2,000 partnership initiatives to help meet the goals have registered with the UN, with participants from all three sectors[48].

Increased Consumer Demand for Sustainability

Consumer sustainability concerns are driving company actions within the food and agricultural sectors. The Business and Sustainable Development Commission estimates that these trends will generate over 72 million jobs in developing countries by driving growth in certified agricultural products and increased engagement between companies and suppliers[49].

Increased Focus on Impact Investing

Impact investing uses environmental, social and corporate governance (ESG) criteria in addition to financial metrics to weight companies, or invests directly in projects with environmental or social benefits[50]. The Forum for Sustainable and Responsible Investment Foundation reported that there was a 33 percent increase in impact investments from 2014 to 2016, accounting for nearly $9 trillion invested in the United States alone[51]. Much of the growth is driven by corporate foundations and investment firms looking to create specific impacts, such as Root Capital[52]. Climate and the environment have emerged as priorities for individual investors and private equity firms[53].

4 | THE IMPLEMENTATION GUIDE

4.1 | Structure and Objectives

The Implementation Guide is designed to support the development of a documentation and translation process. The approach is to focus on means of documenting and validating local knowledge embedded in communities around environmental benefits. It can be used to begin evaluating the opportunities for such a program in a specific community.

This section is organized into four pieces:

1) How to determine standard metrics and community-specific indicators.
2) How to establish a baseline of environmental conditions through documentation of local knowledge and application of low-cost, readily available methods for validating that information.
3) Methods for translating and correlating environmental benefits.
4) Methods for maintaining records over time.

4.2 | Standard Metrics Determination

Standard metrics ensure that members in the sustainable agriculture community have a common language. For smallholder farmers to participate in this community, they may review which metrics are relevant to their practices and adopt basic forms of measurement. This effort will aid them in communicating the benefits of their agricultural innovation, which can be shared with a broader audience.

4.2.1 | Approach to Determining Metric Categories

Conducting the review:

The standard metric categories are intended to bridge the gap between smallholder farmers and the global sustainable agriculture conversations. Three steps are necessary to complete this: (1) Review of global stakeholder concerns, (2) review of smallholder concerns, and (3) a cross-comparison of the two lists to identify commonality.

Environmental concerns were the focus of the field test in Kasejjere conducted by the Capstone Team, but this approach applies to other aspects of sustainability.

1) Global Sustainable Agriculture Actors: A survey of nonprofits, NGOs, investors, governments, and companies can be used to ascertain the most consistent categories of interest through:
    - Interviews with academics, industry experts, and investors.

- A literature review of available sustainable agriculture standards and key indicators.

A list of entities and standards reviewed for the test case is available in Section 8.2.

2) Smallholder concerns: Smallholder farmer concerns can be ascertained remotely or in the field. Questions should not be limited to environmental issues. Instead, they should focus on the farmer's concerns that will reveal their relationship with the environment. A sample set of questions can be found in Section 5.

3) Establish Relationships: The list of global actor and farmer concerns can then be cross-compared to identify consistencies. This comparison is best done by listing out keywords and looking for comparisons. Many of these will be straightforward. However, some might be abstract such as the connection between farmers' interest in ecosystem services and the role of biodiversity.

Implementation Tip

Given the differing contexts of smallholder communities, the core metric categories might not cover all relevant areas of concern or interest. Ideally, an assessment of farming practices, local resources, social health, and other local concerns should be completed for each community. This background can be used to determine the best testing methods and documentation considerations specific to that community.

4.2.2 | Standard Metric Categories

For this initial approach, four metric categories were identified as areas of interest: soil, water, biodiversity, and productivity. These categories are by no means comprehensive but are intended to be applicable in a diverse of situations. Indicators in each category can also serve as proxy indicators for more complex environmental concerns. For example, the soil structure (silt, sand, and loam) can provide context for the water carrying capacity and is one aspect of drought and climate resilience[54].

While sustainable agriculture actors consistently include energy and greenhouse gas-related metrics in their consideration of environmental sustainability (see Section 8.2), the Capstone Team chose not to include these metrics with the core categories. Initial conversations with A Growing Culture and farmers in the test case community indicated that the smallholder communities use limited energy, making energy-related metrics insignificant[55]. Additionally, while farmers reported concerns about climate change, the focus was on resilience, not mitigation[56]. The greenhouse gas emissions indicators that overlap most with the smallholder farmer context are also captured in biodiversity indicators, namely deforestation and land cover.

For each category, the relevance to smallholder agriculture and sustainability are identified below, along with the most relevant Sustainable Development Goals and examples of indicators:

Soil: Soil quality can be defined as the *"continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans.[57]"* Practically speaking, soil health encompasses multiple characteristics of soil. Healthy soil is not directly related to soil fertility, as different crops have specific pH and nutrient demands. However, soil is a complex living organism with multiple components that can be measured either by an empirical or scientific approach. Thus, it can be used as a proxy for ecosystem health by testing it for the presence of chemical inputs that might leach into the water table, nutrients that crops need to thrive, or the presence of organic matter for plants to feed on[58].

Related Sustainable Development Goals

- Goal 2: Zero Hunger | Target: Ensure sustainable food production systems and implement resilient agricultural practices by 2030[59].
- Goal 15: Life on Land | Target: Halting and reversing land degradation by 2030[60].

Examples of Soil Health Metrics

- **Chemical:** pH level, nutrient content, salinity
- **Physical:** soil texture and structure; infiltration capacity, water retention, erosion
- **Biological:** earthworms, microbial biomass, carbon content, soil respiration

Water: Agricultural water concerns relate both to use and quality. Water use, an input to the agricultural system, refers to the total quantity of water from precipitation or groundwater and surface water withdrawals[61]. Water quality can be considered an output from an agricultural perspective, as it is impacted by chemical, pesticides, and fertilizer runoff[62]. Both quantity and quality can serve as proxies for resource efficiency and ecosystem health, although the relationship between agricultural practices and water quality is less direct. Research shows that improved agricultural management will not necessarily lead to improved water quality, as water quality is an indicator of a system's health and is impacted by a range of other factors, including industrial and construction activities[63].

Related Sustainable Development Goals

- Goal 6: Ensure access to water and sanitation for all | Target: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally[64].

Examples of Water Metrics

- Total water used by source (precipitation, surface water, groundwater)
- Total annual precipitation
- Total volume of irrigation
- Groundwater intrusion rate or volume
- Water table depletion rate
- Eutrophication
- Concentration of chemical contaminants

Biodiversity: Biodiversity can be defined as *"the variability of life among living organisms,"* and forms the foundation of a large number of ecosystem services critical to agriculture, including but not limited to pollination, water retention, and the mitigation of risks for crop disease and pests[65]. There are two main measurements of biodiversity: (1) Richness, which counts the number of different species in a given area, and (2) abundance, which counts the number of individuals in a given species[66]. The Millennium Ecosystem Assessment, sponsored by the United Nations, found that changes in biodiversity had a discernible impact on farm productivity, particularly changes in pollinator abundance and plant richness[67]. More than the other categories, the complex combinations of systems that constitute biodiversity makes measurement challenging, especially on a local level[68]. Comprehensive biodiversity assessments are time and cost intensive. Proxy indicators are therefore needed to help derive a sense of agricultural health[69].

Related Sustainable Development Goals

Goal 15 | Life on Land: By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally[70].

Examples of Biodiversity Metrics

- Biodiversity as measured by indicator species (macroinvertebrates, birds, amphibians, native plants)
- Land coverage and conversion

Productivity: Although productivity does not directly relate to the environment, productivity records are used as a means of tracking agriculture performance and can support farmer access to additional support and benefits[71]. Productivity can be divided into subcategories: (1) measurements, such as field size and (2) ratios, such as yield. Across almost every agricultural standard or series of indicators reviews, some means of quantifying the production of the farm, whether through crop volume, income, or other means, was used (see Section 8.2). However, these metrics could potentially be some of the most challenging to capture due to the necessity of mathematical literacy.

Related Sustainable Development Goals

- Goal 8: Decent work and economic growth | Target: Improve progressively, through 2030, global resource efficiency in consumption and production and endeavor to decouple economic growth from environmental degradation[72].

Examples of Productivity Metrics

- Field area
- Volume of expected crop (based on seeds planted)
- Volume of harvested crop
- Income from crop sales
- How much money farmers have left over at the end of the month
- Yield (measurement of crop/area of land farmed)
- Resource efficiency ratios (water use per unit of field area, etc.)

4.3 | Establishing Conditions and Baseline

This section provides actions to determine the context for identifying and documenting both qualitative and quantitative knowledge. The objective at the end of this step is to have a strong understanding of the current environmental conditions to compare change to over time.

4.3.1 | Establish Physical Conditions Off-site

Understanding the physical conditions through off-site research is helpful to understanding the context for which local and conventional knowledge could be captured. This research can be done through some methods including:

- Literature Review of case studies, scientific reports, and other material detailing the general conditions of the region
- Interviews with regional and topical experts to understand the general conditions
- Conversation with community members

The objective of this step is to build an understanding of the regional area of the community to identify potential environmental concerns that can be raised during interviews. This research can help provide context for interpreting any conventional test results.

Experiences from Test Case

In the test case, physical conditions were established off-site using a combination of research and interviews. A critical discovery for the Team was publications describing the typical soil characteristics in central Uganda, including data from the African Soils Project[73] and Eurosoil[74] databases. Understanding that Ugandan soil is typically high in iron and clay content and low in essential nutrients helped explain issues with water retention and management of soil nutrients. This discovery helped the Capstone Team identify key overlaps from on-site interviews around soil performance. For more information, see Section 6.2.

4.3.2 | Establish State of Local Knowledge

Establishing the state of local knowledge on-site is central to the question of whether there is a relationship between how smallholders view the world and the achievements sought by the sustainable agriculture community. Local knowledge research and documentation could be done through a series of activities. It will be up to the field coordinator to determine the best approach for a community:

- Group calls or meetings with farmers: Meeting in small groups for detailed conversations gives the field coordinator the opportunity to explore farmers' perspectives while minimizing the amount of time required for a facilitator. However, there is a risk of bias, as a small number of farmers' experiences could influence the responses of others in the room[75]. Such conversations can be completed remotely, depending on the available technology.
- One-on-one interviews: Meeting with farmers one-on-one provides the potential to explore a given farmer's knowledge and experience more deeply than group meetings. Such interviews on-site allow the field coordinator or facilitator to ask follow-up questions based on observations or ask for demonstrations to capture more detailed documentation. However, building a solid baseline requires more time to document knowledge from a wide enough sample of farmers in the community.
- Surveys: Surveys provide the opportunity to collect a large amount of information with little cost. However, this approach has limited applicability due to varying literacy levels[76].

It is critical, regardless of which activity is being applied, to avoid leading questions, which will result in answers that individuals think the interviewer wants to hear, not what is observed[77]. Additionally, it is important to keep in mind the role of translation when the farmer and interviewer speak different languages. Language is used to express meaning. However, it can also influence the meaning that is conveyed[78]. Interviewers should be aware of this issue and strive to pose questions in basic terms. To help overcome any language barriers, interviewers should bring a recording device to capture the audio for later reference and a camera to visually document the world from the farmer's perspective.

Sample questions for interviews are available in Section 5.

Experiences from Test Case

The Capstone Team worked backward from the final metric categories to develop a list of core topics and ideal results for onsite interviews. The goal was not to develop a set list of questions, but allow the interviewers to work with the conversation flow and explore the knowledge and perspective of smallholders on topics related to the four categories. The full question set can be found in Section 5.2 and recordings of many of the interviews can be found in the Recording Database (See Section 8.1.3).

The most significant challenge was capturing the perspective of the farmers through an interpreter. For example, the Capstone team was unsure if word choices such as "climate resilience" or "microenvironments" were the direct translation of what farmers were expressing or the interpreter finding a way to express the farmer's words in English. Photos taken on-site were a valuable resource when reviewed in relationship to farmer interviews, and in some cases provided context beyond word choice.

4.3.3 | On-site Physical Condition Quantification

While the focus of this approach is on capturing and translating local knowledge, conventional tests can be used to build a correlation between local knowledge and measurements. The Capstone team sympathizes with the fact that there is a tension between A Growing Culture's mission to support the sharing of local knowledge and the use of conventional testing techniques. There is no question that conveying the validity of local knowledge is invaluable to the sustainable agricultural community. However, as many of the actors in this broader community allocate resources based on numbers, it is equally valuable to equip farmers with tools to speak that language, too. To understand how their own knowledge relates to conventional metrics can open up new opportunities and dialogues for farmers that are interested in having them.

There may be pitfalls to introducing more conventional metrics into a strong, intact community built on local knowledge: overvaluation of knowledge from the outside, susceptibility in techniques that are no longer holistic, and a reorientation away from what makes the community strong. Introducing basic metrics in a considerate, careful way that honors traditional practices can empower the community to adopt only what is useful. The work done here is intended to support the thoughtful introduction of conventional testing and metrics in a way that strengthens community bargaining power and quality of life.

Section 5 of this Toolkit contains a comprehensive set of field tests that could be useful for collecting both qualitative and quantitative data within the four metric categories. Many of these tests are derived from educational programs or training and require few or no additional materials or specialized training. When tests required specialty materials, the team strived to select easily obtainable options. These tests are by no means a requirement but are intended to support local documentation over time, as needed by a given community.

Experiences from Test Case

It is easy to get lost in the number of field tests that could be done to support data collection on local environmental conditions. Members of the Capstone team identified possible tests using school curriculum projects, gardening blogs, and farmer resources including the Farmer's Almanac, United States Department of Agriculture's Field Guide, and United States Agricultural Extension programs, to name a few.

Given the contexts that such tests would be used in, the Capstone team then filtered out techniques that would require materials or equipment that would be expensive or difficult to obtain in-country or transport. For example, lab-tested soil samples would have provided more precise measurements of essential nutrients and carbon content. However, testing facilities in Kampala would have charged $50 per sample[79], making a community-wide sample set unfeasible. Instead, the team used off-the-shelf soil testing kits that cost $1.38 per sample and were available for purchase in eight country-specific Amazon marketplaces[80]. While the test results from the off-the-shelf test are less precise and less comprehensive, being more affordable and more widely available makes it a viable option for use in local communities.

Implementation Tip

When conducting or supporting conventional testing techniques on-site, field coordinators should be very clear with farmers about what tests will be performed and what the results will mean. While trialing some testing techniques in Banda, a community near Kasejjere, the Capstone team encountered concern from farmers about testing their water sources. Members of the community associated water testing with being the cause of contamination, as several years prior several community members fell ill after a government agency had tested a water source.

4.4 | Translation and Correlation

Due to the limited time on-site and the need for demonstration of change over time, the translation and correlation step is still in the initial design phase. That being said, this is where documentation can provide value for farmers through access to resources and conversations beyond their villages. This translation is also valuable to the broader sustainable agriculture community that often struggles with the scope of engagement due to the vast number of smallholders distributed around the world[81].

4.4.1 | Analyze Knowledge

The documentation of environmental benefits and existing environmental conditions may provide a significant amount of qualitative data. Initial options to analyze these results include:

- **Frequency analyses:** Spot trends between farmers in the same community and highlight changes over time by reviewing interviews to track word choice. For example: How do farmers describe soil? Are "good" and "poor" soil consistent within a community?
- **Comparisons between local knowledge trends and conventional testing:** Such comparisons can potentially validate farmers' observations regarding conventional language. Options for this step include listing out local and conventional word choices and then then identifying those that relate to each other, or developing scales based on farmer knowledge and conventional results. For example, looking at soil sample images and soil results, what is the commonality between texture, color, and nutrient content?

Experiences from Test Case

Given the limited time frame, the Capstone team was only able to collect data from a small sample of farmers for a single point in time. Any attempt to establish correlations will require more data taken at different periods to determine whether these suggestions are viable. A frequency analysis of words related to biodiversity did show promise in connecting essential environmental benefits of trees and agroforestry with international biodiversity concerns (See Section 6.4). Additionally, the relationship between soil appearance and nutrient levels had initial success (See Section 6.2).

4.4.2 | Communication to Broader Sustainable Agriculture Community

Correlation approaches are still in the early stages of development and more data over time is needed to fully determine their validity. Tracking more tangible connections, such as the relationship between local understanding of soil health and conventional nutrients, appear more promising than connections that are difficult to observe, such as the relationship between pesticide and fertilizer use and water quality. However, more data is needed to determine how closely related they are. As correlations are established, farmers can be equipped with the language to discuss their observations and the connections to metrics common in sustainable agriculture to international actors. Communication is an area where A Growing Culture is already proficient, and many of the lessons learned in supporting knowledge sharing will help address knowledge translation.

Experiences from Test Case

The strongest potential correlation from the test case in Kasejjere is between farmer’s observations of soil performance, soil appearance, and the conventional testing results for essential nutrients. The initial results showed that soil described by the farmers as “poor” was typically reddish in color, and was observed to be more dense or rocky. Soil described by the farmers as “good” tended to be darker in color, with visible organic matter. When lined up along a color chart from red to dark brown and compared to the results for essential nutrients, darker soil tended to have greater nutrient availability. The exception was soil from Banda, which has red color but had elevated nutrient levels because of added chemical fertilizers.

Using more test results and farmer interviews will help determine whether the relationship between farmer knowledge and conventional testing is robust. If it is, farmers can refer to the study when discussing their soil, without the need for frequent/periodic soil testing

4.5 | Collecting / Reporting

The ability to measure progress over time is key to accessing new opportunities. The steps discussed in the section above help establish the baseline environmental conditions. Continued documentation and record keeping will allow for the identification of change.

Studies have found that recordkeeping by smallholder farmers is most successful when records are kept by the farmers themselves. In fact, one study found that recordkeeping increased by 78% when done by the farmers, but decreased by 72% when responsibility was shifted to a spouse. Recordkeeping decreased even further by 82% when shifted to children in part due to time conflicts with school[82]. However, as stated in Section 1.2.1, starting and sustaining recordkeeping is a significant challenge. Additionally, given the small size of individual farm, pooling community results together could generate a greater response from the sustainable agriculture community.

4.5.1 | Collective Record-keepers

A Growing Culture can help facilitate recordkeeping by acting as a central collection point or helping to determine the individual who would be appropriate for a given community. An appropriate Collective Record-keeper should typically have ties to the community and knowledge of the local language. Additionally, they should have access to sufficient resources so that the strain on themselves and the farmers in the community is limited.

Farmer Cooperatives

Farming cooperatives already serve as collection points for farmers, through both selling inputs (seeds, fertilizers, etc.) and brokering deals for harvests[83]. Not every community has a cooperative, but those that do can leverage the network of farmers to support recordkeeping. There are precedents for farming cooperatives to maintain records for farmer production, thus expanding that scope to include environmental conditions and progress may not pose a significant stretch on capacity[84].

Local School

A formal monitoring system in partnership with students in a local school could help overcome challenges to recordkeeping. It could also help children improve literacy and mathematics skills, and showcase the value of recordkeeping to farmers. At the same time, this option also has the added layer of accountability through reporting results to the teachers.

Teachers and students could collect and analyze data, research key issues, and identify solutions to test, for example in a school garden/plot. The result of these tests could then be shared with the community to show how to mitigate or avoid downward or negative trends. If a community wants to take this approach even further, a local school garden could be used as a testing ground for a variety of solutions to an issue, and to potentially identify a promising solution to the wider community.

There are many curriculums available to teach children how to store seeds and grains, and how to germinate seedlings from collected seeds. Incorporating people within the community who have knowledge in these areas into curriculum development will help spread this knowledge across families and generations.

A few examples of approaches that partner local schools with data collection are:

African Revival: African Revival's school demonstration gardens in Uganda. Through this program, students learn how to choose and cultivate crops, and prepare the land. Local farmers are brought in to train the students, who can take the knowledge back to their own farms and communities.

Creek Connections: Creek Connections, a partnership between Allegheny College in the United States and local schools, teaches students to assess water quality. While much of Creek Connections' educational materials and training is specific to the ecosystem of Pennsylvania, these methods can be adapted to other locations with the help of research or identifying academic contacts familiar with the region's waterways.

Additional curriculum resources can be found in the Literature Review (See Section 7.1.1 for more details).

University Partnerships

Creating partnerships between farming communities and universities is a potentially good alternative to bridging the knowledge gap on both ends. On the university side, it is an opportunity to step out of the academic world of abstract ideas, into the real world where people face real struggles and concerns. From the farmer's side, this partnership presents an opportunity to gain access to external knowledge and technology that they might not be exposed to otherwise.

A few examples of university approaches that partner with communities:

School for Field Studies: The School for Field Studies is the largest environmental study abroad program for college students. Across ten field locations worldwide, students participate in semester-long research projects designed to contribute to the local communities. While there is not a field school near every location, these programs could be a valuable resource for starting and sustaining recordkeeping.

Local Universities: Many programs offer agricultural studies, due to the role that agriculture plays in developing countries' economies. Establishing partnerships with such programs could provide the support needed for farmers in maintaining records while serving the dual purpose of connecting university students with local communities.

Citizen Science Networks

Citizen science networks built on public participation help to increase scientific knowledge or understanding. Through citizen science, people contribute to data collection programs, often as volunteers. Some specialty training or technology might be involved, but successful citizen science efforts are inclusive, allowing for greater participation[85].

A few examples of related citizen science networks include:

Season Spotter: Crowdsourced data on weather patterns and season changes, which could help to establish or validate farmer observations related to rain.

Local Environmental Observer (LEO) Network: LEO is a global network of observers that share unusual animal, environment, and weather events to help document the impacts of climate change.

KOPEL: An agrotourism cooperative in Malaysia uses village networks to track water quality and report incidences of fish kills.

BioDiversity Heritage Library: The Heritage Library is a global index of nature photos uploaded using the online image-sharing site, Flickr. Scientists then analyze the content to provide the context of regional biodiversity

Implementation Tip

Programs that address barriers to adoption and implementation in a way that is responsive to the needs of the community are likely to be the most successful. A Growing Culture's beekeeping program in Kasejjere is a good example of this. The training was done in-person by a local beekeeper, who spoke in their local language. Farmers were presented the benefits and value of beekeeping in a way that reflected their worldview. Each step on how to do the beekeeping was documented by the field coordinators, who could find additional information as needed and translate it for the community[86]. The program showed farmers how to use tools and resources that already existed in their community, and did not place undue financial burden on them.

4.5.2 | Options for Knowledge Collection

Finding a knowledge collection method that is time and cost effective, while being accessible within a given community, can help increase participation by farmers[87]. In the most basic situation, data can be collected and aggregated using pen and paper, but more technical options are available.

Tool	Pros	Cons	Cost	Examples
Written Surveys	• Able to collect many responses with little time required	• Needs high literacy rates	$	• The Living Standards Measurement Study-Integrated Surveys on Agriculture • CGAP Smallholder Household Survey • International Finance Corporation
In-person Interviews	• Avoids potential technology issues • Works great in low literacy contexts • Good for more complicated questions and explanations	• Needs significant field coordinator support • Time intensive to collect signification responses	$	• International Finance Corporation • Ayanlade et al. Comparing smallholder farmers' perception of climate change with meteorological data • Clinton Global Initiative

Community Meetings	• Works great in low literacy contexts • Good for more complicated questions and explanations • Able to collect many responses	• Needs significant field coordinator support	$	• Smallholder Farmers Alliance • Department of Agriculture, Forestry, and Fisheries • Sustainable Food Lab
Digital Recordings	• Documentation is in farmers' voice. • Options for sharing knowledge through multi-media	• Needs access to video or voice recording technology	$	• Agricultural Extension Messages Using Video • Global Food Systems Innovation
Excel database	• Can complete data analysis more readily • More readily available than software or online databases	• Needs centralized collector • Requires some training	$	• Better Cotton Initiative
SMS text	• Can be completed at farmer's convenience • Relatively simple to use (farmers are already learning the technology)	• Needs high literacy rates • Needs high mobile use and service	$$	• FarmForce • eSoko • WeFarm
Smartphone reporting	• Can be completed at farmer's convenience • Relatively simple to use (farmers are already learning the technology) • Can include images or recordings	• Needs high literacy rates • Needs high mobile use and service	$$	• Sustainability Assessment of Food and Agriculture – Smallholder App • Olam Farmer Information System • Taro Works • GeoTraceability
Database software	• Centralized collection point • Can complete data analysis more readily	• Needs significant field coordinator support • Learning curve for coordinator that will input data	$$$	• Farm Force • Group Integrity
Web-based database	• Results can be more easily shared between farmers and communities • Readily customizabl	• Needs significant field coordinator support • Most expensive option	$$$	• SourceTrace • Sustainable Harvest

Table sourced from: Acumen. 2015. The Lean Data Field Guide. Acumen, J. Anderson and W. Ahmed. 2016. Smallholder Diaries: Building the Evidence Base with Farming Families in Mozambique, Tanzania, and Pakistan. CGAP

5 | FIELD GUIDE

5.1 | Structure and Objectives

This comprehensive field guide was designed to be used by A Growing Culture's field coordinators in order to help them validate and analyze farmer practices based on standardized metrics. The guide contains survey questions and a mix of easy and low-cost tests for different metrics on soil, water, biodiversity and productivity. These tests were selected from various sources such as US Agricultural Department field guides, student curriculum, Universities, science fair project recommendations, community garden resources, and Penn State Extension resources.

These survey questions and tests are designed to be conducted by A Growing Culture or by the smallholder farmers that they work with.

5.2 | Surveys

When working with farmers anywhere in the world, more important than testing their soils and tracking their performance is learning what they know, how they work, how they live and what they value. Establishing a relationship on a personal level is the best way to build a connection that fosters understanding and trust overtime. A good start is observing how farmers work and having conversations or surveys in an attempt to see their world through their eyes. Below are a few sample sets of questions:

5.2.1 | Initial Community Assessment

The following questions are meant as examples for conducting an initial review of a community. The responses of these questions or ones like them can be used to help understand what members of the community care about in terms of the environment.

Introductions

Based on lack of clarity about how well a community may know A Growing Culture and a way to connect with the farmers

- Please introduce yourself.
- Please tell us how you met or heard about A Growing Culture.
- Please tell us how many people in your family live together and how many people in your family farm.
- How many families are in your community? How many of those families are farmers?
- Are any of you part of a farmers' collective.
- What other work do people in the community do?

Farming

- What are you growing/farming now?
- Have you tried to grow other crops in the past?
- Do you recall your most successful crop(s)?
- Do you recall your least successful crop(s)?
- What is the most difficult part of farming for you?
- How do you decide what crops to plant and where to plant?
- How do you decide how much to plant?
- What other decisions/choices do you need to make before starting the planting season?
- What decision/choices do make during the planting season?
- How do you decide when to use products like pesticides?
- What kind of pesticides, if any, have you used?
- What kind of fertilizers, if any, have you used?

5.2.2 | Metric Category Questions

The following questions can be used to help understand the environmental conditions and local knowledge of farmers. These are not intended to be asked in any particular order, nor to be asked exactly how they are written. Rather, these are intended to be a guide for a conversation.

General Context

- What are the biggest challenges of farming?
- What have you noticed changing on your farm in the past few years?
- Are there any crops the community used to, but no longer grows? If so, why did you stop growing them?
- What programs, if any, have other "outsiders" attempted to implement? What worked or did not work about these programs?
- What are the community's great challenges today? (What worries community members?)
- What material or non-material goods could our network provide for the community?
- What local education and technology resources are there and how are they used?

Soil

- What is done to soil in preparation of planting seeds? What is done after planting?
- How is decided what to plant?
- Which crops have worked best and which crops didn't work?
- What kind of fertilizer is used, if any?
- How can the soil texture be described, how does it feel?
- Describe what happens to your field when it rains - a little or a lot? (is there a lot of water running off your fields? Do pools of water form?)
- Do you rotate your fields?
- How to know when it's time to let the field rest?
- How to know when the field has rested enough?

Water

- Where does the water that you regularly use come from? (lake, river, spring, well)
- How can the water quality be described? (turbid, taste, smell)
- Does the water source ever dry up?
- Are you concerned about the safety of the water or how much you have?
- Where do you get your water?
- How do you use your water?
- Do you collect rainwater? If so, what is it used for?
- How does your soil feel after rain? How long does it take to dry?
- How does drought affect farming?
- How does too much rain affect farming?
- Have you been noticing any differences in the patterns of rain or drought season?
- How are crops irrigated?
- If irrigation is not based on rainwater, how often are crops watered?
- Is it believed or normal for people to get sick from drinking the water?
- What is done to try/prevent people from getting sick?

Biodiversity

- What type of crops do you grow?
- Do you have different varieties of the same crop?
- Do you grow different types of crops together (intercropping)?
- How would you describe the quality of your soil?
- What does the general landscape look like (stands of trees, unfarmed fields, etc.)?
- What types of animals do the farmers see around them?
- What native and invasive plants do you recognize?
- What do you think you need to adjust to climate change/other observed changes?
- Where do the seeds you use come from? How are they chosen?
- What types of pests/diseases are encountered on the plants or soil?
- Are there wild animals out in the fields/ what is common or uncommon in the area?

Productivity

- What are your farming goals? (subsistence, grow more variety of crops, grow more staples or different crops, grow for the market, etc.)
- How do you decide how much to plant?
- How many crops are raised on the land?
- How large is your harvest?
- How large is your field?
- How did your harvest due last year? Was it more or less than the year before?
- Did you sell any of your harvest? If so, to whom?
- Do you purchase crops or outside goods?
- How many people work on the field?

A template for recording basic farmer information and question responses is available in Section 5.4.

5.3 | Conventional Tests

The tests were divided into low-tech and high-tech based on research into the expected feasibility of obtaining the necessary materials, the materials cost, and the level of technical knowledge needed to interpret the test results. Low-tech tests are conventional tests that require little additional material, cost, or training. High-tech tests will cost more and take more time, but provide more detailed results.

5.3.1 | Soil

Different plants have unique needs when it comes to soil nutrients, irrigation and light[88]. This part of the field guide was designed to focus on the soil nutrients aspects and it contains a mix of options of easy and low-cost tests on soil quality, type, moisture, granularity, texture, and evaporation that can be performed to validate and support farmer practices.

Soil Health Card

Test Category: Low-Tech

Source: The Ohio State University, College of Food, Agricultural and Environmental Sciences. *Ohio Soil Health Card.*

Test Objectives: Evaluate a soil's health or quality as a function of soil, water, plant and biological properties identified by farmers to assess each soil's ability to function within its capabilities and site limitations.

Why is this Important: This card can help monitor and improve soil health based on field experience and a working knowledge of soils. Regular use is advised in order to record long-term changes in soil health and compare effects of different soil management practices.

Observation: The card is most effective when filled out consistently by the same person over time. It was developed for farmers by farmers with assistance from Ohio State University Extension and the Natural Resources Conservation Service (USDA-NRCS).

Materials:

- Card
- Pen/pencil
- Shovel or spade

How to Conduct the Test:

1. Use the “Best Times to Assess Indicators” chart for the best times to assess each indicator of soil quality and health.
2. Divide the farm and fields into separate sections for evaluation in the same way you would divide them for soil-fertility sampling: separate by factors like soil type, topography, and history of tillage, crop rotation and manure application.
3. Enter the Date and Field Identification information at the top of the card.
4. Select two–three representative spots in the field and evaluate each soil health Indicator. Read the Descriptive Ratings in the rectangular boxes and based on your judgment rate the indicator Good, Fair or Poor by checking the small square in the lower left-hand corner of the box with the best description.
5. In the Notes section following each group of soil health indicators, record any observations or soil conditions that will help you review and evaluate your ratings.
6. Follow changes in each of the soil health indicators over time, examine current field management practices, and consider ideas for management changes in problem areas.

Soil card available from Ohio State University

Soil Kit Test

Source: Rapitest Soil Kit Instructions, by LusterLeaf

Test Category: High-Tech

Test Objectives: To determine levels of pH, nitrogen, phosphorus, and potassium in soil using a Color Comparator test. The team used Luster Leaf 1601 RapiTest Soil Test Kit[89], but there are similar options available for NPKpH color comparator tests in the market.

Figure 2 | Soil Kit Used

Why Is this Important?
A soil test can help confirm farmers' observations of soil performance and provide additional information to help target soil amendments and reduce trial and error.

Materials List:

- Color Comparator test - the RapiTest (Figure 2) contains:
  - 4 individual color comparator strips for pH, nitrogen, phosphorus, and potassium (potash)
  - 10 tests each for pH, nitrogen, phosphorus, and potassium
- On-site soil sample - follow instructions to collect sample above
- Water - ideally distilled or rainwater
- One clean cup per sample

How to Conduct the Test:
Based on the RapiTest. If using a different one, use the included directions.

<u>Preparing and Collecting Soil Samples:</u>

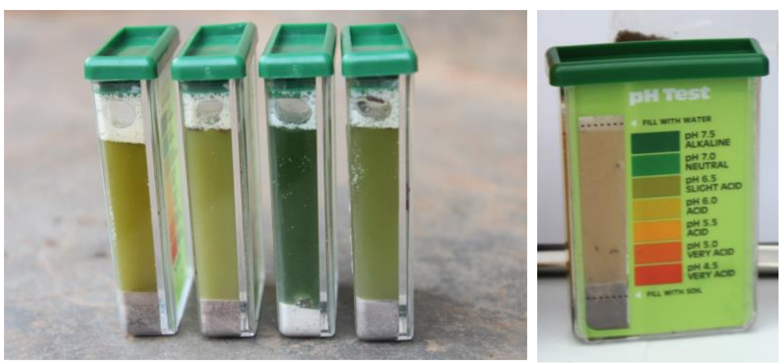
1. Take the soil sample from about 2-3" below the surface for lawns, annuals or houseplants. For perennial plants like shrubs, vegetables and fruits, the sample should be 4 inches deep. **Avoid touching the soil with your hand.**
2. Make individual tests on several samples from different areas. For comparison, choose at least two samples of each area. Be sure to document the samples locations with whatever information found to be relevant (examples: by water source; uphill/downhill; "good" for certain crops or "bad" for certain crops; fallow for a certain amount of time; by certain tree, etc. or use a cell phone to collect the GPS coordinates for the sample site - See Section 5.2.4 for more details).
3. Place your soil sample into a clean container.
4. Break the sample up with a clean trowel or spoon and allow it to dry out naturally.

5. Remove any small stones, organic material such as grass, weeds or roots and hard particles of lime.
6. Crumble the sample finely and mix it thoroughly.

pH Test Instructions

1. Remove the cap from the green comparator. Make sure the color chart (film) is in place.
2. Fill test chamber to soil fill line with soil sample.
3. Holding the capsule horizontally over the test chamber, carefully separate the two halves of the green capsule and pour powder into the test chamber.
4. Using the dropper provided, add water (preferably distilled) to water fill line.
5. Fit the cap onto comparator, making sure it is seated properly and caps tightly. Shake thoroughly.
6. Allow soil to settle and color to develop for about a minute.
7. Compare color of solution against pH chart. For best results allow daylight (not direct sunlight) to illuminate the solution. See Figure 3 for examples.

Figure 3 | pH Soil Testing Examples



Four pH tests performed with four samples showing different colors, indicating different pH levels per sample.

Nitrogen, Phosphorous and Potash Tests

1. Fill a clean container with 1 cup of soil and 5 cups of water. (Larger or small quantities may be tested as long as the 1 part soil to 5 parts water proportions is maintained.) For best results use bottled or distilled water.
2. Thoroughly shake or stir the soil and water together for at least one minute; then allow the mixture to stand undisturbed until it settles (30 minutes to 24 hours, dependent on soil). *A fine clay soil will take much longer to settle out than a coarse sandy soil. The*

clarity of the solution will also vary, the clearer the better, however cloudiness will not affect the accuracy of the test.

3. Select the appropriate comparator for the test. Remove the cap and take out the capsules, which should be the same color as the cap. Make sure the color chart (film) is in place. *Do not interchange color charts between comparators.*
4. Using the dropper provided, fill the test and reference chambers to the fill mark on the chart with solution from your soil sample. *Solution is added to the reference chamber to compensate for any discoloration in the tested sample caused by the soil. Avoid disturbing the sediment. Transfer only liquid.*
5. Remove one of the appropriate colored capsules from its bag. Holding the capsule horizontally over the test chamber, carefully separate the two halves and pour the powder into the test chamber.
6. Fit the cap on the comparator, making sure it is seated properly and caps tightly. Shake thoroughly.
7. Allow color to develop for 10 minutes. Do not allow the color to develop for more than 10 minutes. *If flakes of blue color appear to have settled to the bottom of the phosphorus color comparator during the 10-minute development period, shake the comparator to suspend them in the solution.*
8. Compare the color of the solution in the test chamber to the color chamber to the color chart. For best results, allow daylight (not direct sunlight) to illuminate the solution in both the test and reference chambers. Judge colors, if necessary, and note your results for future reference.

How to Interpret the Results:

Figure 4 | Manufacturer's Ranges for Soil Kit Nutrient Categories

SOIL MACRONUTRIENTS	Surplus	Sufficient	Adequate	Deficient	Depleted
NITROGEN Nitrate	N4	N3	N2	N1	N0
(NO3) parts per million	80	40	20	10	0
PHOSPHORUS Phosphate	P4	P3	P2	P1	P0
(PO4) parts per million	100	50	20	10	5
POTASSIUM Potash (Potassium Oxide)	K4	K3	K2	K1	K0
(K2O) parts per million	900	600	400	200	50

Figure 4 references the *Rapitest* Soil Test Kit and the color gradient scale for the presence of the nutrients Nitrogen (N), Phosphorus (P), and Potassium (K) in the sampled soil. The test kit offers a descriptive scale that ranges from “Surplus” through “Depleted”, but does not indicate the nutrient’s parts per million (ppm) measurement in the soil. The relevant ppm measurement as disclosed in a private communication with the manufacturer.

What is pH?
pH is a measure of soil acidity or alkalinity. Acidic soil has a pH lower than 7. The lower the number the more acidic the soil. Alkaline soils have a pH higher than 7. Most types of crops grow better in soils slightly more acidic (between 6 and 7).

Why is pH Important?
pH is an important indicator of soil health because it affects crop yields, crop suitability, plant nutrient availability, and activity of soil micro-organism activity[90].

How to Interpret pH Results[91]:

When soil is acidic (pH less than 7):

- The availability of nitrogen, phosphorous and potassium is reduced and there are usually low amounts of calcium and magnesium in the soil.
- Most micronutrients are more soluble and available to plants with some acidity. When very acidic, aluminum, iron and manganese may reach toxic levels.
- The ability for root growth is reduced.
- Beneficial soil organisms do not reproduce as much.
- Some herbicides become less effective.
- Some crop diseases thrive better.

When soil pH is between 6 and 7.5
(Proper level except for acid-loving exceptions, such as blueberries and tomatoes):

- The nutrients available in the soil are more available for the plants.
- The impacts of any toxic material in the soil are minimized.
- The beneficial soil organisms are most active.

Soils with high clay and organic matter content are more able to resist a drop or rise in pH than sandy soils. Management can change organic matter content since the clay content can’t be modified. Sandy soils usually have low organic matter content, which results in a low ability to resist change in pH (buffering capacity), high rates of water percolation and infiltration[92].

Implications of Soil pH:
Soil pH is affected by land use and management. Different vegetation types will have different soil pH (forestland areas tend to be more acidic than grassland). Transforming forestland or grassland to cropland can cause drastic pH changes after a few years due to loss of organic matter, removal of soil minerals when crops are harvested, topsoil erosion and effects of nitrogen and sulfur fertilizers[93].

Other options include:

- Apply irrigation water, manure and organic materials with high content of calcium or magnesium bicarbonates.
- Apply agricultural limestone. The quantity of limestone is to be determined by target pH based on intended crops to be grown and the soil's buffering capacity.

For more details on the optimal pH for crops, see:

- http://www.agiweb.org/education/aapg/invest/PreferencesforpH.pdf

What is Nitrogen?
Nitrogen is the most limiting crop nutrient. Deficiencies in nitrogen can have a greater effect on plant growth than deficiencies in other nutrients[94].

Why is Nitrogen Important?
Nitrogen is crucial to help plants produce chlorophyll, which makes the plant color green and helps convert sunlight into energy. This way, nitrogen encourages healthy foliage and stem and root growth, which are necessary to support the plant and fruit formation[95].

How to Interpret Nitrogen Results?
As soil and weather conditions can cause nitrogen levels to fluctuate, soil testing is not very useful to predict the need for soil management in humid environments. However, as plants use up the nitrogen in the soil over the course of a growing season it is possible to understand nitrogen demands based on crop need, with the assumption that little available nitrogen remains in the soil after a growing season[96].

Nitrogen is an essential nutrient to every aspect of plant growth. Usually, a measurement of 20 parts per million (ppm) is sufficient to support maize and most other crops that demand high nitrogen levels. A value of 14 ppm is sufficient when animal manure is applied or where a nitrogen-demanding crop follows a legume crop (beans, lentils, alfalfa, etc.). Bacteria and legumes cannot fix nitrogen to the soil to prevent it from being washed away by rain at values above 40 ppm. 14 - 20 ppm is considered sufficient nitrogen level in most regions[97].

Having too much nitrogen[98]

- Some foliage will respond well and grow wild but other plants will suffer.
- Plant leaves turn yellow or brown and wilt. The excess nitrogen in the soil removes the water from the plant and leaves salts behind.
- The plants have no flowers or fruits and too many big leaves because the energy for their growth is redirected to growing leaves.
- Root growth slows, making the plant unstable in weather events (wind, rain) and makes the plant more vulnerable to disease.
- The excess nitrogen leaches out of the soil through water runoff, contaminating groundwater and drinking water.

Not having enough nitrogen[99]

- The leaf changes color, usually going from deep green to paler shade. If the deficiency continues, the leaves begin to develop yellow spots or veins. Eventually, the whole leaf turns a pale yellow.
- The plant doesn't grow well and has few new leaves that appear small or badly formed. The plant may appear small when compared to same-age plants that receive enough nitrogen.
- Plants become more vulnerable to disease or pest infestations.
- Fruit production is affected because the plant doesn't have the healthy foliage or roots necessary to support fruit production. Fruit may grow more slowly or do not ripen.

Implications of Nitrogen

Nitrogen is added to soil naturally through bacteria, legumes, and rainfall. Additional nitrogen can be added to crop with fertilizers, manure and organic materials. However, care must be taken to prevent the impacts of excess nitrogen[100].

Soil drainage, texture, and slope steepness impact nitrogen's availability to crops. Warm humid climates decompose organic matter faster, resulting in faster nitrogen availability than in cool dry climates. Having well-aerated soils is also better than wet saturated soils for nitrogen release. Standing water promote the development of gases that release nitrogen from the soil. Sandy soils have a higher risk for runoff. Farming practices that increase organic matter such as use of manure and compost; use of nitrogen fixing legumes in rotations and avoiding soil compaction are good for stabilizing crop nitrogen supply, increasing aeration and limiting nitrogen losses[101].

Additional sources for nitrogen management:

- Nitrogen Fixing Plants for Temperate to Sub-tropical Climates
- List of Nitrogen-Fixing Plants

What is Phosphorus?

After nitrogen, phosphorus is the second most important nutrient for plant development[102].

Why is Phosphorus Important?

Phosphorus' primary role is to store and transfer energy for plant growth. Adequate levels of phosphorus help plants mature at a healthy pace, promote root growth, and make plants stronger and more resistant to cold, heat, drought, flood, and wind[103].

How to Interpret Phosphorus Results?

Soils with pH values between 6 and 7.5 are ideal for phosphorus availability. Values below 5.5 and above 7.5 limits phosphorus availability to plants[104].

Having too much phosphorus[105]:

- Soil cannot hold all the phosphorus and some is lost in runoff. Phosphorus runoff reduces water quality by increasing the amount of algae, which takes oxygen away from other aquatic plants and animals.
- Limits the ability of plants to absorb other nutrients, including zinc and iron, causing plants to grow poorly or die.

Not having enough phosphorus[106]:

- Turns leaves purple, starting with the tips and progressing along the outside of the leaves.
- Leaves can die, especially under persistent hot, dry and windy conditions.
- Plant growth is delayed, impacting the amount that can be harvested.

Implications of Phosphorus

Soil phosphate level varies depending on the field location, past soil management, and the time of the year. Unlike nitrogen, it does not readily leach out of the root zone, it only does so with erosion and runoff. Soil phosphorus exists in many forms, as part of soil organic matter that becomes available to plants through decomposition and through natural soil minerals (iron and aluminum oxides). Manure and other organic amendments can be applied to soil to adjust phosphorus level, ideally in small amounts applied directly near the plants[107].

To reduce excessive soil phosphorus, future phosphorus applications of any kind should be avoided, which includes organic composts and manures. If organic nitrogen sources are needed, low phosphorus products like blood meal or pine bark mulch can be used instead. Climatic and site conditions like rainfall and temperature, moisture and soil aeration, and salinity impact the release of phosphorus from organic matter. Like with nitrogen, organic matter decomposes and releases phosphorus quicker in warm humid climates than in cool dry climates, and the release is also faster when soil is well aerated than in heavily wet soils[108].

What is Potassium?

Potassium is an essential nutrient for plants and plays a vital role in proper growth and reproduction of plants[109].

Why is Potassium important?

Potassium is crucial to enhance crop quality because it helps the plant produce energy and absorb and retain water and other soil nutrients. Appropriate levels of potassium help plants grow, increase resistance to drought, create a favorable environment for microbial action and help plants stay upright[110].

How to Interpret Potassium Results?

Having too much potassium:

- Can be detrimental to plant growth because it interferes with the plant's uptake of other nutrients[111].

Not enough potassium:

Moderate potassium deficiencies are not easy to detect visually. However, severe deficiencies have some clear signs that can be identified[112]:

- Plants cannot utilize nitrogen and water efficiently and become more vulnerable to diseases.

- The outside of the leaves turns yellow. Some crops, such as maize, have leaves that turn brown and die, while others, such as alfalfa, develop yellow or white spots on the outside edges. Other symptoms can include spotting, streaking or curling of leaves, starting with the lower portion of the plant. Leaf symptoms appear in older leaves first.
- Roots are weak and unhealthy.
- Plants grow slowly or will stop growing altogether. Grains experience a slow growth, delayed ripening, and shriveled seeds. Fruits ripen unevenly.
- Plants have poor resistance to drought and temperature changes as potassium affects the plant’s ability to absorb water. When reaching a critical level of potassium deficiency, plants lose their leaves sooner and even faster in cases of drought or elevated temperatures.

Implications of Potassium

Most available potassium exists in the soil and is slowly released from native soil minerals and fixed forms in clays, that help replenish some of the potassium lost by crop removal and leaching.

Potassium is easily washed away by rain. Like with nitrogen, crops take up a large proportion of the available potassium from the soil each growing season[113].

Potassium can be affected by several factors[114]:

- Soil Moisture: Soils with high moisture usually have more available potassium, as water increases the movement of potassium between plant roots and soil. However, too much moisture prevents soil aeration, leaving the oxygen levels very low.
- Root and ground cover: Cover crops can hold reduce soil runoff during rainfall.
- Soil temperatures: Potassium uptake is reduced at low soil temperatures and optimized in temperatures between 60 and 80 F (15.5 - 26.6 C). Root activity, plant functions and physiological processes increase as soil temperatures increase.

Soil Characteristics and Color Scale

Source: J. Debruyn. Leaders Guide: The Color of Soil. 4-H

Test Category: Low-Tech

Test Objectives: To record the varying soil colors (if any) of each plot of land, and determine its classification. Collect soils samples and create a color scheme that can be useful for progress recordkeeping, but note that further studies and analyses are needed to determine the types of minerals and nutrients found in the soils.

Why Is This Important: The color of soils can be used as an indicator of mineral content of a soil and organic matter from dead plants and animals. Color is also an indicator of the environmental conditions that the soil is exposed to. Fertile soil is rich in minerals because it contains nutrients, but different types of soil minerals hold and retain different amounts and types of nutrients. Knowing the mineral content of the soil can help predict which nutrients are supplied to plants[115].

Materials List:

- Notebook and camera (to document observations)
- Plain, white index cards

How to Conduct the Test:

1. Dig a hole a few inches deep
2. Collect some of the soil and put it on top of a white index card to photograph. Be sure to identify the soil sample on the index card using the soil location and date, or an identification number and record the specific information on a list of soil samples.
3. Record observations such as color, plant material, texture, etc.
4. Repeat for every plot of land that is tested.
5. Using images or the index cards with the soil, arrange the samples into a color scale, with lightest on one end and darkest on the other. This process can also be done once a year and the progress overtime can be documented (See Figure 5 for an example).

Figure 5 | Example of Soil Color Scale

How to Interpret the Results[116]:

- **Red -** red soils might be rich on iron oxide minerals because they are well drained, which allows water to move through quickly and for oxygen to circulate. The oxygen penetration in the soil forms oxides.
- **Grey -** the opposite of red soils, it is often poorly drained or so saturated that oxygen can't get in, causing it to have less iron minerals.

- **Dark shades -** usually, dark shades of any color indicate that the soil is rich in organic matter.

It is possible to compare the results of the soil kit tests with the color scale to better understand the relationship between soil color and texture and soil nutrients in a particular location.

Soil pH Using Baking Soda and Vinegar

Source: M. Pinola. 2013. Quickly Test if Your Soil is Acidic or Alkaline with Vinegar and Baking Soda, Lifehacker.

Test Category: Low-Tech

Test Objectives: To determine if the soil is more alkaline, acidic or neutral without taking a specific pH reading.

Observation: This test might only be effective in soils highly acidic or alkaline, otherwise there is not much reaction with the baking soda or vinegar.

Materials List:
- Baking soda
- Vinegar
- Distilled or rainwater
- Dirt sample (about ¼ cup)
- 4 cups - 2 for soil samples, 2 for vinegar and baking soda

How to Conduct the Test:
Vinegar:
1. Take a sample of dry dirt (about 1/4 cup).
2. Mix with distilled water to make a liquid "mud."
3. Start pouring ½ cup of household vinegar over top.

Baking soda:
1. Mix dry dirt and distilled water as above.
2. Start sprinkling ½ cup of baking soda over top.

How to Interpret the Results:
- If the mixture fizzes with Vinegar, it's alkaline (pH greater than 7).
- If the mixture bubbles with Baking Soda, it's acidic (pH less than 7).
- If neither test produces a reaction, the soil is neutral (pH of 7).

Soil Moisture (1)

Test Category: High-Tech

Test Objectives: To determine soil moisture using the moisture meter.

Why is This Important: It is important to know the soil's moisture content because water in the soil supports the movement of nutrients needed for plant growth, regulates soil temperature, and otherwise supports soil and plant health. Soil moisture is often more important for the crop production than nutrients[117].

Observation: The meter used by the team is the VIVOSUN 3-in-1 Soil Moisture Light and pH Meter Plant Soil Tester, but similar devices can be found in the market[118].

Materials List:

- Moisture meter
- Notebook
- Camera (for documentation)

How to Conduct the Test:

1. Slide the switch to the "MOIST", "pH" or "LIGHT" setting, depending on the desired reading.
2. Insert the probe 3/4 of its length into the soil.
3. The moisture reading registers on a scale of 0 (dry) to 10 (moist) and is located in the middle row of the reading output area. The pH reading is the straight line at the very bottom in red and green and the Light reading is at the top from 0 to 2000 in white.

How to Interpret the Results:
If the moisture reading registers in the first half of the RED zone (0 to 1.5), the plant should be watered. Moisture-loving plants can be watered if the reading registers in the second half of the GREEN zone (5 to 7). No water is needed with reading registered in the BLUE zone (8 to 10)[119].

Soil Moisture (2)

Source: USDA. 1998. Estimating Soil Moisture by Feel and Appearance.

Test Category: Low-tech

Test Objectives: Determine the moisture content of the soil over time in fields.

Why is This Important: It is important to know the soil's moisture content because water in the soil supports the movement of nutrients needed for plant growth, regulates soil temperature, and otherwise supports soil and plant health. Soil moisture is often more important for the crop production than nutrients[120].

Materials List:

- Notebook and camera (to document observations)

How to Conduct the Test:

1. Obtain a soil sample at a selected depth.
2. Squeeze the soil sample firmly in your hand several times to form an irregularly shaped ball.
3. Squeeze the soil sample out of your hand to form a ribbon.
4. Observe soil texture, ability to ribbon, firmness, surface roughness of ball, water glistening, loose soil, soil/water staining on fingers, and soil color. (Note: a very weak ball will disintegrate with one bounce of the hand. A weak ball disintegrates with two to three bounces).
5. Compare observations with photographs/charts to estimate water percentage available.

Using the following table (Figure 6) from the USDA for reference.

Figure 6 | USDA Reference Table for Estimating Soil Moisture

Available Soil Moisture Percent	Coarse Texture	Moderately Coarse Texture	Medium Texture	Fine Texture
Soil Texture	Fine Sand and Loamy Fine Sand	Sandy Loam and Fine Sandy Loam	Sandy Clay Loam, Loam, and Silt Loam	Clay, Clay Loam, or Silty Clay Loam
Available Soil Moisture Percent	Available Water Capacity 0.6 to 1.2 inches per foot	Available Water Capacity 1.3 to 1.7 inches per foot	Available Water Capacity 1.5 to 2.1 inches per foot	Available Water Capacity 1.6 to 2.4 inches per foot
0 to 25	Dry, loose, will hold together if not disturbed, loose sand grains on fingers with applied pressure. SMD 1.2 to 0.5	Dry, forms a very weak ball, aggregated soil grains break away easily from ball. SMD 1.7 -1.0	Dry. Soil aggregations break away easily. no moisture staining on fingers, clods crumble with applied pressure. SMD 2.1-1.1	Dry, soil aggregations easily separate, clods are hard to crumble with applied pressure SMD 2.4-1.2
25 to 50	Slightly moist, forms a very weak ball with well-defined finger marks, light coating of loose and aggregated sand grains remain on fingers. SMD O.9-0.3	Slightly moist, forms a weak ball with defined finger marks, darkened color, no water staining on fingers, grains break away. SMD 1.3-0.7	Slightly moist, forms a weak ball with rough surfaces, no water staining on fingers, few aggregated soil grains break away. SMD1.6-0.8	Slightly moist, forms a weak ball, very few soil aggregations break away, no water stains, clods flatten with applied pressure SMD 1.8-0.8
50 to 75	Moist, forms a weak ball with loose and aggregated sand grains on fingers, darkened color, moderate water staining on fingers, will not ribbon. SMD O.6-0.2	Moist, forms a ball with defined finger marks. very light soil/water staining on fingers. darkened color, will not slick. SMD O.9-0.3	Moist, forms a ball, very light water staining on fingers, darkened color, pliable, forms a weak ribbon between thumb and forefinger. SMD 1.1- 0.4	Moist. forms a smooth ball with defined finger marks, light soil/water staining on fingers, ribbons between thumb and forefinger. SMD l.2-0.4
75 to 100	Wet, forms a weak ball, loose and aggregated sand grains remain on fingers, darkened color, heavy water staining on fingers, will not ribbon. SMD O.3-0.0	Wet, forms a ball with wet outline left on hand, light to medium water staining on fingers, makes a weak ribbon between thumb and forefinger. SMD O.4-0.0	Wet, forms a ball with well defined finger marks, light to heavy soil/water coating on fingers, ribbons between , thumb and forefinger. SMD O.5 -0.0	Wet, forms a ball, uneven medium to heavy soil/water coating on fingers, ribbons easily between thumb and forefinger. SMD O.6-0.0
Field Capacity (100 percent)	Wet, forms a weak ball, moderate to heavy soil/water coating on fingers, wet outline of soft ball remains on hand. SMD 0.0	Wet, forms a soft ball, free water appears briefly on soil surface after squeezing or shaking, medium to heavy soil/water coating on fingers. SMD 0.0	Wet, forms a soft ball, free water appears briefly on soil surface after squeezing or shaking, medium to heavy soil/water coating on fingers. SMD 0.0	Wet, forms a soft ball, free water appears on soil surface after squeezing or shaking, thick soil/water coating on fingers, slick and sticky. SMD 0.0

Soil Texture

Source: D. Lipford. Today's Homeowner

Test Category: Low-Tech

Test Objectives: Determine the densities of materials in the soil to show clear striations that will reveal the content of the soil (sand, silt, clay).

Why is This Important: Texture is a soil characteristic that refers to the size of the particles that make up the soil. It is important because it influences storm water infiltration rates, aeration, susceptibility to erosion, organic matter content, and pH buffering capacity. Soils can be classified as one of three major classes: sands, silts, and clays[121].

Materials List:

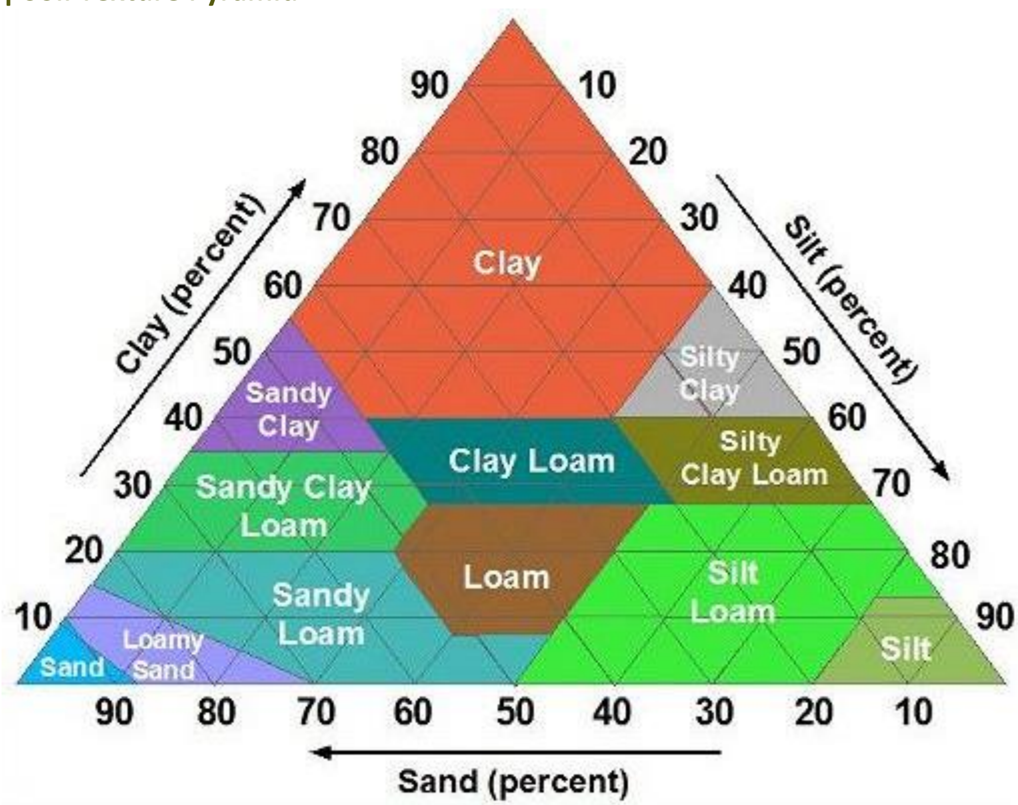
- Transparent containers with cap (water bottles or jars)
- Trowel/shovel
- Measuring tape
- Sharpie
- Masking Tape
- Plastic Bag
- Spoonful of powdered laundry or dish detergent (dispersant to aid in settling)

How to Conduct the Test:

1. Remove the top 2 inches of soil and any plant coverage and roots. Dig a small hole at least 8 inches deep.
2. Point the trowel straight down. Slice off a chunk of soil about 1 inch thick and carefully lift it out of the hole. Remove any roots, twigs, or rocks.
3. Place the soil sample carefully on the ground and use the trowel to slice off a small cross-section.
4. Do Steps 1-3 a few times (2-4) in different spots of the field and mix the samples together thoroughly in a bag.
5. Place the soil in the bottle, so that the jar is about 1/3 full of soil.
6. Fill the jar with water, add a teaspoon of detergent, and shake for several minutes until the soil is thoroughly suspended in the water.
7. Use the masking tape to label the farm that the sample is from.
8. Bring the sample back to your residence and shake again until the soil is thoroughly suspended. Mark the sand level on the jar after one minute, the silt level after 4-6 hours, and the clay level after two days (if you don't have time for two whole days, do 1 day).

9. Once the soil has settled, calculate the percentage of sand, silt and clay relative to the total soil level: using the measuring tape, measure the depth of each layer of soil. Divide the depth of each layer of soil by the total soil depth in the jar, and multiply by 100.
10. Based on the percentages and the pyramid below, you can classify the soil.

Figure 7 | Soil Texture Pyramid



How to Interpret the Results[122]:

- **Sand -** largest size of particles, feels gritty to touch. Water drains rapidly, straight through places where roots often cannot reach. It is often poor in nutrients because it's swiftly carried away with runoff.
- **Silt -** moderate in size, has a smooth or floury texture. It gets soapy slick when moistened and for that reason it retains water longer. It is fairly fertile, but it can't hold on to as much nutrients. It is cold and often drains poorly. Aeration can be a problem for silty soils.
- **Clay -** smallest size of particles, feels sticky when wet, but smooth when dry. It has the best water storage qualities, but poor aeration since little air passes through its spaces. It is slower to drain water and can better hold plant nutrients.
- **Loam -** combination of sand, silt and clay-sized particles. It is often dark in color and soft, dry, and crumbly to touch. It holds water and plant nutrients well, but also has good drainage and aeration.

Soil Granularity

Source: CSGP.org

Test Category: Low-Tech

Test Objectives: To distinguish soil grains based on different size categories and shape by comparing to a Pocket-Size Sand Grain Sizing Folder (See Figure 8).

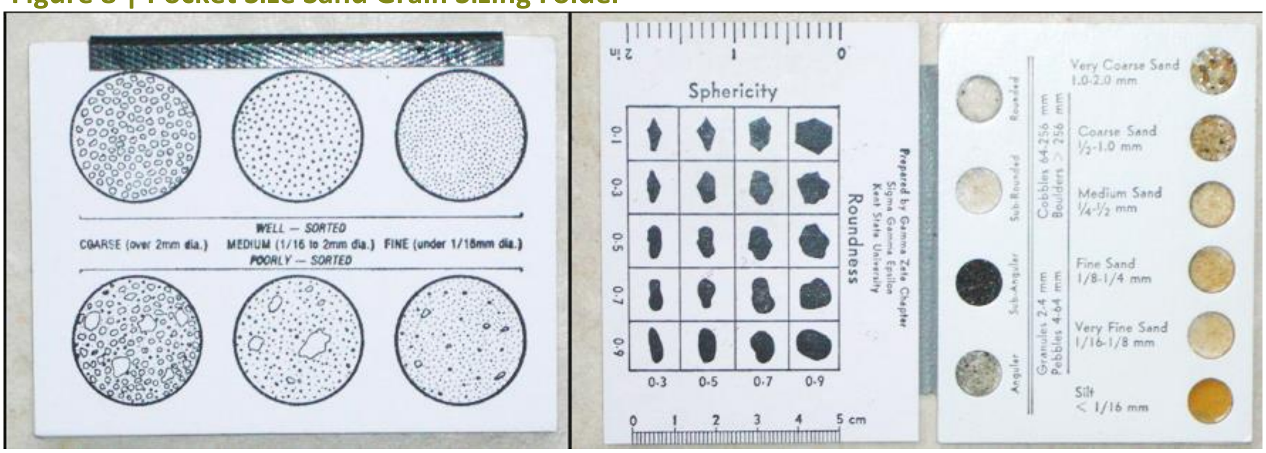
Materials List:

- Pocket Size Grain Sizing Folder
- Notebook to document

How to Conduct the Test:

1. Use the Pocket Size Sand Grain Sizing Folder to compare size, sphericity, sorting and grain roundness.

Figure 8 | Pocket Size Sand Grain Sizing Folder



Soil Content

Source: National Resources Conservation Service. Guide to Texture by Feel. USDA

Test Category: Low-Tech

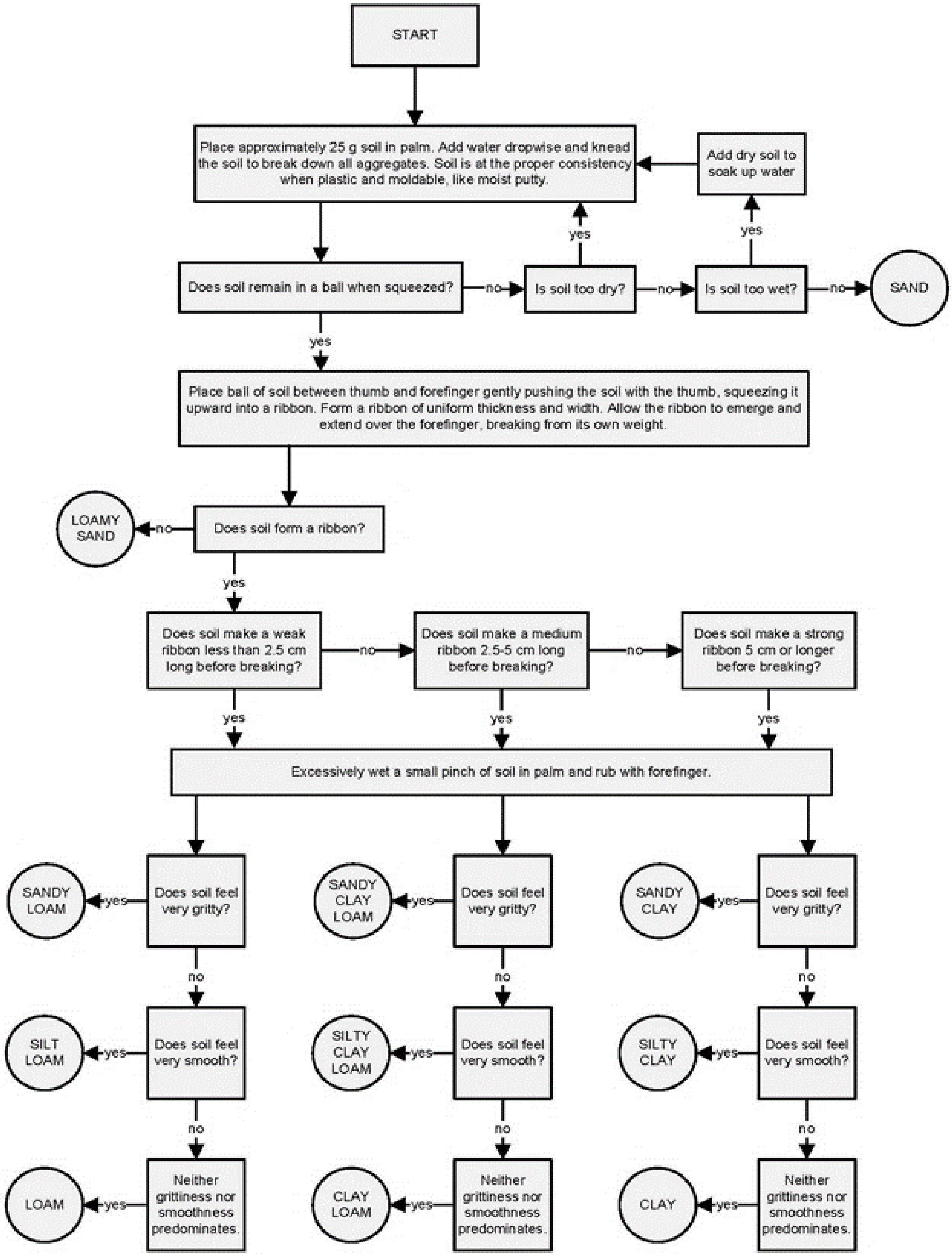
Test Objectives: To determine the texture with low-tech test.

Materials List:

- Freshwater
- Soil sample
- Camera (to photo document)

How to Conduct the Test:
Follow the flow chart in Figure 9. Take photos throughout to document the test.

Figure 9 | Texture Flow Chart by the Natural Resources Conservation Service



Evaporation

Source: P. Stevens. Interview on March 7, 2017.

Test Category: High-Tech

Test Objectives: To measure the weight of water lost during evaporation and determine the approximate evaporation rate of soil in different conditions.

Materials List:

- 2-4 deep containers (water bottles, graduated cylinders, other)
- Trowel/shovel
- Scale
- Moisture reader
- Mulch or plant cover

How to Conduct the Test:

1. In different areas of the field, point the trowel straight down. Slice off a chunk of soil of at least one foot deep (30 cm), but ideally 24" (61cm) deep and carefully lift it out of the hole.
2. Remove any roots, twigs, or rocks.
3. Place the soil sample carefully on the ground and use the trowel to slice off a small cross section and carefully place in the container (cup, water bottle with top cut off, graduated cylinder).
4. Repeat 1-3 times so that you have 2-4 soil samples.
5. Water each sample with an equal amount of water (enough so that it is saturated).
6. For half of your samples, cover with mulch or plant cover (basically pulling up some weeds) so that the soil isn't exposed.
7. Weight and record each weight and moisture content reading, use the masking tape to label the original weight on the container.
    a. With the moisture content - take 2-3 measurements in equal distance along the container to better understand evaporation at different depths.
8. Place somewhere out of the way (so they won't be knocked over) but in full sunlight.
9. For the next 3 days, check the weight and the moisture content of each sample.

Soil Health Using Earthworms

Sources: Weekend Gardener

Test Category: Low-Tech

Test Objectives: To determine soil biodiversity and quality.

Materials List:

- Measuring tape
- Trowel / Shovel
- Notebook
- Towel / tarp / etc. (something to put dirt on)

How to Conduct the Test:

1. Dig a 12-inch by 12-inch hole, carefully placing the dirt aside on something that separates it from the ground.
2. Carefully shift through the earth and count up the number of worms found.
3. Observe the hole for 15 -60 minutes and count the number of bugs that crawl through the hole.

Implications of Results

Positively affect soil structure, aeration, soil decomposition and nutrient cycling, as well as water capacity, which all improve soil fertility. Earthworms can also help anchor soil and reduce runoff and erosion. Therefore, the presence of earthworms is a good indication of soil health. Additionally, earthworm presence is low in acidic and very wet soils, thus an absence of worms could also be an indicator of soil pH (In acidic soils, earthworms are replaced by enchytraeids, a group of related but usually smaller worms[123].

Additional Sources:

- A handy guide for identification of earthworms

Soil Compaction

Source: Penn State Extension. Diagnosing Soil Compaction Using a Penetrometer (Soil Compaction Tester)

Test Category: High-Tech

Test Objectives: To measure the extent and depth of subsurface compaction using a penetrometer, or soil compaction tester

Why Is This Important: Soil compaction can be a big concern for farmers that use large and heavy equipment as it can lead to reduced crop yields, destroy soil structure, increase resistance to root penetration, and lead to water and soil quality degradation due to increased runoff[124].

Materials List:

- QCQA Pocket Penetrometer
- QCQA Adapter Foot
- Notebook for documentation of cone index

How to Conduct the Test:

1. Move the ring towards the handle to the lowest reading on the scale. The ring should rest against the lower edge of the instrument handle.
2. Hold the top portion of the handle and slowly push the piston into the soil up to the calibration groove located ¼" from the tip.
3. Read the unconfined compression strength directly in tons/ft2 or in kilograms/cm2 on the low load side of ring closest to top of handle.
4. To obtain the correct, unconfined compressive strength of the soil, the reading should be divided by 16.
5. To use the adaptor foot, grip the handle and push the foot into the soil up to the full thickness (1/4") of the adaptor foot.

Results:
The following table could be used to interpret the penetration resistance measurement.

Figure 10 | Interpretation of Penetration Resistance Measurements

PERCENTAGE OF MEASURING POINTS HAVING CONE INDEX > 300 PSI IN TOP 15 INCHES	COMPACTION RATING	SUBSOILING RECOMMENDED
< 30	Little to none	No
30–50	Slight	No
50–75	Moderate	Yes
>75	Severe	Yes

Adapted from: Lloyd Murdock, Tim Gray, Freddie Higgins, and Ken Wells, 1995. *Soil Compaction in Kentucky*. Cooperative Extension Service, University of Kentucky, AGR-161.

5.3.2 | Water

This section contains a few options of high-tech and low-tech tests for water turbidity and quality, to test for levels of lead, bacteria, pesticide, iron, copper, alkalinity, pH, hardness, chlorine, nitrates and nitrites in water.

Water Quality

Source: Complete Water Analysis Test Kit

Test Category: High-Tech

Test Objectives: To check the levels of Lead, Bacteria, Pesticide, Iron, Copper, Alkalinity, pH, Hardness, Chlorine, Nitrates and Nitrites in water source. The Team used the Complete Water Analysis Test Kit, but there are similar alternatives in the market[125].

Why Is This Important: To determine the water quality used for irrigation and/or home use. It is especially important to find out if there is any contamination from agricultural activities or other sources and to determine whether essential nutrients from soil are being lost through runoff.

Materials List:

- Water Testing Kit
- Water samples (well or surface water)

How to Conduct the Test:

Bacteria Test

If using a different test, refer to its instructions as they might differ:

1. Get the small plastic vial that is located in the testing supplies. Remove the protective plastic wrapper from the vial.
2. After removing the protective wrapper place the test vial upright on a flat surface.

3. Collect your water sample from the water source in a small cup. If collecting it directly from your tap make sure to turn water stream to a very low setting.
4. Carefully twist off the cap of the vial and fill it to ½ inch below the top, where the 5mg line is marked. Make sure not to overfill or spill the bacterial growth powder located within the vial.
5. Screw cap back on vial and secure it tightly. Once secure, shake the vial forcefully for 20 seconds.
6. Place the vial upright in a warm area (70 to 90 degree F). Make sure it is in a location that will not be disturbed for 48 hours.

Results:

If the test displays a purple color, that means the result is negative. A negative result implies that no bacteria were detected in your water sample. If the test displays a yellow color, that means the result is positive. A positive result implies it is very likely that potentially harmful bacteria were detected and further testing is advised.

Lead and Pesticide Test Instructions[126]

1. Open the foil pouch that contains the Lead and Pesticide test kits. The package should contain a test vial, dropper pipette, two test strips and a desiccant pack (to be discarded).
2. Using the dropper, place exactly TWO dropperfuls of water sample into the test vial. To pick up a water sample, squeeze the top bulb at the end of the dropper and place the open end into your water. Release the bulb to suck in the water sample into dropper. To expel the water into your test vial, simply squeeze the bulb again.
3. Swirl the test vial for a few seconds then place it on a flat surface.
4. With both arrows pointing DOWN, place both test strips into the vial.
5. Wait for 10 minutes. Do not disturb the test during this time.
6. After 10 minutes, you will see blue lines appear on the strip. Take the strips out of the vial and lay them on a flat surface with the arrows pointing to the LEFT.

Results:

- Negative: LEFT line next to the number 1 will be darker than the RIGHT line next to the number 2.
- Positive: RIGHT line next to the number 2 will be darker than the LEFT line next to the number 1 or both lines are equally dark.

Total Chlorine/ Copper/ Nitrate/ Nitrite Test Instructions[127]

1. Rinse out test vial and fill to ¼” from top with water.
2. Remove test strip from foil packet labeled CL/CO/NA/NI.
3. Pick up strip on end with no pads.
4. Dip in water, swirl strip 3 times and remove.
5. IMMEDIATELY read Chlorine pad by comparing to chart below.
6. Next, read the copper test and after a total of 45 seconds has elapsed from when the test strip was first dipped, read the Nitrate/ Nitrite Test.

Alkalinity/pH/ Hardness Test Instructions[128]

1. Rinse out test vial and fill ¼" from top with water.
2. Remove test strip from packet labeled ALK/ pH/ Hard. Pick up strip on end with no pads.
3. Dip the ALK/pH/HARD strip in water for one second and remove.
4. Hold test strip level and wait ten seconds. Compare to color chart below in order starting with alkalinity, then pH and hardness.

Iron Test Instructions[129]

1. Rinse out test vial and fill to ¼" from top with water
2. Remove iron reagent tablet (DO NOT EAT) from foil packet and place in test vial.
3. Place cap on test vial and shake until table completely disintegrates then remove cap from test vial.
4. Remove the iron test strip from foil package. Do not touch pad.
5. Immerse test pad in sample for 2 seconds.
6. Remove test strip from sample with pad face up.
7. Shake once to remove excess water.
8. Wait 60 seconds and compare to color chart.

Implications of Results

Bacteria: A positive result signifies that total coliform bacteria are present. Total Coliform is an "indicator" organism, meaning testing for it can be a reasonable indication of whether other pathogenic bacteria are present. Coliforms come from the same sources as pathogenic organisms that cause disease. Coliforms are relatively easy to identify, are usually present in larger numbers than more dangerous pathogens, and respond to the environment, wastewater treatment, and water treatment similarly[130].

Pesticides: A positive result indicates the detection of Atrazine and Simazine, two herbicides, at or above the United State Environmental Protection Agency (EPA)'s maximum allowable contaminant level (Atrazine: 3 ppb; Simazine: 4 ppb)[131]. Both pesticides are banned by the European Union and Atrazine is by Syngenta, which has a huge presence in Uganda[132].

Nitrates and Nitrites (Nitrogen): Positive results indicate Nitrate/Nitrite nitrogen over 10 ppm (10 mg/l). Concentrations of around 10 ppm can cause health problems in children under 6 months, but is considered a low health threat to older children and adults. From fertilizer additives and/or human and animal waste leaching into groundwater[133].

Alkalinity: The threshold for Alkalinity is 20 miligrams per liter (mg/l). Alkalinity measures water's ability to resist changes in acidity (pH), which can reduce the impact that harmful pollutants have on water quality[134].

pH: Water kit tests for pH between 5 to 8.5. A pH of less than 7 indicates acidity, whereas a pH of greater than 7 indicates a base. The pH of water determines how much of essential nutrients (phosphorous, nitrogen, and carbon) and heavy metals (copper, iron, lead) that stays in the water. pH also determines how much of each nutrient aquatic life can use it and how toxic heavy metals are. In the case of heavy metals, the degree to which they are soluble determines their toxicity. Metals tend to be more toxic at lower pH as they are more soluble[135].

Lead: A positive result indicates lead levels over 15 parts per billion (ppb). 15 ppb is the US EPA max safe level of lead in drinking sources[136].

Hardness: Under 50 ppm is considered “soft” water. “Hard” water has high concentrations (50 parts per million or more) of dissolved calcium and magnesium in the water. Higher water hardness leaves a feeling of residue after using soap. In hard water, soap reacts with the calcium, which is relatively high in hard water, to form "soap scum". When using hard water, cleaning requires more soap or detergent[137].

Iron: Positive results indicate iron levels above 0.3 mg/l. Higher iron content results in a metallic taste; discolored beverages; yellowish stains and can stain laundry[138].

Copper: Positive result indicates copper levels above 1.3 mg/l, which the EPA limits. Higher copper content gives drinking water has a bitter metallic taste[139].

Chlorine: Positive results indicate chlorine levels above 4 ppm. For context, 3 ppm is the maximum recommended limit in the US for pools (0.5-3 ppm). At 5 ppm, people typically notice that their skin, hair and eyes are irritated or burning[140].

Water Turbidity/Clarity (1)

Source: World Health Organization. Factsheet 2.33: Measuring Turbidity

Test Category: Low-Tech

Test Objectives: To determine the cloudiness or turbidity in water

Why is This Important: Turbidity is the amount of cloudiness in the water, it can be due to silt, sand and mud; bacteria and other germs; minerals or chemical precipitates. Highly turbid water can block filters and stop them from working, fill tanks and pipes with mud and silt, or damage valves and taps[141].

Materials List:

- 2-liter transparent plastic bottle
- Paper (or other material like a magazine, poster etc.) with large letters printed on it

How to Conduct the Test:

1. Fill the bottle with water
2. Check if you can see something printed in large text placed underneath → yes or no
    a. You can also mark whether you can see the print when the bottle is half-full → yes or no

Implications of Results

High concentrations of particulate matter affect the clarity of water. The presence of soil sediments and other materials that enter the water through runoff flows or high natural levels of minerals may cause increased turbidity. High turbidity can indicate the presence of other pollutants, notably metals and bacteria. For this reason, turbidity can be used as an indicator of potential water pollution[142].

Water Turbidity/Clarity (2)

Source: World Health Organization. Factsheet 2.33: Measuring Turbidity

Test Category: High-Tech

Test Objectives: To evaluate the turbidity of the water by using a graduated cylinder. This approach is more accurate than the low-tech turbidity method but requires more specialized equipment.

Materials List:

- Graduated cylinder
- Paper (or other material like a magazine, poster etc,) with large letters printed on it. Instead of letters, could also draw a circle and color half of it.

How to Conduct the Test:

1. Fill the cylinder with water.
2. Check if you can see the print/shape the text placed underneath the cylinder.
    a. Note the grade/how much water is in the cylinder and whether you can see the print/shape.
3. Pour some water out of the cylinder, and repeat the second step. Do this until you can see the print/shape clearly. Note how much water you have to pour out before you can see the print/shape clearly.

Implications of results

High concentrations of particulate matter affect the clarity of water. The presence of soil sediments and other materials that enter the water through runoff flows or high natural levels of minerals may cause increased turbidity. High turbidity can indicate the presence of other pollutants, notably metals and bacteria. For this reason, turbidity can be used as an indicator of potential water pollution[143].

Precipitation

Source: Royal Meteorological Society. Make a Rain Gauge.

Test Category: High-Tech

Test Objectives: Take the volume of rainfall for a given area. It is important to note that lower elevations will receive more rainfall than measured due to runoff.

Materials List:

- Clear plastic ruler
- 2 liter plastic bottle
- Scissors
- Cylinder jar (like an olive jar) or graduated cylinder
- Paper clips / Transparent tape

How to Conduct the Test:

1. Take an empty 2-liter plastic bottle. Cut off the top of the bottle about a quarter of the way down, where it reaches a consistent diameter. Be careful to cut this smoothly
2. Remove the bottle top and invert the upper part of the bottle into the bottom part. It should fit snugly but to make sure it does not fall out, use a few paper-clips or tape to hold the two halves together.
3. Place your rain gauge upright in the ground, in a location where it will collect rain without being affected by buildings or trees etc. To help it stand upright, you can pile soil up around the edges.
4. Every day, visit the rain gauge and carefully remove it from its support. Take out the inverted top and carefully pour the rain collected into another container, preferably a measuring cylinder.
5. Measure the height of the collected rainwater with the ruler in millimeters.

Implications of Results

The rain gauge can help track the amount of rain for a given weather event or the amount of rain over seasons. To determine volume of rain for a given area, multiply the height of water in the rain gauge by the area desired.

5.3.3 | Biodiversity

Biodiversity is one of the most important attributes for an ecosystem or community that determines stability, sustainability, and productivity[144]. Biodiversity or biological diversity can be defined as the variety of life.

Biodiversity can be broken into two major categories- species richness and evenness. Species richness is the number of species that exist in an ecosystem or habitat while species evenness is the measurement of species richness combined with how evenly distributed the number of each species is[145].

Bird Counting

Test Category: Low-Tech

Test Objectives: To document local bird species as a marker of biodiversity

Materials List:

- Measuring tape
- Recording device
- Bird book
- Cellphone or other recording device

How to Conduct the Test:

Count Bird Sounds

1. Under appropriate weather conditions, allot time frame (around 15 minutes) for species sounds' counts.
2. Break up your viewpoint/listening point into four quadrants between North-South-East-West.
3. Mark the time and quadrant of each sound -- helps identify bird movement if happening, better analysis of population, rare species in an area, etc.

Record Bird Sounds

1. Record songbirds' sounds from sunrise to ~11 am (a recording for someone else's analysis, probably). Can use a cell phone to capture 15-minute intervals.

Bird Watching

1. Conduct a bird count over a day, and attempt to identify the birds.
2. Cell phone apps or citizen science networks are available to help with bird identification.

Optional: Performing these procedures in several locations close to and away from the farming community could identify whether there may be some ecological attraction to one place over another such as food resources, protection from predators.

Implications of results

Birds can be used as an indicator for overall biodiversity as the abundance (count of species) and richness (number of individuals of a specific species) have been found to be directly related to the abundance and richness of other animals, insects, and plants[146]. However, individual research will have to be done for each location to understand the expected types of bird species and populations to fully understand whether biodiversity around the community is strong.

5.2.4 | Productivity

Various methods have been developed to quantify productivity at several stages including research plot, national, and regional level agricultural statistics. This is an important metric to calculate, document, and record over time, to address new challenges such as climate related weather changes, and their impact on productivity[147]. Productivity, or agricultural productivity, can be described as the ratio of agricultural inputs to outputs. This section of the field guide will focus on low-tech methods of data collection of the harvest, crop mapping, and easy methods for yield estimation.

Consistent with the United Nations Food and Agricultural Organization, this field guide will use the following definitions for crop area, crop yield, and harvest season.

Crop Area for this field guide will be used as Harvested Area. Harvested area is the part of the sown or planted area that results in crop produce[148].

Crop Yield is the average amount of produce per unit crop area[149]. In cases of tree crops, yield can be defined as the average amount of produce per tree and the production is calculated as the product of the average yield per tree and the number of producing trees (global strategy working paper).

Harvest Season is the time frame in which the harvest begins

Measuring Distances

Source: Global Strategy for Improved Agricultural Statistics. 2016. Research on Improving Methods for Estimating Crop Area, Yield and Production under Mixed, Repeated and Continuous Cropping.

Test Category: Low-Tech

Test Objectives: To measure distances to estimate farm area

Materials List (subject to change depending on local resources):

- Rope or cord

Operating Procedure:

1. Use an instrument of known length.
2. Convert the length of the instrument to standard unit and use that to determine an average length of the land area.

Advantages	Challenges
• Cost effective standardized way to record length and breadth of a field. • Instruments are cheap and easy to use.	• Common source of error could come from miscounting or misreporting. • Total dependence on instrument for measuring length. • Uneven ground is more challenging to measure.

Field Mapping

Test Category: High-Tech

Test Objectives: To determine the area of fields remotely.

Materials List (subject to change depending on local resources):

- Smart phone with **Motion X-GPS downloaded** (cost: USD 0.99)
- **Computer with Google Earth Pro** (cost: free)

How to Conduct This Test:

1. Walk the boundary of the field, periodically using the MotionX-GPS app's "Mark Waypoint" feature to capture the coordinates of your location (For a full tutorial on MotionX-GPS, go here: http://gps.motionx.com/iphone/tutorials/).
2. Using the app, email all the saved waypoints to an email account of someone who can access Google Earth.
3. Open the email and drag all of the attached KMZ files into Google Earth or save them and import them into Google Earth. This should appear as points on Google Earth now (using the typical Google Earth waypoint icon).
4. Use the "Draw Polygon" feature in Google Earth to trace a polygon using the imported waypoints. Label the polygon with a name that helps to distinguish it (sample number, farmer's name, etc.)
5. Right click on the new polygon listed in the left navigation panel, and click "Save Place As". Save the polygon as a KMZ file.
6. Open up this tool by the University of New Hampshire (https://extension.unh.edu/kmlTools/) and upload the polygon file.
7. Once uploaded, the option to calculate area by unit will appear. Select the most relevant unit for the community (feet, meters, acres) and click the area button. The area of the polygon will be calculated.
8. Return to Google Earth and right click on the polygon listed in the left navigation panel. Type the field area into the description box. Photos and other features can be included to provide additional details.
9. Right click on the polygon in the navigation panel again and click "Save Place" to save the recent description additions for future reference.

Advantages	Challenges
• This method requires minimal in-field work and many data points can be emailed and sent remotely for processing.	• Requires decent GPS service on location and a smart-phone, both of which may not be available at every location.

Crop Estimate and Recall Method

Source: Global Strategy for Improved Agricultural Statistics. 2016. Research on Improving Methods for Estimating Crop Area, Yield and Production under Mixed, Repeated and Continuous Cropping.

Test Category: Low-Tech

Test Objectives: To estimate harvest using farmers' prior experience and knowledge about farms

Materials List (subject to change depending on local resources):

- Paper to document
- Archive to hold the records
- Field coordinators

How to Conduct This Test:

1. Ask the farmers to predict what quantity they expect to harvest.
2. Ask them about their last harvest and document the time estimates.

Advantages	Challenges
• **If done at maximum harvest stage,** field coordinators could verify the farmers' response by visual observation of the crop over time • **Post harvest,** field coordinators could examine farmers' house or the site where harvest is stored in order to cross-check estimate with the harvested products	• This method requires complete dependence on farmers' memories

Crop Card Data Collection

Source: Global Strategy for Improved Agricultural Statistics. 2016. Research on Improving Methods for Estimating Crop Area, Yield and Production under Mixed, Repeated and Continuous Cropping.

Test Category: Low-Tech

Test Objectives: To document quantity of harvest during an extended period or harvest season

Materials List (subject to change depending on local resources):

- Crop Cards (custom made cards that record date of seeding, date of harvest, quantity of crops, notes to include details when required)
- Supervisor or field coordinator that collects data
- Archive that holds all crop cards

How to Conduct This Test:

1. Farmers will be given ready-made crop cards that record details about their harvest including date of seeding, date of harvest, quantity of crops, notes to include additional details when required.
2. Each farmer will volunteer to participate in the record collection.
3. Supervisor or field coordinator will ensure proper data collection regularly and help when farmers in data collection to avoid errors.

Advantages	Challenges
• Crop cards are more reliable for recording harvesting data than recalling the amount of quantity.	• High illiteracy rate amongst farmers could slow the data collection.

Daily Recording of Crops

Source: Global Strategy for Improved Agricultural Statistics. 2016. Research on Improving Methods for Estimating Crop Area, Yield and Production under Mixed, Repeated and Continuous Cropping.

Test Category: Low-Tech

Test Objectives: To record the weight and condition of the harvest daily

Materials List (subject to change depending on local resources):

- Supervisor/ Field Coordinator
- Weighing scale
- Archive that holds all the records (paper or electronic)

How to Conduct This Test:

1. Supervisor or Field Coordinator would visit each plot of farm daily and record the weight and condition of the harvest using weighing scale.
2. **For multiple harvesting seasons:** Field Coordinator could also take a subsample of the harvest of crops like cassava, banana, coffee, maize, indeterminate legumes.

Advantages	Challenges
• This method will ensure data collection of high level and give a better understanding on the harvest.	• It is time and labor intensive. • Recording errors could increase because of frequency of data collection. • Lack of motivation from field coordinators or farmers could result in errors.

Yield Estimation using Crop Weight

Source: Global Strategy for Improved Agricultural Statistics. 2016. Research on Improving Methods for Estimating Crop Area, Yield and Production under Mixed, Repeated and Continuous Cropping.

Test Category: High-Tech

Test Objectives: To estimate crop yield by using pre-estimate test weight

Materials List (subject to change depending on local resources):

- Sample frame or measuring tape/rope
- Scale

How to Conduct this Test:

1. Wait for harvest time.
2. Use a sampling frame or measuring tape to mark off one square meter for a test plot.
3. Within the test plot, count the number of pods (grain), individual produce (vegetables, fruit) in the plot.
4. Repeat at least 5-7 times within a field
5. Record all the counts for the test plots and find the average.
6. **For grains:** Count the number of grains in 20-25 heads/pods and take the average. Multiply the number of grains per head by number of pods times the weight of the pod to get the yield per square meter. Multiply that number by the total area of the field to get the yield of the field.
7. **For fruits/vegetables**: determine how many individual fruit/vegetables are in 0.5 kilograms or 2.5 kilograms. Divide the number of vegetables/fruit by the number of vegetables/fruit per determined unit of weight (0.5 kg or 2.5) and multiply by unit of weight to get the yield per square meter. Multiply that number by the total area of the field to get the yield of the field.

Advantages	Challenges
• Can be used to estimate large fields or multiple fields.	• Time intensive. • Estimation accuracy, regardless of method, depends on the accuracy of observations taken in the field.

5.4 | Reporting Templates

5.4.1 | Farmer Profile

Farm Identification: ______________

Farmer Name(s):

Photo Description/ ID number:

Number of people that work on farm:

Farm size:

Crops Grown:

Farming Practices:

General Observations

5.4.2 | Soil

TEST: Soil Test Kit

Soil Sample Site	pH	Nitrogen	Phosphorus	Potassium
1				
2				
3				

TEST: Soil Characteristics and Color Scale

Soil Sample Site	Iron oxide minerals **RED**	Iron sulfide minerals **BLACK**	Calcium minerals **WHITE**	Low Oxygen **GRAY**	Organic matter **DARK**	Comments
1						
2						
3						

TEST: Soil pH Baking Soda and Vinegar

Soil Sample Site	Reacts with Vinegar	Reacts with Baking Soda	Reacts with Neither
1			
2			
3			

TEST: Soil Moisture (1)

Soil Sample Site	Moisture Meter Reading	pH	Light
1			
2			
3			

TEST: Soil Moisture (2)

Soil Sample	Available Soil Moisture content	Soil Texture	Available Water Capacity
Sample 1			
Sample 2			
Sample 3			

TEST: Soil Texture

Soil Sample Site	SAND LEVEL (After 1 minute)	SILT LEVEL (After 4-6 hours)	CLAY LEVEL (After 1 or 2 days)
1			
2			
3			

TEST: Soil Content

Soil Sample Site	SAND	LOAMY SAND	SANDY LOAM	SILT LOAM	LOAM	SANDY CLAY LOAM	SILTY CLAY LOAM	CLAY LOAM	SANDY CLAY	SILTY CLAY	CLAY
1											
2											
3											

TEST: Evaporation

Soil Sample Site	Site Description / Location
1	
2	
3	

Soil Sample Site	Condition	Day 1	Day 2	Day 3
1.a	Covered with mulch or plant			
1.b	Not covered			
2.a	Covered with mulch or plant			
2. b	Not covered			

3.a	Covered with mulch or plant			
3. b	Not covered			
4.a	Covered with mulch or plant			
4. b	Not covered			

TEST: Soil Health Using Earthworms

Soil Sample Site	Number of worms in sample	Number of worms in hole
1		
2		
3		

5.4.2 | Water

TEST: Water Quality

Water Sample Site	Lead	Bacteria	Pesticide	Iron	Copper	Alkalinity	pH	Hardness	Chlorine	Nitrates and Nitrites
1										
2										
3										

TEST: Water Turbidity/Clarity (1)

Water Sample Site	Turbid? Yes/No	Comments/Observations
1		
2		
3		

TEST: Water Turbidity/Clarity (2)

Water Sample Site	Turbid? Yes/No	Comments/Observations
1		
2		
3		

TEST: Precipitation

Date	Gauge Height	Comments/ Observations

5.4.4| Biodiversity

TEST: Bird Counting

Location	Time	Bird Type	Bird Count

6 | TEST CASE: KASEJJERE

6.1 | Introduction

Kasejjere is a farming community in Uganda that A Growing Culture has been involved with for two years. A Growing Culture has worked with farmers in Kasejjere in partnership with the Kikandwa Environmental Association (KEA), co-hosting a beekeeping workshop to bolster farmers' resilience to climate change and enhance crop yields through pollination, and a gathering of international stakeholders to discuss how to best support smallholder farmers. A Growing Culture suggested Kasejjere as a test case for the Capstone Team, given the positive impact agroecological farming practices have had on the community and the community's interest in building greater external relationships.

This Capstone project provided an opportunity for the farmers to share their empirical knowledge and observations through one-on-one interviews, and for the visiting Team to perform some basic tests on soil and water quality to create a baseline for tracking changes over time. This test case helped to inform the approach discussed in Section 4.

6.1.1 | Locational Context

The village of Kasejjere is located in central Uganda, about 80 km northwest of the capital, Kampala[150]. The city is a draw for the youth of the farming village seeking less arduous employment and is one of the primary markets for their crops[151]. Crops in this region are raised for both subsistence and to sell to the market. Intermediaries collect produce directly from the farmers and are responsible for transporting it into the city; the farmers have no interaction with the consumers of their produce. Crops that are in high demand due to scarcity, or that command a high price, may attract intermediaries who will travel to remote villages like Kasejjere to purchase the produce for resale. In some cases, they will even bring in laborers to harvest the crop from the farmer's field[152].

Although subsistence farming is currently prevalent in Kasejjere, it was not always the case. In 1999, a resident, John Kaganga, co-founded the Kikandwa Environmental Association in response to alarming rates of food insecurity, and to protect against the rapid degradation of the region due to poor farming practices and rampant deforestation. Mr. Kaganga shared stories with the Team about the time when the primary crop was a variety of banana that was distilled into liquor. Few other crops were grown. KEA united the farmers to broaden crop diversity to include a mix of subsistence and cash crops and launched a reforestation project called *Half + Half* that encouraged farmers to set aside a portion of their land to grow trees.

KEA also raised funds to build a primary school in the center of the community, the site of which is used for holding workshops aimed at sharing local knowledge with the farmers about agroecological farming methods. Increasing concern about climate change, particularly reduced rainfall in the region, has encouraged farmers to seek alternative methods of cultivation and to participate in the reforestation project[153].

Many of the farmers in Kasejjere have adopted agroecological practices, including intercropping, use of natural fertilizers, and crop diversification, which have improved their output. However, there has been no documented evidence of improvement in soil or water quality, increases in yield, or specific crops' successes or failures[154]. While the farmers can anecdotally discuss changes to crops due to droughts, for example, there is no data to confirm changes in the volume of water or decreases in crop yield.

Social Context of Uganda

Uganda gained independence from British rule in 1962, but the country has been embroiled in a series of civil conflicts between rebel groups. The most destructive was the 20-year insurgency led by the Lord's Resistance Army, which affected four countries, displaced more than 2 million people, and destroyed Northern Uganda's agricultural base[155]. Malnutrition, child enslavement, and human rights abuses plunged Uganda into one of the worst humanitarian crises in the world, according to the UN Under-Secretary-General for Humanitarian Affairs and Relief Coordinator, Jan Egeland[156].

Agriculture is the country's primary industry and is the main source of sustenance and income for smallholder farmers. However, they face many challenges including internal conflict, lack of government support, and competition with industrial agriculture. Violence continues in western Uganda over land use between tribes that raise livestock versus agriculturalists; this conflict is being fueled by high unemployment rates of young men who have been forced to leave their farms in search of work[157]. Children have also been victimized and are forced to work on industrial tobacco farms where they are exposed to chemical hazards and are targets for sexual trafficking. Despite enormous natural resources and fertile land, Uganda is one of the poorest countries in the world.

6.1.2 | Field Visit Overview

To build an understanding of local practices and to gather farmer knowledge and concerns, the Capstone Team interviewed 15 farmers in Kasejjere. For comparison, the Team also interviewed three farmers from a nearby village, Banda, where the farmers use mono-cropping practices and commercial fertilizers and pesticides. While at each farm for interviews, the Team also took soil samples and ran a total of 16 soil tests to assess the levels of pH, phosphorus, nitrogen, and potassium using an inexpensive off-the-shelf garden test, *Rapitest® Soil Test Kit* by *Luster Leaf®*. Three water samples from local water sources in Kasejjere were tested with the *Complete Water Analysis Test Kit* by *Test Assured*. Both tests are sold in multiple countries but are calibrated to United States Department of Agriculture (USDA) standards. Please refer to Section 5 for more details on the soil and water tests.

Interview questions focused on building an understanding of the basic metrics the Team had identified as pertinent to the context, including management of land, soil, water, and waste, experience with climate change, shared community knowledge, and previous engagement with entities external to the community. The farmers were well informed about their individual farming methods, drawing on a range of intergenerational, commercial, and agroecological practices. The interviews documented a wide variety of practices to grow a narrow range of crops. The land under cultivation was typically farmed by a household for smaller plots (average of two acres), while larger plots producing crops for market were frequently farmed with additional hired help.

Agroecological methods were shared with the Team by KEA members Seruzi Alexander (Alex) and Salongo Kakembo Ziboyumu (Kakembo), who encouraged crop diversification, seed preservation, and cultivation of heritage varieties. Alex also encouraged "target marketing" by monitoring which crops were currently flooding the market. Increased availability forced prices down and often deterred farmers from planting those crops the following season. Following a cycle, scarcity drove up prices the following harvest; though prices for crops can swing widely from week to week, based on availability. He also outlined four questions that farmers should answer: what to plant, when and where to plant it, and how to cultivate the crop. In addition to access to water, Alex considered this information the key to succeeding[158].

The Team learned that no scientific testing of soil, water, or biodiversity had ever been conducted in Kasejjere. Farmers were eager to learn their individual results of the tests and receive crop recommendations based on the findings. This interest was a concern for the Capstone Team, as agriculture is not its area of expertise, and the Team wanted to avoid making practice-specific recommendations. To avoid this scenario, an overview of the results was presented to the villagers at the culmination of the trip. Individual results were provided to KEA to share and interpret on a specific farmer basis. Additional testing materials were left with KEA to continue soil testing.

In addition to the tests, the Team shared some general observations with representatives of A Growing Culture, including:

- Some farmers are interested in marketing strategies for their crops and are looking for help with price setting. While marketing strategies were outside the scope of this

Capstone project, the Capstone Team had been informed by PELUM that crop prices are broadcast via radio. The Team was unable to confirm if farmers were aware that this information was available.

- Throughout the Team's interaction with the farmers via Skype calls before the trip, and in-person interviews, the farmers expressed deep concern about their vulnerability to climate change, specifically as it related to changes in rain patterns and rising temperatures. They requested additional resources to help them retain resiliency.
- Farmers are predominantly reactive, instead of proactive, using trial and error to inform decisions.
- Farmers are interested in recommendations and technologies that could improve their crop yield without increasing their labor.
- Some farmers are leasing the land for cultivation, but the Team was not able to meet with many landlords to understand their roles and interests in their land.

6.2 | Soil

6.2.1 | Context

Most of Africa's soils are ancient, derived from granite weathered over millennia. The soil of Kasejjere, in the Mityana District of Uganda, is classified as *red ferritic*[159]. Red ferritic soils are mainly described as a sandy clay loam but can be highly heterogeneous. The soil is high in iron with a high depletion of nitrogen and potassium, and a high absorption of phosphorus, meaning that less phosphorus is available for plants' uptake. Hillside ferritic soil retains little water, typically resulting in poor moisture content, soil erosion, and nutrient depletion. The soil is described as weathered, red, deep, and porous with large amounts of clay-sized iron and aluminum oxides. The iron gives the soil its characteristic red color[160]. The Team observed that farms in the village of Kasejjere are built on slopes of differing grades, leading to potential challenges in nutrient and moisture retention.

The United States Department of Agriculture (USDA) references a Soil Taxonomy that classifies the soil of the broader region of central and eastern Africa as Ultisols/Oxisols. Oxisols and Ultisols tend to be acidic, though Ultisols are more so, and are typically nutrient deficient in nitrogen, phosphorus, and potassium. The soil can have medium to high phosphorus fixation, meaning lower nutrient availability for plants' uptake. The extent of fixation will vary depending upon the levels of iron, calcium, and aluminum present, as well as the pH level. A lower pH level helps the soil retain phosphorus while a higher pH level is more likely to lose phosphorus through runoff[161].

6.2.2 | State of Local Knowledge

Farmers in Kasejjere described the consistency of their soil in a variety of ways, including texture (stony, pebbly, smooth); color (red, brown, black); moisture content (damp, dry); and productivity (poor, healthy). They showed the Capstone Team wide variations in soil quality, even within the same plot. As most of the farms are on differing slope gradations, the variation in soil between the top and the bottom of a hill was often visually evident. The soil in the village of Kasejjere had notably more organic material than the soil observed in the community of Banda. However, almost all the interviewed farmers indicated that they did not practice composting or mulching. The two farmers who practiced the use of mulching with organic material, including green manure and animal waste, had comparatively darker and richer soil[162]. Farmers who practiced no-till farming had crops with visually complex root systems[163].

Four factors determine what crops are grown:

- Current market demand and price, although this can vary widely week-to-week depending on availability of crop type.
- Seed expense: For instance, lima bean seeds are often too expensive for the farmers[164].
- Required labor: As groundnuts need extensive tiling, for example, few farmers have the labor capacity for this crop[165]. The Team observed only one lima bean crop and one groundnuts crop during their time in Kasejjere.
- Local conditions: some farmers struggled to grow some crops, such as melons, given the elevation[166].

The Team observed that nearly all Kasejjere farmers apply a trial and error approach to crop management. Farmers often begin their planting season by scattering a few seeds of the same crop variety on different plot areas, and if shoots successfully grow, the farmers will add seeds to that area[167]. If the growth appears weak, then the farmer might try that crop variety on a different plot area or decide not to attempt to grow that crop variety altogether[168]. Some farmers may grow just two or three crop varieties from season to season, relying on previous successes or failures to determine which crops they cultivate. The trial and error approach is time and resource consuming, and not always fruitful. Nutrient-depleted soil, erosion, and other factors can further hinder such an approach but are not always realized until the crop proves unsuccessful.

When crops stop growing well, farmers might allow the land to lie fallow for three to four years. Many of the farmers interviewed worked at least two different small plots. They determine that soil fertility has improved by the appearance of indicator weeds, such as Wandering Jew, tall grasses and certain varieties of clover. Farmers who rested their fields might tether goats in the area, which serves to naturally till the soil with their hooves, organically enrich the soil with their manure, and feed on the weeds[169]. However, not all farmers can afford livestock. Those who raised cattle grazed them offsite, leaving nutrient-rich manure in fields not currently used for cultivation. The Team was informed that transporting the manure to the farm had been done in the past, but it is no longer done due to the labor required[170].

While all interviewed farmers were concerned about the impacts of climate change and related drought on their levels of production, very few employed water-preservation strategies. Almost all the farms visited were on sloped land, but only one farmer used terracing or irrigation ditches to slow water runoff and prevent erosion[171]. Only two farmers used mulching or groundcover to retain soil moisture[172].

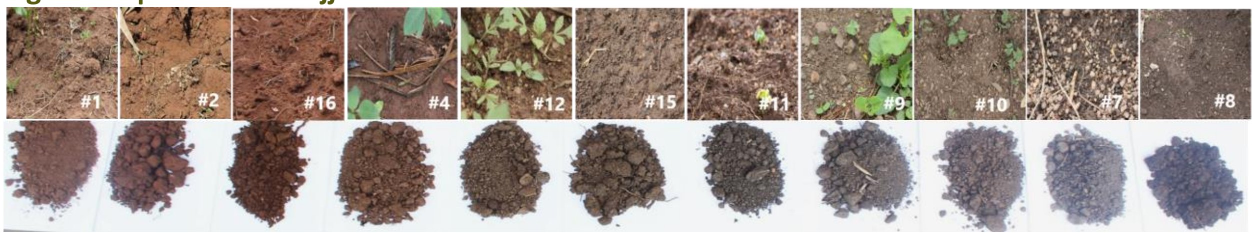
6.2.3 | Test Results

Soil samples taken from the interviewed farmers were dried overnight and then mixed with cold water previously boiled as per instructions. 16 soil tests were conducted using the *Rapitest Soil Test Kit* by *Luster Leaf*. The samples were combined with chemical reagents to test for color reaction to gauge the level of pH, and soil elements, including nitrogen, phosphorus, and potassium. The Team additionally used a garden tool, *Soil Moisture Meter, 3-in-1 "Soil Tester,"* to test the pH and moisture content of the soil. pH is an indicator of nutrient availability. Nitrogen, phosphorus, and potassium are yield-determining nutrients in most farming systems and are necessary for maintaining soil's organic matter. Phosphorus is often a yield-limiting nutrient in impoverished soils, particularly in parts of Africa[173]

The soil test results did not vary widely in the village of Kasejjere, with a pH level that ranged from slightly acidic to acidic, an average level of "sufficient" potassium, and an average level of "depleted" to "deficient" phosphorus and nitrogen. These results confirmed previously documented findings of the general state of the soil in this region of Uganda. The general findings were communicated to the farmers present at a village gathering, but individual results were reported to KEA to be interpreted and communicated to farmers on an individual basis. The Team communicated to the farmers that soil is a complex living organism that needs to be cultivated like a crop. The Team's findings combined with their research indicate that the soil would benefit from continuing to be enriched with green compost and animal manure over time[174].

Samples taken from each field location were aligned based on color from light red to dark brown to provide a visual representation of the differences in soil (see Figure 11).

Figure 11 | Soils of Kasejjere and Banda



The three soils on the left are from the community of Banda and use chemical additives to supplement their soil. The remaining soils are from Kasejjere. The amount of organic material in the soil contributes to the shade (red to black).

6.2.4 | Baseline and Translation

Soil fertility is a concern for both conventional and subsistence farmers, but their measurement tools differ. Conventional or industrial farmers often have the means to perform soil quality tests and use commercial methods to adjust the pH and nutrient levels. Out of financial necessity, smallholder farmers, particularly in the developing world, typically rely solely on observation and personal experience to inform any adjustments they attempt to make to their soil. Aside from crop performance, they use the color, feel, the moisture content of the soil, or the performance of indicator weeds, to judge the soil's fertility. Given the gap in measurement methods, the Capstone Team sought to understand whether it was possible to correlate local empirical methods with conventional methods.

Baseline

The *Rapitest Soil Test Kit* by *Luster Leaf* and the color gradient scale for the presence of the nutrients nitrogen (N), phosphorus (P), and potassium (K) was used in the sampled soil, as well as pH. The results of the 16 soil tests are shown in Section 8.4.3.

The test kit offers a descriptive scale of "*Surplus*," "*Sufficient*," "*Adequate*," "*Deficient*," and "*Depleted,*" which are based on United States Department of Agriculture's (USDA) calibrations for optimal soil nutrients. However, it does not offer an indication of the nutrient's parts per million (ppm) measurement in the soil. This table also details the relevant ppm measurement as disclosed in a private communication with the manufacturer (See Section 5.3.1 for more details). The test results showed that many of the samples had *depleted* or *deficient* levels of nitrogen and phosphorus. The relevance of this test and its results given the testing region is discussed below.

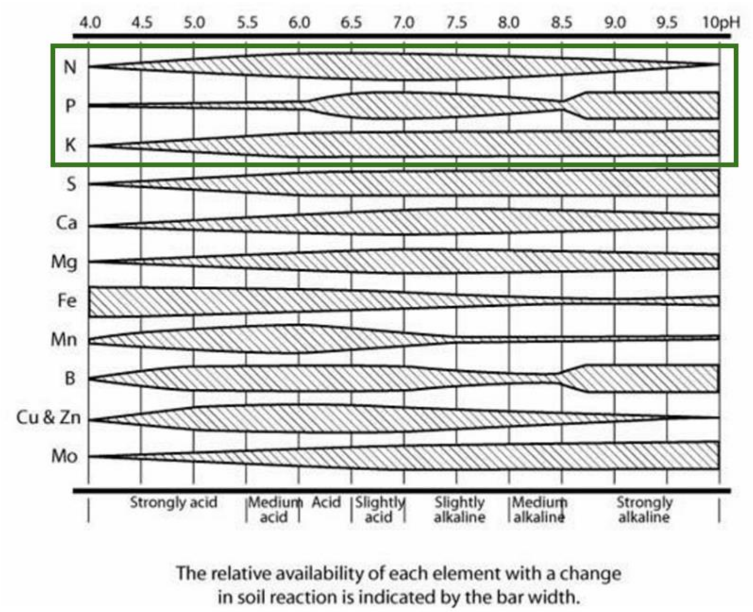


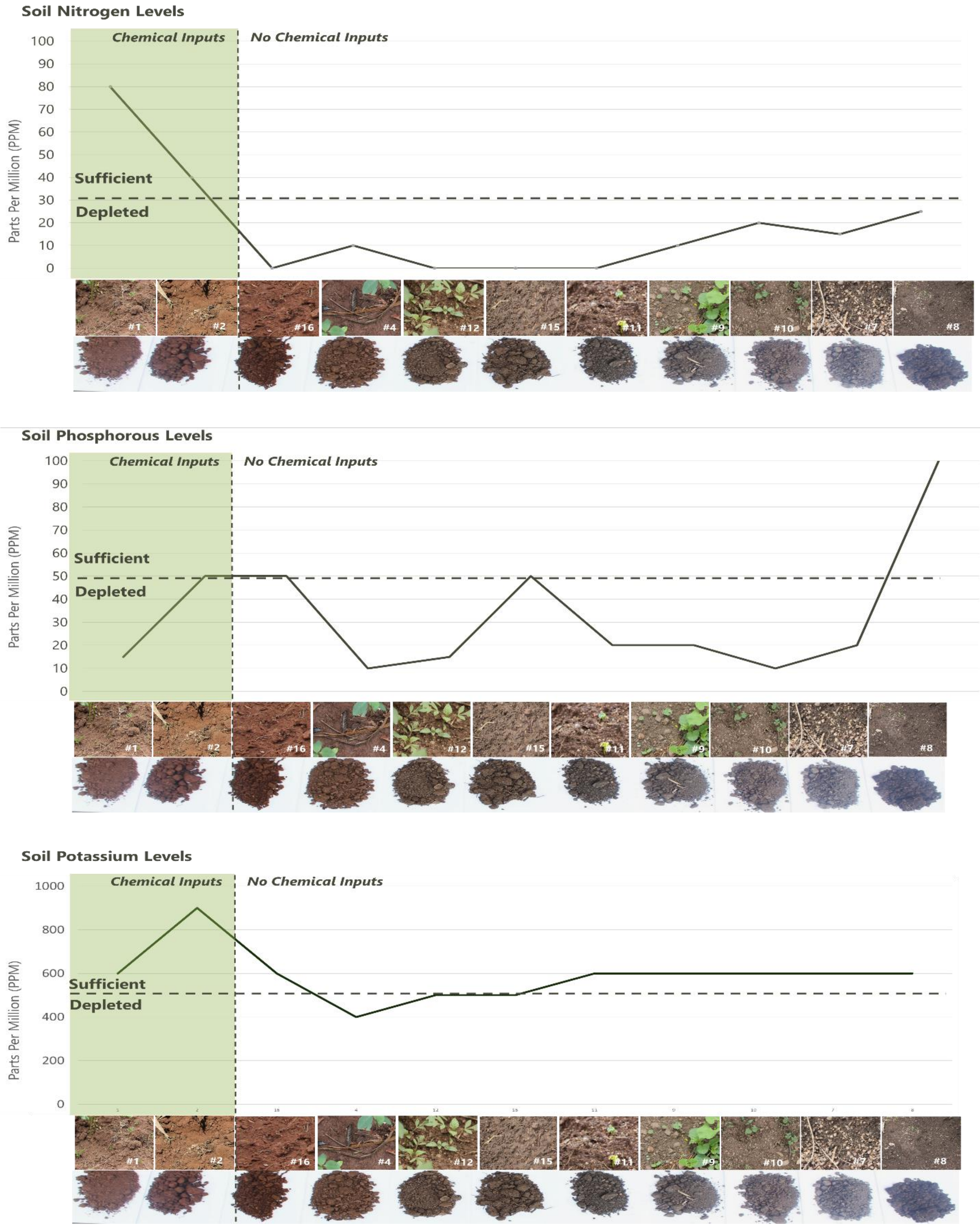
Figure 12 | Effects of Soil Reaction on Plant Nutrient Availability[175]

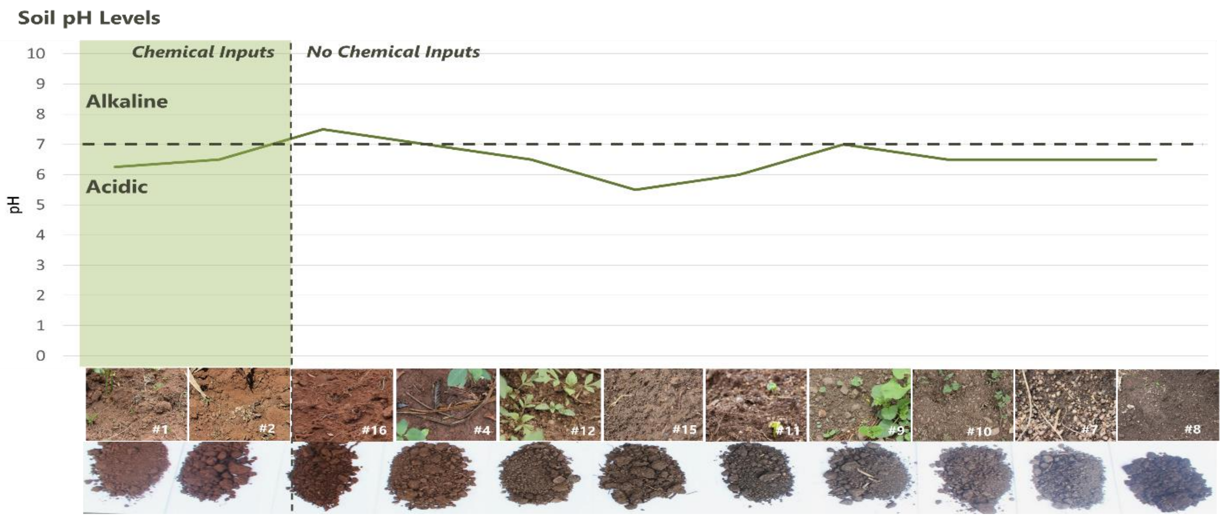
Given the pH levels measured in Kasejjere, Uganda, the presence of the other tested nutrients (N, P, K) should not be adversely affected according to the below chart (Figure 12). That is, given that the Kasejjere soil samples indicated an average pH level of 6.0 - 6.5, or slightly acidic - acidic, N and K nutrient availability should be strong, and P availability may be lower but still present.

Validation and Correlation

In Kasejjere, the Team observed the deep-red, clay-like soil of the roads and residents' yards, which represents the natural state of soil without any improvements. As soil samples were collected from different farm plots, the Team observed a seemingly improved soil quality based on deepening brown colors, weight and workability of a palm-full of dirt, and the presence of organic matter. Test results concluded a beneficial presence of essential nutrients in some of the darkest soils, particularly those soil samples that were taken close to nitrogen-fixing plants. But the test results also indicated the problematic nature of the local soil and practices that included little if any natural fertilizer application (in the form of green mulch or animal manure). Many soil samples were found to have deficient or depleted levels of nitrogen and phosphorus. Importantly, the farmers were aware that the soil lacked productivity capacity, labeling it "poor" quality, but were unaware that the problem might be attributable to a lack of essential nutrients. Figure 13 shows the relationship between the observed color scale and the conventional soil test results for the three essential nutrients and pH.

Figure 13 | Soil Testing Results and Color Comparison





Based on these results, it seems feasible to correlate empirical and conventional methods of measurement to an extent, though the precise factor of soil fertility may not be detectable with empirical observation.

Implications for Kasejjere

The context research into the natural state of Uganda soil underlines the significant progress farmers in Kasejjere have achieved for building up soil fertility. Leveraging inexpensive soil testing kits and uncovering well-documented studies on the state of soil in this region of Uganda confirmed a general baseline from which the Capstone Team could draw greater conclusions. Importantly, transferring this knowledge to farmers can empower them, aiding them in their efforts to move beyond the time and resource-consuming trial and error farming methods typically used. Many farmers noted the soil was “poor” or “bad” based on the performance of their crops. Understanding the deficiencies of nitrogen and phosphorus will take some of the guesswork out of crop selection. Either the farmer can select crops that will grow well in the existing soil conditions, or adjust the soil to grow the crops they wish to cultivate. It was noted that farmers who use a variety of agroecological practices, including the use of organic matter composting, mulching, ground cover, no-till, and animal manure had slightly more positive results than farmers who did not employ these practices. The inclusion of nitrogen fixing plants and trees, especially when intercropped with nitrogen reliant crops like maize, should be encouraged. Crop-specific growing notes can be found in Section 8.4.1. More details on the nutrients tested for by the soil kits are found in Section 5.3.2.

Farmers work to replace soil nutrients in cultivated land to ensure the soil remains productive. Without management for soil fertility, the nitrogen, phosphorus, potassium and other trace elements necessary for growth will become exhausted. In Kasejjere, farmers are already working to manage their soil using intercropping, ground cover crops, green manure, mulching, and resting the land[176]. The soil test results and the initial relationships between soil color and phosphorous and nitrogen could be used build support for practices that produce darker soils.

6.3 | Water

6.3.1 | Context

Africa is vulnerable to the impacts of climate change and weather variability for many reasons that range from the absence of government assistance to lack of access to information and resources. While many producers around the world have access to physical, agricultural, economic and social resources to moderate or adapt to the impacts of climate variability on food production systems, this is not the case in many parts of Africa[177]. The 10-year average monthly rainfall for the region that Kasejjere is located in, according to the World Bank, is 110 millimeters with one primary rainy season (See Section 8.4.2 for monthly precipitation averages) [178].

Irrigation methods, water source, availability, and quality are some of the water-related concerns for the agricultural community[179]. In a developing world context, as in Kasejjere, tracking and documenting water use for irrigation is an unlikely practice as most farmers either draw water from a well to hand-water their crops or solely depend on rainwater for crop irrigation. The broader sustainable agriculture community is concerned with capturing data on water usage because such information is indicative of farm productivity and efficiency, as well as food security. Water usage data can warn of groundwater depletion, long-term climate change, and seasonal vulnerability[180].

Given the lack of technological resources for measuring water usage in developing world contexts, farmers usually recollect seasonal rainfall patterns and drought periods by memory, which is subjective and results in action based on perception[181]. If, however, farmers were to track and record weather patterns and crop productivity they could validate their observations with data, and communicate the impact of drought on harvests to members of the broader sustainable agriculture community.

6.3.2 | State of Local Knowledge

All of the interviewed farmers in the village of Kasejjere indicated that their primary method of crop irrigation was rain. Several noted that a previous harvest was reduced due to an 18-month drought. All of the farmers raised concerns over the changing weather patterns with a reduced volume and frequency of rain. Although no records have been retained, the consensus among the interviewees was that the trend started around 5-10 years ago. Farmers noted that the rainy season normally came in the winter (between December and March), and is becoming shorter, however, precipitation measurements indicate that the rainiest months of the year are April and May[182].

The community has two springs that have been used by the community for generations. One of them is situated in a granite crevice on the hill that is believed to be the water source for the area; it is most often used for animal husbandry, except in periods of severe drought when the community relies on it for household water needs. According to the farmers in Kasejjere, while this spring's water level may lower, it is believed that it never dries up, regardless of how harsh or long a drought season is. When that happens, there is an expectation of people from neighboring communities to come to draw their water from the spring as well because their own sources have been depleted. The other natural spring is located at the base of a commercial passion fruit farm that was established in 2015. The community was initially barred by the current owner of the land, but he relented due to the needs of the villagers. However, concerns were raised over Katsushaba's use of commercial fertilizers and pesticides might pollute the water. To address their concerns, the farmer created irrigation ditches adjacent to the spring as a remedy. The third water source is a hand-dug well, for which KEA obtained funding to dig. It is located near the schoolyard and is kept locked for KEA member use only. Kakembo is one of the few farmers who irrigates his crops by hand, accessing this well for this purpose.

Water from the springs and the well are primarily used for household use and is transported by hand in plastic containers known as jerry-cans. Water used for cooking and drinking is boiled before use. The community believes that the water is healthy because no water-borne disease has occurred in the village.

While all farmers expressed grave concerns about access to water, citing reductions in rain volume and frequency, few of the interviewees practiced any form of water retention methods, such as terracing, irrigation channels, crop cover or mulching. The few farmers who employed rain catchment used the collected water for household use and brick fabrication (in the village of Banda); none described using it for irrigation. The cost of rain barrels was noted to be a deterrent. However, a large cistern at the KEA schoolyard was on its side and unused. Following a significant drought in 2011, and the current ongoing drought, more farmers are willing to consider reforestation attempts with the belief that the trees "bring rain" by creating microenvironments.

6.3.3 | Test Results

The Team took water samples from all three local sources in Kasejjere. The water was tested using the *Complete Water Analysis Test Kit* by *Test Assured* for minerals and the presence of nitrates or nitrates, bacteria, and pesticides. The water samples were also tested for mineral composition and chemical elements. The tests were conducted on-site by dipping test strips into the water samples. A color change indicated the approximate level of the tested mineral. The bacterial tests were left to sit for 48 hours, per instructions.

While the Team recognized that not all sustainable farming communities, particularly in developing world contexts, may have access to technological testing, this approach was chosen as a means to understand better the water sources' relationship with the local soil, including whether fertilizer or waste runoff or other aspects of soil erosion might be problematic. The Field Guide also includes test examples, such as turbidity tests, that may be applicable in differing circumstances, but only an individual community assessment — its farming, health, or other challenges — can aid in determining appropriate test and documentation considerations.

The three tested water sources included the KEA hand-dug well by the school; the natural spring northeast of the school; and the natural spring near the passion fruit farm. The test results are provided in Section 8.4.3.

6.3.4 | Baseline and Translation

Baseline

The *Complete Water Analysis Test Kit* provided results as either positive or negative for many of the minerals and contamination tests. Documentation on the thresholds for positive results was obtained from *Test Assured*, the manufacturer. The results and a brief description of what a positive result means for the water source are listed below:

Bacteria: A positive result signifies that total coliform bacteria are present. Total coliform is an "indicator" organism, meaning testing for it can be a reasonable indication of whether other pathogenic bacteria are present. Coliforms come from the same sources as pathogenic organisms that cause disease. Coliforms are relatively easy to identify, are usually present in larger numbers than more dangerous pathogens, and respond to the environment, wastewater treatment, and water treatment similarly[183].

Kasejjere results: Negative (0), Positive (3)

Pesticides: A positive result indicates the detection of atrazine and simazine, two herbicides, at or above the United State Environmental Protection Agency (EPA)'s maximum allowable contaminant level (atrazine: 3 ppb; simazine: 4 ppb)[184]. Both pesticides are banned by the European Union. Atrazine is produced by Syngenta, which has a huge presence in Uganda[185].

Kasejjere results: Negative (3), Positive (0), Inconclusive (1)

Nitrates and Nitrites (Nitrogen): Positive results indicate nitrate/nitrite nitrogen over 10 ppm (10 mg/l). Concentrations of around 10 ppm can cause health problems in children under six months but are considered a low health threat to older children and adults. Contamination comes from fertilizer additives and human and animal waste leaching into groundwater[186].

Kasejjere results: Negative (3), Positive (0)

Alkalinity: The threshold for alkalinity is 20 milligrams per liter (mg/l). Alkalinity measures water's ability to resist changes in acidity (pH), which can reduce the impact that harmful pollutants have on water quality[187].

Kasejjere results: Low Alkalinity (0), High Alkalinity (3)

pH: Water kit tests for pH between 5 to 8.5. A pH of less than 7 indicates acidity, whereas a pH of greater than 7 indicates a base. The water's pH level depends on how much of essential nutrients (phosphorous, nitrogen, and carbon) and heavy metals (copper, iron, lead) are present in the water. pH also determines how much of each nutrient aquatic life can use it and how concentrated heavy metals are. In the case of heavy metals, the degree to which they are soluble determines their toxicity. Metals tend to be more toxic at lower pH, as they are more soluble[188].

Kasejjere results: Acidic (3), Base (0)

Lead: A positive result indicates lead levels over 15 parts per billion (ppb). 15 ppb is the US EPA max safe level of lead in drinking sources[189].

Kasejjere results: Negative (3), Positive (0)

Hardness: Under 50 ppm is considered "soft" water. "Hard" water has high concentrations (50 ppm or more) of dissolved calcium and magnesium in the water. Higher water hardness leaves a feeling of residue after using soap. In hard water, soap reacts with the calcium, which is relatively high in hard water, to form "soap scum." When using hard water, cleaning requires more soap or detergent[190].

Soft water (3), Hard water (0)

Iron: Positive results indicate iron levels above 0.3 mg/l. Higher iron content results in a metallic taste; discolored beverages; yellowish stains and can stain laundry[191].

Kasejjere results: Negative (1), Positive (2)

Copper: Positive result indicates copper levels above 1.3 mg/l, which the EPA limits. Higher copper content gives drinking water has a bitter metallic taste[192].

Kasejjere results: Negative (1), Positive (2)

Chlorine: Positive results indicate chlorine levels above 4 ppm. For context, 3 ppm is the maximum recommended limit in the US for pools (0.5-3 ppm). At 5 ppm, people typically notice that their skin, hair, and eyes are irritated or burning[193].

Kasejjere results: Negative (3), Positive (0)

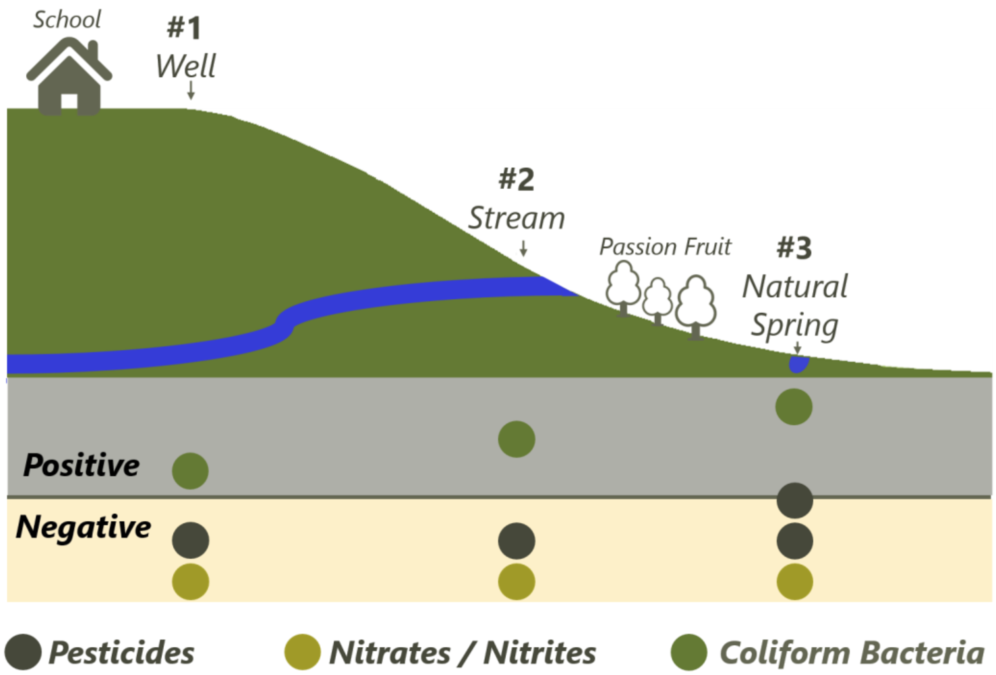
The water tests conducted by the Team are not comprehensive. However, they offer an inexpensive option to measure certain elements in the water. Additionally, the positive and negative test results are based on standards established by the EPA, which has set limits based on public health and safety[194]. Thus, there is a context-specific aspect to the results of the water tests run on-site as the EPA's guidelines set the levels that were considered safe with industry input.

If additional water testing is done in the community, the Penn State University Agricultural Extension offers excellent resources for understanding the test results[195].

Validation and Correlation

Establishing a relationship between empirical observations and conventional testing of water quality was limited, due to the small sample size and the lack of physical attributes for water quality issues. Based on the geographic location, farmers' observations of fertilizer and pesticide use, and the test results, there is some potential relationship that can be further explored. (See Figure 14) The presence of coliform bacteria, but the farmers' reports of no one getting ill, does not suggest a relationship between the local and conventional knowledge for this indicator.

Figure 14 | Geographic and Water Test Result Comparison



No presence of nitrates or nitrites was found at any of the water sources. All sites tested positive for coliform bacteria, however, the reaction times for results increased the further downhill the test was conducted. The natural spring, which is near where a farmer has started to spray a crop of passion fruit, had one inconclusive result.

Implications for Kasejjere

Nitrates, nitrites, and pesticides were not found at any location, which supports farmers' assertions that they do not typically use chemical additives. However, one location, downhill from a passion fruit field that is sprayed with commercial pesticides, initially produced an inclusive pesticide test result. The Capstone Team ran a second test, which produced a negative result, but the Team has concerns about increasing contamination[196]. The inconclusive nature of the test results support the farmers' concerns and provide justification for finding ways to reduce runoff from the passion fruit field in the future. The positive bacteria tests indicate that there is the potential for contamination from animal or human waste in the water sources. However, farmers did not report illnesses in the village. Thus, if there were a greater interest in understanding the types of bacteria present in Kasejjere's water sources, more comprehensive testing would be required.

To maintain the limited runoff contamination, it is important to consider ways to address soil nutrient deficiencies and pest issues without the use of chemicals. This modification could be done by documenting and sharing practices currently used by those farmers whose soil is more nutrient-rich.

6.4 | Biodiversity

6.4.1 | Context

Uganda has a relatively small geographic area, in relation to other countries in Africa, yet due to the intersection of several biomes, it has one of the continent's highest levels of biodiversity. According to the Wildlife Conservation Society, Uganda hosts approximately half of Africa's bird species—ten percent of the world's— is the second richest country in Africa for mammals; and seventh richest in higher plants. However, this abundant natural capital is being threatened by a variety of factors such as land use, mining and other human activities[197].

Land use is the most pronounced threat to Uganda's biodiversity. Demand for land is being driven by the needs of the country's rapidly growing population. Forests are being clear-cut for timber and agriculture, and the extraction industry is exploring the country for minerals, oil, and gas. Today, Uganda's landscape is one where natural habitats are shrinking islands between farms, mines and other human activity. Biodiversity loss is not factored into development plans as the country's leadership looks for avenues of economic growth and international groups have grown concerned about stemming the destruction of natural habitats that leads to the extinction of unique species. Biodiversity surveys and conservation planning are two tools used to identify species and determine areas for conservation efforts, but awareness building is key to those efforts[198].

6.4.2 | State of Local Knowledge

Biodiversity is widely used by international stakeholders as a measurement of ecosystem health. However, the concept of biodiversity is not always intuitive for farmers who are focused on the practical day-to-day demands of cultivation and harvesting. As their livelihood is dependent on protecting their habitat, including soil, water, plants and pollinators, they understand biodiversity as the way these ecosystem services impact their output. Therefore, there is an opportunity to capitalize and build on that understanding and engage farmers in protecting biodiversity. These efforts can include limiting or eliminating chemical inputs, intercropping, reforestation, and the creation of microenvironments. Those who live closest to the environment witness firsthand the changes occurring over time. They can have a positive impact in protecting it.

A baseline for biodiversity can be extracted from farmer experiences and observations through interviews. The interviews conducted by the Capstone Team in Kasejjere revealed that farmers support local biodiversity when they actively preserve natural conditions. For example, many years ago, concern about the disappearance of natural forests, KEA started a reforestation project and tried to teach farmers about the benefits of having a standing forest and get volunteers to willingly leave part of their land alone and let trees come back. At first, they had very few people interested. Few farmers saw value in not using part of their field for cultivation. However, a severe drought in 2011 highlighted the benefits of the reforestation project such as the preservation of moisture in the soil, minimization of high temperatures, the attraction of birds, insects and pollinators, stormwater retention, protection from heavy winds and rain, among many others. However, farmers near these areas reported less impact from the drought (Kakembo, Bam). Since then, farmers in Kasejjere have recently started adding more trees to their land.

Crop Diversity

One theme that was raised through many of the interviews was the importance of raising different varieties of the same crop, such as different types of beans, potatoes, yams and bananas. There were several reasons for this practice, including the differing time frames to maturity, different resource needs, pest resistance, and ultimate use of the crop. However, specific names of those different varieties and whether or not they were native to the region were questions more difficult to get answers. Only three crops were mentioned as being native to Kasejjere, a particular variety of amaranth, a 100-year-old mango tree, and passion fruit[199]. It is difficult to ascertain if this lack of knowledge about native plants was a knowledge gap or translation barrier.

Some farmers practiced intercropping by pairing crops that helped improve the output. For instance, one pairing was maize and beans, which need to be planted at different times. Maize depletes the soil of nitrogen while beans replenish it. However, beans have to be planted first because they are smaller than maize and would be shaded by the taller crop. Although farmers may not have been aware of this symbiotic relationship with regard to nitrogen, they understood the importance of pairing them together[200]. Another crop pairing observed by the Team was banana trees and coffee, as the banana trees create shade for the coffee plants.

One of the members of the community, Kakembo, harvests and preserves seeds from crops. As a former conventional commercial farmer, he learned the knowledge of seed keeping from his grandmother and places emphasis on keeping heritage and drought-resistant varieties. He provides the seeds and farming advice to anyone in the community who is interested, for free[201].

Reforestation and Land Cover

The *Half + Half* reforestation project is intended to address several issues, including increased biodiversity, but the farmers did not speak about the project in those terms. They discussed the reforestation as the creation of microenvironments to attract moisture, in their words, "to bring rain." This belief has increased interest in planting trees, especially along the borders between properties. This project was the first initiative of KEA, and some of the first reforested areas have matured over the last 10-15 years. The Capstone Team observed higher levels of animal, bird and flora diversity in these areas, as well as more amenable temperatures. Kakembo also runs a tree nursery where he raises saplings from scratch to be used for the reforestation project. One deterrence noted by Geofrey Kizito, a farmer in Kasejjere who is affiliated with KEA, is that the saplings need a great deal of attention and water for the first 4-5 years.

Livestock and Wildlife

Some farmers raised livestock, including goats, cattle, pigs, and chicken. Sheep were mentioned during the interviews but not observed. A handful of dogs were seen in the village, but they are not kept as pets. The Team also saw additional wildlife such as rabbits, butterflies and a variety of birds, but was unequipped to identify the species.

While farmers in Kasejjere noted some variety of pests, the majority of farmers interview did not bring up pests and none of them appeared to employ integrated pest management techniques aside of using wood ash[202]. Among the farmers that did, insects and plant infestations were the greatest concern. Two farmers in the community, Kakembo and Salongo Kamya Jackson, discussed their issues with pests extensively in relation to the challenge of pest management without commercial pesticides and regarding pests affecting his coffee crop, respectively. Termites were seen as beneficial for most crops because they added nutrients to the soil and helped with soil aeration, and they are believed to only attack maize. Additionally, a variety of white ants are harvested in the winter when they are roasted and eaten[203].

Soil samples taken on site showed very little insect presence, and it was known that worms were not common in the soil (cite John). However, the Team did observe other insect life, including millipedes, grasshoppers, and butterflies. Many farmers mentioned that the area was not known for mosquitoes that carry malaria, and it is believed that if anyone in the village gets the disease, that they got it elsewhere[204].

6.4.3 | Test Results

While on site, the Capstone Team did not perform any specific tests for biodiversity, due to time and resource constraints. However, the Team reviewed the results of the interviews and listened for keywords to get an understanding of what biodiversity means to the farmers in Kasajjere. As the questions posed by the Team targeted farming practices, the focus was on the bigger picture of farming and the farmers were not specifically asked questions about biodiversity.

6.4.4 | Baseline and Translation

Baseline

The results shown below were taken from interviews, and the key understandings or themes brought up by the farmers while discussing their farming practices. It is worth noting that most of the interviewed farmers are subsistence farmers, who are more concerned with their livelihood. These plants and animals can serve as a baseline of biodiversity for the community.

Crops Mentioned	Animals Mentioned	Observed Onsite
• Bananas • Maize • Beans • Coffee • Cassava • Eggplant • Sweet potato • Irish potato • Tomato • Cabbage • Passion fruit • Amaranth • Groundnuts • Watermelon • Guava • Onions	• Goats • Cattle • Pigs • Chickens • Cats • Dogs	• Birds • Crickets • Butterflies • Millipedes • Ornamental flowers • Fig tree

Validation and Correlation

The interviews revealed that what farmers observe as markers for aspects within the other key categories - such as soil health and crop security - can also reflect biodiversity. Farmers are already supporting local biodiversity when they preserve the natural conditions that produce these vital markers. For example: after a significant drought, farmers saw clear benefits from reforesting their lands - more amenable temperatures, pollinators, and retained water in the soil. Figure 15 shows the link between key interview themes and observations in the test case.

Figure 15 | Comparison of commonly mentioned biodiversity inputs and benefits with onsite observations

Photo Credit: Leticia Neves, Columbia University, 2017

Implications for Kasejjere

Leveraging documentation of the varieties of crops planted, livestock kept, and wild animals, insects, and plants in their natural habitats would help the community build a better baseline for the current state of biodiversity in the area. Being able to communicate the issues that led to the decline of the native passion fruit variety, for example, and the community's understanding that the decline can be tied to the loss of shade from trees would be of value to global stakeholders interested in conservation. This kind of experience, along with Kakembo's extensive knowledge on seed keeping practices, should be documented to ensure that expertise is not lost and can be shared with other farmers in the community and sustainable agriculture actors. This information could be key for engaging with the global sustainable agriculture community and expanding economic opportunities.

6.5 | Productivity

6.5.1 | Context

Productivity was added as a metric category after the trip to Kasejjere, as some farmers indicated strong interest in accessing new market opportunities[205]. As farmers seek to sell a portion of their crops, they must become better versed in the common language of agricultural markets. An ability to understand and speak to their current yields, engage in price negotiations and navigate the ever-changing consumer demands, cooperative organizations, and related financial markets, particularly credit extension practices, is necessary to empower farmers[206]. The sustainable agriculture community identifies productivity as a metric for the reasons just mentioned, but also to understand the relationship between productivity and environmental sustainability[207]. Production-related measurements including crops harvested to land area, seed count, or irrigation volume, for example, are relevant ratios for identifying correlations with environmental outcomes such as loss or gain in soil fertility, soil erosion, etc[208]. An accurate measure of land area is critical to the success of productivity tracking.

6.5.2 | State of Local Knowledge

Currently, smallholder farmers in Kasejjere are not maintaining measurements, including acreage, yield, or results year over year, even on the commercial farms. Farm plot size is staked out using reference points: homes, trees, including saplings placed as markers, demarcate a family's land area. Farmers gesture to these markers and explain the measurement of their land area on a relative basis, but typically do not know the exact measurement of their land area. The map in Figure 16 was drawn by Kakembo to represent the village, an illustration of how he understands the location of his home and farm plots relative to the community around him.

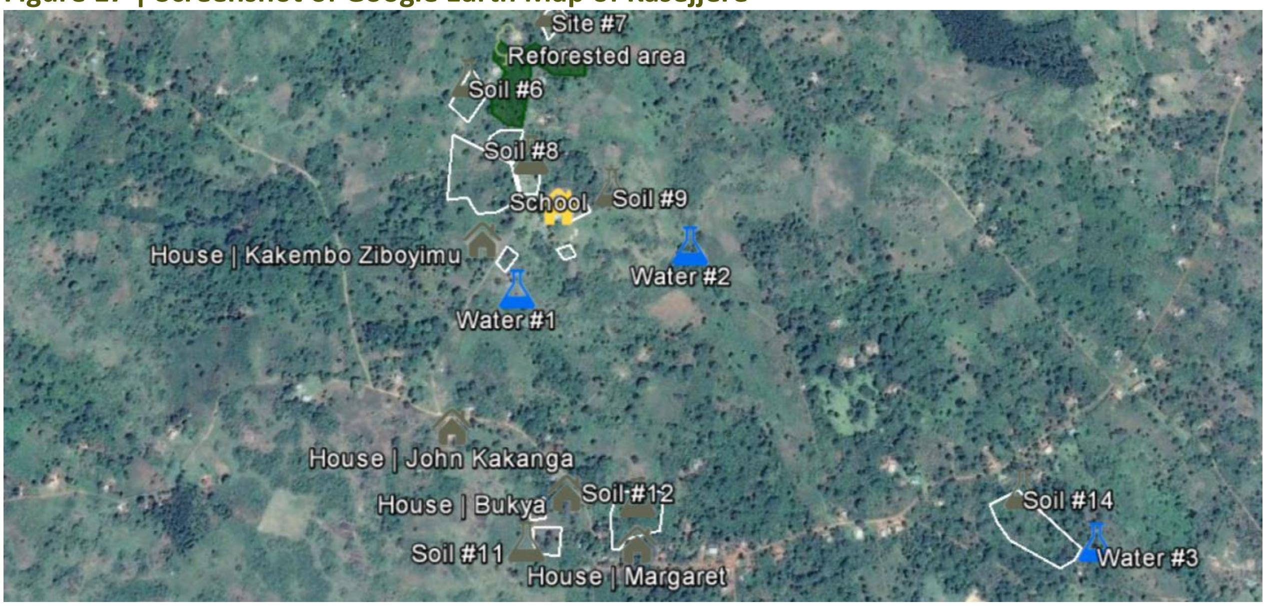
From interviews, the Team learned that yield is also described on a relative basis. That is, farmers, explain production levels by saying, "this crop did well last year," or "that crop isn't growing well this year." Such farmer observations inform the "trial and error" approach discussed in Section 6.2.2 "State of Local Knowledge."

Figure 16 | Hand Drawn Map of Kasejjere, by Salongo Kakembo Ziboyimu

6.5.3 | Test Results

No tests on productivity were carried out in the field. However, using the photos taken on-site and recollections of the Team in the field, a Google Earth map of Kasejjere using satellite data from October 2016 was produced. The Google Earth map gives an overview of the community layout and identifies the locations of the farm plots the Team visited to conduct interviews and conventional tests (See Figure 17). As farmers had just planted their fields for the season when the Team visited in March 2017, some of the fields that the Team visited do not appear at the time the satellite image was recorded, making the approximation of field boundaries challenging. Section 5.2.4 contains directions for recording GPS coordinates that could be used to make more accurate field boundaries and ultimately measure the area of fields remotely.

Figure 17 | Screenshot of Google Earth Map of Kasejjere



This map was developed using a combination of aerial imagery and the Team's recollection. The full database is accessible from Section 8.1.4.

6.5.4 | Baseline and Translation

Baseline

Farmers reported that less rain was one of the primary drivers for reduced harvests. However, not enough data was gathered during the interviews to provide context for the exact years that farmers experienced less rain, which could have otherwise been compared to the World Bank's precipitation data to confirm the anecdotal evidence. There was also not enough time, nor information, to speculate on harvest size from season to season.

Validation and Correlation

As no tests were conducted in the field, validating and correlating farmer observations were not possible. However, the Google Earth mapping exercise demonstrates that it is possible to combine farmers' knowledge of the local area with mapping technology to produce a geographic representation of the community. Further, time-based data collection on planting (seed count and growing periods, for example), harvest quantities, and rainy periods could all enhance the local awareness of productivity relative to land area. Then, a more comprehensive assessment could be shared with the broader sustainable agriculture community.

Implications for Kasejjere

Collecting productivity measurements would provide a historical record to track harvest trends and could be used to forecast future outputs or successful crops. This application could be critical in helping the farmers that expressed an interest in increasing their market participation. Customers, including the middlemen and larger buyers, are looking for means to reduce the risk of receiving inconsistent crop volumes[209]. Additionally, maintaining records for harvest quantities relative to farm plot size can help farmers understand how efficient their farms are. Such knowledge has implications for soil fertility, seed quality, etc. Over time, combining such awareness with increased knowledge about agricultural markets could improve farmers' profitability.

6.6 | Recommendations

The Capstone trip to Kasejjere provided rich details about the local knowledge of the smallholder farmers that work with A Growing Culture. These details were instrumental in the development of the Environmental Benefits Toolkit and also provided the Team with a more nuanced understanding of the farmers' concerns and goals. This section contains a summary of requests from the community and key takeaways from the experience not found elsewhere in the test case.

6.6.1 | Requests from the community

During the Team's time in Kasejjere, members of the community approached them with the following requests:

- Alternatives to intermediaries for produce sale, to have more control over pricing.
- Ways to make organic farming easier/less manual.
- Ways to manage pests without spraying pesticides.
- How to get access to rainwater catchment and irrigation equipment.

- How to package and sell organic seeds in the market to be able to compete with the other seed vendors on the market.
- How to preserve, package and market dried fruits to an international market.
- How to pack and distribute more of the amaranth products.
- How to gain knowledge or training on activities that improve resilience to climate change, like the beekeeping workshop.
- How to get funding for things like buying seeds and building the school.
- How to encourage people to visit the community.
- How to farm organically.
- How to deal with unpredictability of rain/drought or how to make it less unpredictable.

Status of External Projects in Kasejjere

Understanding the context of the community and working to connect projects to farmers' needs and wants is critical to a project, whether it is a new practice or this documentation proposal. Learning from other projects that have been completed in the community made help improve the success of future ones.

SUCCESSFUL
Beekeeping: Initially launched through a workshop hosted by A Growing Culture and featuring a knowledgeable beekeeper from Uganda, beekeeping has been very successful within Kasejjere. Farmers nearby believe the bees helped increase harvests while herbal mixtures made from honey are used to treat animals, which saves vet expenses. The honey is also sold at nearby markets to generate income. As a program, this meets the farmers' requests, as reported by A Growing Culture: a desire for a source of income not significantly impacted by rainfall, as to help diversify earnings[210].

UNSUCCESSFUL
Human waste as fertilizer: The Team noted a cultural understanding that people in Uganda will not eat or buy produce grown using human waste fertilizer.
Rainwater collection: A donated cistern was seen lying on its side, unused.
Computer Lab: The lab was established by KEA for farmers to research farming methods and practices but the hours in which it operates and the fact that it is located far away from farms create obstacles to frequent visits.

6.6.2 | Key Takeaways

Kasejjere has some farmers with a significant amount of knowledge of sustainable farming techniques and who are interested in accessing additional resources for themselves and their community. Helping these farmers quantify their knowledge through documentation and translation could support their goals of participating more in the sustainable agriculture community.

The students in the school provide an unleveraged resource for passing on sustainable farming techniques, as well as documenting practices in the local language, record keeping, and translating farming documentation from English to Lugandan, the local language. This service would help the community and could be used as a teaching tool for the students. As the local school curriculum includes mathematics and English lessons, incorporating measurement activities (mathematics) and documentation/recordkeeping (English), students can practice their lessons using relevant activities that can be are useful to the community. Establishing connections between school work and the community could also potentially increase interest with the next generation in sustainable farming.

7 | CONCLUSION

A Growing Culture has developed an effective approach to preserve and share farmer-led agricultural innovation and documentation from smallholder communities around the world. These success stories have aided them in their advocacy of farmers. Our Team looked for ways to aid them in this mission. Our off-site research and firsthand experience in Kasejjere indicated that farmers who want to confirm that their agroecological methods are more beneficial than commercial farming practices eagerly seek information and knowledge This Capstone project developed an approach to capture measurements important to both farmers and the sustainable agriculture community, and to identify resources to capture them consistently over time.

Documenting the progressive environmental benefits of farmer innovation will aid A Growing Culture and their on-site partners in the communities where AGC works with information exchange. Creating a baseline and taking periodic measurements will identify practices that are especially beneficial to a particular region, reducing individual trial and error methods that waste limited resources. Identifying environmental benefits, such as creating microenvironments with reforestation, can also engage farmers who may be hesitant to experiment, or who are considering commercial agriculture practices that may have a negative impact on the soil and water. The tools developed will help with farmer advocacy and empower communities to tap into resources from sustainable agriculture initiatives. A Growing Culture has a unique position in this space to offer support for farmers looking to access new resources and opportunities, but do so with their own voice, building off A Growing Culture's existing documentation and knowledge sharing expertise.

Finally, the Capstone Team would like to thank A Growing Culture, the Kikandwa Environmental Association who graciously hosted Team members onsite and acted as our guides and translators, and most especially the farmers of Banda and Kasejjere in Uganda, who took time to share their knowledge and experiences with our Team. Our project would not have been possible without their combined hospitality.

8 | APPENDIX

8.1 | Supplemental Documents

The Supplemental Documents are resources hosted in Google Drive that support the work done for the test case in Kasejjere as well as the development of the documentation and translation approach for A Growing Culture.

8.1.1 | Literature Review

Digital database of international metrics/indicators, Uganda-specific research, quantified sustainability benefits of agroecological methods, and curriculum resources. This is intended to support any follow-up research on the topic of environmental quantification and metrics.

It can be accessed here:
https://drive.google.com/open?id=0B95u_vAeTXPsZURXTEh6cWo3dXc

8.1.2 | Image Database

The Image Database contains images taken during the five-day trip to Kasejjere. It has been organized into logical topics to allow for easier navigation.

It can be accessed here:
https://drive.google.com/drive/folders/0B82F4Rc3MN3cZ09POE5TZDdrVTg?usp=sharing

8.1.3 | Recording Database

The Recording Database contains all the recorded material from calls and onsite interviews with farmers in Kasejjere. It also contains a recording of the final presentation.

https://drive.google.com/open?id=0BzXah9PICp1zUjlLM0RmUllwSVE

8.1.4 | Google Earth Database

The Google Earth Database contains all the information captured in the Google Earth-based map of Kasejjere, developed after the Team's visit. Downloading the program is required to view the database, but Google Earth can be freely downloaded from here. It is not recommended that this mapping is done on location in communities, however, as the program requires significant electricity compared to other computer programs, based on the Team's experiences.

https://drive.google.com/open?id=0B95u_vAeTXPscGFEaEZnSnoxUHM

8.2 | Global sustainable agriculture community review

	Entity	Agro-chemicals	Air Quality	Climate Change	Biodiversity	Energy & Greenhouse Gases	Land Use	Livestock	Soil quality	Water Quality	Water Use	Production	Waste Management
Sustainable Agriculture Initiative	Industry Group	●		●	●	●			●			●	
Root Capital	Investor	●		●	●	●					●	●	
Global Impact Investing Network	Nonprofit				●	●	●	●	●			●	●
World Resources Institute	Nonprofit	●		●			●		●	●	●		●
Rainforest Alliance	Nonprofit				●				●	●			●
OECD	Intergovernmental	●		●	●	●	●		●	●	●	●	
Sustainable Agriculture Network	Nonprofit	●		●	●	●	●		●	●	●	●	
One Acre Fund	Nonprofit	●		●	●	●			●	●	●	●	
Environmental Performance Index	Multi-stakeholder	●		●	●	●	●	●	●	●	●	●	
Stewardship Index for Specialty Crops	Multi-stakeholder	●			●	●			●		●		
Field to Market	Industry Group	●			●	●	●		●		●	●	
Unilever	Company	●			●	●		●	●	●	●	●	●
Pepsi, Co	Company	●	●		●	●			●	●	●	●	
Landscape Fund	Intergovernmental	●			●	●	●		●		●	●	

8.3 | Kasejjere Smallholder Farmer Profiles

FARMER ASSESSMENT SUMMARY
MARCH 2017

1 ………… Frank Alideki
2 ………… Rogers Tamale
3 ………… Omolo Postiano
4 ………… KEA Resource Center
5 ………… Leonard Buuma (Beekeeping)
6 ………… Nakanwagi Correti
7 ………… Hillary Bam Muburi
8 ………… Salongo Kakembo Ziboyimu
9 ………… Leonard Buuma
#10 ………… John Kaganga
#11 ………… Joseph Bukya
#12 ………… Margaret Nabatanzi
#13 ………… Steven Kiranda
#14 ………… Simon Katsushaba
#15 ………… Geofrey Kizito
#16 ………… Jackon Salongo Kamya

Farmer Identification: #1

Farmer Name: Frank Alideki

Number of People that Work on the Farm: 1

Farm Size: Approx. 1 acre(s) (Other plot(s?) nearby)

Plot Description: Slight slope; Broad sun exposure

Crop(s): Beans

Unsuccessful Crop(s): N/A

Farming Practices:
- Cash Crop/Subsistence: Cash Crop (Beans)
- Mulch/No Mulch: No
- Intercropping: No
- Fertilizer Use: Yes; Commercial Animal Manure (Chicken)
- Pesticide Use: Yes; Commercial insecticide
- Irrigation (by Hand): Yes

General Observations:
- Will shift crop areas if land becomes less fertile
- Rested the plot, tested for 3 years prior to current crop
- Drought/lack of rainfall the biggest problem

Soil Sample: Beans

Soil Color/Texture: Red soil was dry and clumpy; 1 insect seen

Results of Soil Test(s)

Location: Bean Crop
- pH: 6 - 6.5 (Acid - Slight Acid)
- Phosphorus: Deficient - Adequate
- Potassium: Sufficient
- Nitrogen: Surplus

Farmer Identification: #2

Farmer Name: Rogers Tamale

Number of People that Work on the Farm: 1

Farm Size: Approx. 0.5 acre(s)

Plot Description: Slight slope; Broad sun exposure

Crop(s): Banana

Unsuccessful Crop(s): N/A

Farming Practices:

- Cash Crop/Subsistence: Cash Crop (Banana)
- Mulch/No Mulch: No
- Intercropping: No
- Fertilizer Use: Yes; Human waste as base for planting
- Pesticide Use: Yes; Commercial insecticide
- Irrigation (by Hand): Yes

General Observations:

- Drought/lack of rainfall the biggest problem

Soil Sample: Banana

Soil Color/Texture: Soil was drier than Farm #1, deep red in color, termite mound nearby provided only insects observed

Results of Soil Test(s)

Location: Banana Tree

- pH: 6.5 (Slight Acid)
- Phosphorus: Sufficient
- Potassium: Surplus
- Nitrogen: Sufficient

Farmer Identification: #3

Farmer Name: Omolo Postiano

Number of People that Work on the Farm: 1

Farm Size: Approx. 1 acre(s)

Plot Description: Wetland area; Broad sun exposure; Some Trees

Crop(s): Cabbage

Unsuccessful Crop(s): Eggplant, Tomato

Farming Practices:

- Cash Crop/Subsistence: Cash Crop (Cabbage)
- Mulch/No Mulch: No
- Intercropping: No
- Fertilizer Use: Yes; Commercial Animal Manure (Chicken)
- Pesticide Use: Yes; Commercial insecticide
- Irrigation (by Hand): Yes

General Observations:

- Monitors cabbage plants for pests/disease and will use chemical pesticides as needed, or after rain
- 3 pests: aphids, caterpillars and …
- Near wetlands; uses irrigation canals and watering can for irrigation
- Field is surrounded by reforestation project with pine trees

Soil Sample: Cabbage

Soil Color/Texture: Soil was very dense and clay-like; grey and heavily clumped. Note the area on slope above wetland is where they create soil-bricks used for building

Results of Soil Test(s)

Location: Cabbage

- pH: 6.5 (Slight Acid)
- Phosphorus: Adequate
- Potassium: Sufficient
- Nitrogen: Depleted

Farmer Identification: #4

Farmer Name: Angel (KEA Resource Center)

Number of People that Work on the Farm: 1 + Demonstration Use

Farm Size: Approx. 0.125 acres

Plot Description: Flat

Crop(s): Bananas, Beans, Coffee, Yam

Unsuccessful Crop(s): N/A

Farming Practices:

- Cash Crop/Subsistence: Demonstration Garden
- Mulch/No Mulch: No
- Intercropping: Yes
- Fertilizer Use: Yes; Household Compost
- Pesticide Use: No
- Irrigation (by Hand): No

General Observations:

- Demonstration garden used to test different types of plants
- Varieties of bananas are grown with varied success
- Soil quality changes from one side of the plot to the other
- Fruit trees nearby (agroforestry)

Soil Sample: Different types of plants
Soil Color/Texture: N/A

Results of Soil Test(s)

Location: Banana (Mix)

- pH: 7.0 (Neutral)
- Phosphorus: P1
- Potassium: K2
- Nitrogen: N1

Farmer Identification: #5 / Beekeeping Area

Farmer Name: Leonard Buuma

Number of People that Work on the Farm: Leonard + 1 Worker (2)

Farm Size: N/A

Crop(s): Honey; each hive produces 5-9 kilos of honey (20,000 per kg(?));
Harvest 6x per year

Unsuccessful Crop(s): N/A

Farming Practices:

- Recent addition to Kasejjere; capacity for up to 50 hives
- Hives are currently spread around the area
- Bee traps are set up to capture newly hatched queen bees; she leaves an existing hive with her contingent. Queen is transferred to new hive.
- Hives are shaded to prevent overheating; iron lid prevents water from entering, but the hives are made of wood to keep cooler
- They do not currently use the wax due to lack of technology to easily purpose it (very difficult to work with)
- Bees are not fed, but need water

General Observations:

- There are 5 other beekeepers in the area
- Can use smoke to calm them, but may make the honey taste smoky
- Bees are attracted to calendula flowers on this plot

Farmer Identification: #6

Farmer Name: Nakanwagi Correti

Number of People that Work on the Farm: 1 + Children

Farm Size: Approx. 0.25-0.5 acres

Plot Description: Slopes Northeast; Near Reforestation Area; Some Canopy Coverage

Crop(s): Banana, Beans, Cassava, Coffee, Jackfruit

Unsuccessful Crop(s): Maize

Farming Practices:
- Cash Crop/Subsistence: Subsistence
- Mulch/No Mulch: No
- Intercropping: Yes
- Fertilizer Use: Yes; Household Compost
- Pesticide Use: No
- Irrigation (by Hand): No

General Observations:
- Uses intercropping based on intergenerational knowledge
- Cleared new area at the bottom of the hill for farming
- Rainwater catchment is used only for household use
- Biodiversity: 4 bird calls, crickets, flies, butterflies
- Near "1000 acre forest" man-made to prevent overharvesting; over 10 years old, where most of the bird calls came from
- Previous harvest was poor due to drought

Soil Sample: Coffee Tree (Crop Sample #3)

Soil Color/Texture: Most soil was dark brown, held shape well; new field at the bottom of hill felt drier; organic material in soil; recently tilled

pH/Moisture Readings with Meter:
- Sample 1: pH 6 / Moisture 5.5-6
- Sample 2: pH 7 / Moisture 6
- Sample 3: pH 8 / Moisture 2
- Sample 4: pH 8 / Moisture 1.5

Results of Soil Test(s)

Location: Coffee (Bottom of Slope)
- pH: 6.5 (Slight Acid)
- Phosphorus: P1
- Potassium: K0
- Nitrogen: N1

Farmer Identification: #7

Farmer Name: Hillary Bam Muburi

Number of People that Work on the Farm: 1

Farm Size: Approx. 1.5 acres

Plot Description: Slopes Northeast; Near Reforestation Area; Broad Sun Exposure

Crop(s): Banana, Beans, Cassava, Coffee, Maize

Unsuccessful Crop(s): Banana and Beans in "Poor" Area (Lowest Elevation Point)

Farming Practices:

- Cash Crop/Subsistence: Subsistence (Some Excess Sold)
- Mulch/No Mulch: No
- Intercropping: Yes
- Fertilizer Use: Yes; Commercial, Animal
- Pesticide Use: No
- Irrigation (by Hand): No

General Observations:

- Plant maize first to germinate, then beans
- Beans need 30-35 days of rainwater before planting
- Farm slopes downhill with healthier growing conditions at the top, worse-performing soil at the bottom

Soil Sample: Coffee Tree (Crop Sample #3); Cassava (Crop Sample #2)

Soil Color/Texture: Soil was rocky and dry at the top of the hill, stonier at bottom; farmer considers it "average"

pH/Moisture Readings with Meter:

- Sample 1: pH 7 / Moisture 1.5
- Sample 2: pH 7.5 / Moisture 2.5
- Sample 3: pH > 7 / Moisture 1.5
- Sample 4: pH 8 / Moisture 1

Results of Soil Test(s)

Location: Coffee (Bottom of Slope)

- pH: 6 - 6.5 (Acid - Slight Acid)
- Phosphorus: P1
- Potassium: K3
- Nitrogen: N0

Cassava (Near Hilltop)

- pH: 6 - 6.5 (Acid - Slight Acid)
- Phosphorus: P2
- Potassium: K3
- Nitrogen: N1 - N2

Farmer Identification: #8

Farmer Name: Salongo Kakembo Ziboyimu

Number of People that Work on the Farm: 1 + Wife & Children

Farm Size: Approx. 3 acres

Plot Description: Flat; Broad Sun Exposure

Crop(s): Banana, Beans, Cabbage, Coffee, Eggplant, Guava, Tomato, Treenut, Watermelon

Unsuccessful Crop(s): None

Farming Practices:

- Cash Crop/Subsistence: Subsistence (Sells Some Produce)
- Mulch/No Mulch: Yes (Ficus Leaves)
- Intercropping: Yes
- Fertilizer Use: Yes; Animal (Cow, Chicken, Goat), Green Manure (Dried Weeds)
- Pesticide Use: No
- Irrigation (by Hand): Yes (Well Water)

General Observations:

- Nitrogen-fixing trees
- Plants some grass for ground-cover protection
- Hail worst “pest”
- Farmed plot for 5 years
- Noted weather to be hotter and drier than previous years

Soil Sample: Coffee Tree (Crop Sample #1); Cabbage (Crop Sample #3)

Soil Color/Texture: Soil was stony in spots, rich with organic matter, use of ground cover and animals for manure witnessed

pH/Moisture Readings with Meter:

- Sample 1: pH 8 / Moisture 1.5
- Sample 2: pH 8 / Moisture 1.5
- Sample 3: pH 7 / Moisture 2

Results of Soil Test(s)

Location: Coffee (School-side Plot)

- pH: 6.5 (Slight Acid)
- Phosphorus: P4
- Potassium: K2
- Nitrogen: < N2

Cabbage (School-side Plot)

- pH: 6.5 (Slight Acid)
- Phosphorus: P4
- Potassium: K3
- Nitrogen: > N2

Farmer Identification: #9

Farmer Name: Leonard Buuma

Number of People that Work on the Farm: 1 + Additional Worker (2)

Farm Size: Approx. 0.25 acres

Plot Description: Slopes South; Near School and Beehives; Some Canopy Coverage

Crop(s): Beans

Unsuccessful Crop(s): Beans ("Over-germinated" in "Poor" Area) but Onions did well here

Farming Practices:
- Cash Crop/Subsistence: Subsistence
- Mulch/No Mulch: No
- Intercropping: No
- Fertilizer Use: No
- Pesticide Use: No
- Irrigation (by Hand): No

General Observations:
- Sample Area 1: Pine needles fell for a long time in this area; believed it enriched the soil and made it "good" for beans
- Sample Area 2: Beans have historically "over-germinated"; onions did well. Described the soil as "too fertile"

Soil Sample: Beans (Crop Sample #1); Vacant (Crop Sample #3)

Soil Color/Texture: Soil was stony, light brown, crumbly

pH/Moisture Readings with Meter:
- Sample 1: pH < 8 / Moisture 1
- Sample 2: pH > 8 / Moisture 1

Results of Soil Test(s)

Location: Beans (School-side Plot)
- pH: 6.5 (Slight Acid)
- Phosphorus: P2
- Potassium: K3
- Nitrogen: N2

Vacant (School-side Plot)
- pH: 7.0 (Neutral)
- Phosphorus: P2
- Potassium: K3
- Nitrogen: N1

Farmer Identification: #10

Farmer Name: John Kaganga

Number of People that Work on the Farm: Several Hires (5-10)

Farm Size: Approx. 6 acres

Plot Description: Slopes Northeast; “Green” Trenches; Some Canopy Coverage

Crop(s): Banana, Beans, Coffee

Unsuccessful Crop(s): Banana (Wilt)

Farming Practices:

- Cash Crop/Subsistence: Cash Crop
- Mulch/No Mulch: Yes (Green)
- Intercropping: Little
- Fertilizer Use: Yes; Green Manure
- Pesticide Use: No
- Irrigation (by Hand): No

General Observations:

- Contract workers commit as long as they have financial need
- Previously used animal manure, but long way (uphill also) to carry manure
- Terracing prevents topsoil erosion and channels for irrigation/water catchment
- Top of slope recently cleared

From Conversation:

- Termites, common in this region, add nutrients to the soil but can be bad for maize
- There are very few earthworms in this region (we did not observe any in soil tests)
- Land frequently left fallow to recharge
- Weeds used as soil health barometer: Wandering Jew - a clover-like plant which co-exists with coffee but “squeezes out” beans; tall grasses - can change soil acidity

Soil Sample: Banana Wilt (Crop Sample #2 - Low Slope); Banana (Crop Sample #3 - Uphill)

Soil Color/Texture: Dark and dense; organic matter; held shape (rained heavily prior night)

pH/Moisture Readings with Meter:

- Sample 1: pH 8 / Moisture 2
- Sample 2: pH < 8 / Moisture 1
- Sample 3: pH < 8 / Moisture 1.5
- Sample 4: pH < 8 / Moisture 2

Results of Soil Test(s)

Location: Banana (Low Slope - Wilt Area)

- pH: 7.0 (Neutral)
- Phosphorus: P1 - P2
- Potassium: K3
- Nitrogen: N1 - N2

Banana (Uphill - Healthier Area)

- pH: 6.5 (Slight Acid)
- Phosphorus: P1
- Potassium: K4
- Nitrogen: N2

Farmer Identification: #11

Farmer Name: Joseph Bukya & Wife

Number of People that Work on the Farm: Husband & Wife (2)

Farm Size: Approx. 2 acres

Plot Description: Slope; Few Trees - Little Canopy Coverage

Crop(s): Banana (for liquor, not consumption), Beans, Cassava, Coffee, Maize

Unsuccessful Crop(s): N/A

Farming Practices:
- Cash Crop/Subsistence: Subsistence
- Mulch/No Mulch: No
- Intercropping: Yes
- Fertilizer Use: Yes; Green Manure
- Pesticide Use: No
- Irrigation (by Hand): No

General Observations:
- Soil is currently productive but they will rest the land for up to 4 years to recharge
- Plant 50% of the farm for first harvest and the rest for second harvest
- When they rest the land they look at health of weeds to determine fertility
- Have other farm plots for cash crops

Soil Sample: Cassava

Soil Color/Texture: Soil rich with organic matter and dark brown; freshly tilled

pH/Moisture Readings with Meter:
- Sample 1: pH < 8 / Moisture 2

Results of Soil Test(s)

Location: Cassava (Right Side of Plot)
- pH: 6.0 (Acid)
- Phosphorus: P2
- Potassium: K3
- Nitrogen: N0

Farmer Identification: #12

Farmer Name: Margaret Nabatanzi (& Deborah, daughter)

Number of People that Work on the Farm: Margaret + 2 Children (3)

Farm Size: Approx. 1 acres

Plot Description: Slight Slope Northeast; Some Trees - Some Canopy Cover

Crop(s): Amaranth, Banana, Beans, Cassava, Groundnuts, Drought-Resistant Lima Beans, Soybeans, Vanilla, Yams

Unsuccessful Crop(s): Unsuccessful Area (Beans, Cassava Currently Planted)

Farming Practices:

- Cash Crop/Subsistence: Cash Crop (Amaranth) and Subsistence
- Mulch/No Mulch: No
- Intercropping: Yes
- Fertilizer Use: Yes; Animal Manure (Cow)
- Pesticide Use: No
- Irrigation (by Hand): Some

General Observations:

- Recent heat has decreased yield
- Soil not holding water and low rainfall has required crop irrigation
- Margaret has her own packaging and is looking to step up into the next phase of commercial farming.

Soil Sample: "Poor" Soil Area

Soil Color/Texture: Dense, dark brown; Organic matter

pH/Moisture Readings with Meter:

- Sample 1: pH 8 / Moisture 2

Results of Soil Test(s)

Location: Cassava & Beans ("Poor" Soil Area)

- pH: 6.5 (Slight Acid)
- Phosphorus: P1 - P2
- Potassium: K2 - K3
- Nitrogen: N0

Farmer Identification: #13

Farmer Name: Steven Kiranda

Number of People that Work on the Farm: Steven + Several Hires

Farm Size: Approx. 3 acres

Plot Description: Slopes East; Deforested (Recently Cleared) - Broad Sun Exposure

Crop(s): Beans, Cassava, Maize, Yams
Unsuccessful Crop(s): Soybeans (Previous Season), Unsuccessful Areas

Farming Practices:
- Cash Crop/Subsistence: Subsistence
- Mulch/No Mulch: No
- Intercropping: Yes
- Fertilizer Use: Yes; Animal Manure (Goat)
- Pesticide Use: No
- Irrigation (by Hand): No

General Observations:
- Small plots used to test crop performance; currently testing beans and maize, which germinated but did not mature quickly.
- Yams grow well, so replaced cassava with yams.
- Cassava suffers if you keep replanting.
- Clears roots and grasses when planting (does not mix into soil for fertilizer) d
- Believes chemical fertilizer would rot sweet potato
- Uses Kakembo's seeds for eggplant and maize
- Goats roam the field, but not intentionally used for fertilizer/tilling. Does use some cow dung on other gardens.
- Planned to grow groundnuts, but expensive and deep plowing is needed to break up the soil (too labor intensive); planted maize instead which is much easier to grow.

Soil Sample: Newly Cleared Area

Soil Color/Texture: Soil tested was sandy, gravely, light brown

pH/Moisture Readings with Meter:
- Sample 1: pH < 8 / Moisture 1.5

Results of Soil Test(s)
Location: Newly Cleared Area
- pH: 6.5 (Slight Acid)
- Phosphorus: P2
- Potassium: K3
- Nitrogen: N1

Farmer Identification: #14

Farmer Name: Simon Katsushaba

Number of People that Work on the Farm: 5

Farm Size: Approx. 3 acres

Plot Description: Steep slope Northwest; Terraced; Broad Sun Exposure

Crop(s): Beans, Passionfruit, Onions, Yams

Unsuccessful Crop(s): Banana, Maize (would wash away), Pineapple, Sugarcane

Farming Practices:

- Cash Crop/Subsistence: Cash Crop (Passionfruit)
- Mulch/No Mulch: No
- Intercropping: Some
- Fertilizer Use: Yes; Commercial (N, P, K, foliar)
- Pesticide Use: Yes
- Irrigation (by Hand): Yes

General Observations:

- Plantation is only 1 year old
- Sunlight, moisture (better at hilltop) and aeration informed farm purchase
- Passionfruit planting holds soil at hilltop
- Passionfruit is a labor intensive cash crop, spend avg. of 8 hours/day for cultivation
- A natural spring used by the villagers is on the property; there was some controversy over access to the water source, which was granted since it has been used by locals for generations. Concern about chemical runoff from the farm required Simon to create a separate irrigation canal; however, note that the spring is at the bottom of the farm hill. Of the three water tests conducted in the area, this sample reacted the fastest to the bacteria tests by turning yellow within 24 hours. Negative/inconclusive for pesticides.

Soil Sample: Passionfruit

Soil Color/Texture: Soil is dark, rich; Organic matter present but no insects

pH/Moisture Readings with Meter:

- Sample 1: pH 8 / Moisture > 1

Results of Soil Test(s)

Location: Passionfruit

- pH: > 6.0 (Acid)
- Phosphorus: P4
- Potassium: K4
- Nitrogen: N1

Farmer Identification: #15

Farmer Name: Geofrey Kizito

Number of People that Work on the Farm: 1

Farm Size: Approx. 2.45 acres

Plot Description: Slopes Southeast into Valley Area; Broad Sun Exposure

Crop(s): Beans, Cassava

Unsuccessful Crop(s): Beans

Farming Practices:
- Cash Crop/Subsistence: Subsistence
- Mulch/No Mulch: No
- Intercropping: Some
- Fertilizer Use: No
- Pesticide Use: No
- Irrigation (by Hand): No

General Observations:
- Land purchased at beginning of a rest period (3 years); this is 2nd planting
- Surrounding plots depleting nutrients? (Chose valley area because neighbors clear the land and nutrients will run off down the slope.)
- Plan to plant nitrogen-fixing coriander; saplings need care, water during first years
- Plan to provide breaks to prevent soil erosion;

Soil Sample: "Poor" Soil Area

Soil Color/Texture: Very pebble-y, many stones, taken from area not yet cultivated

pH/Moisture Readings with Meter:
- Sample 1: pH < 8 / Moisture 1

Results of Soil Test(s)
Location: Uncultivated Area
- pH: > 6.0 (Acid)
- Phosphorus: P3
- Potassium: K2 - K3
- Nitrogen: N0

Farmer Identification: #16

Farmer Name: Jackson Salongo Kamya

Number of People that Work on the Farm: 1 + 2 Children Age 16, 19 (3)

Farm Size: Approx. 8 acres

Plot Description: Flat, Stretches East/Northeast; Mix of Broad Sun Exposure, Canopy Cover

Crop(s): Banana, Beans, Cassava, Coffee, Eggplant, Maize, Yam

Unsuccessful Crop(s): Oranges (atypical for area also), Some Banana Wilt

Farming Practices:

- Cash Crop/Subsistence: Cash Crop (Coffee and Some Excess) and Subsistence
- Mulch/No Mulch: Yes (Green Mulch on Roadside/Pathway Coffee Trees)
- Intercropping: Yes
- Fertilizer Use: Yes; Animal Manure
- Pesticide Use: No
- Irrigation (by Hand): No

General Observations:

- Has not let the fields lie fallow; believes soil losing fertility after long farming period
- Hires some labor during coffee harvests
- Intercrops fruit trees with crops

Soil Sample: Coffee Tree in “Poor” Soil Area

Soil Color/Texture: Dark, clay-like

pH/Moisture Readings with Meter:

- Sample 1: pH 7.5 / Moisture 4

Results of Soil Test(s)

Location: Uncultivated Area

- pH: < 7.0 (Neutral)
- Phosphorus: P3
- Potassium: K3
- Nitrogen: N0

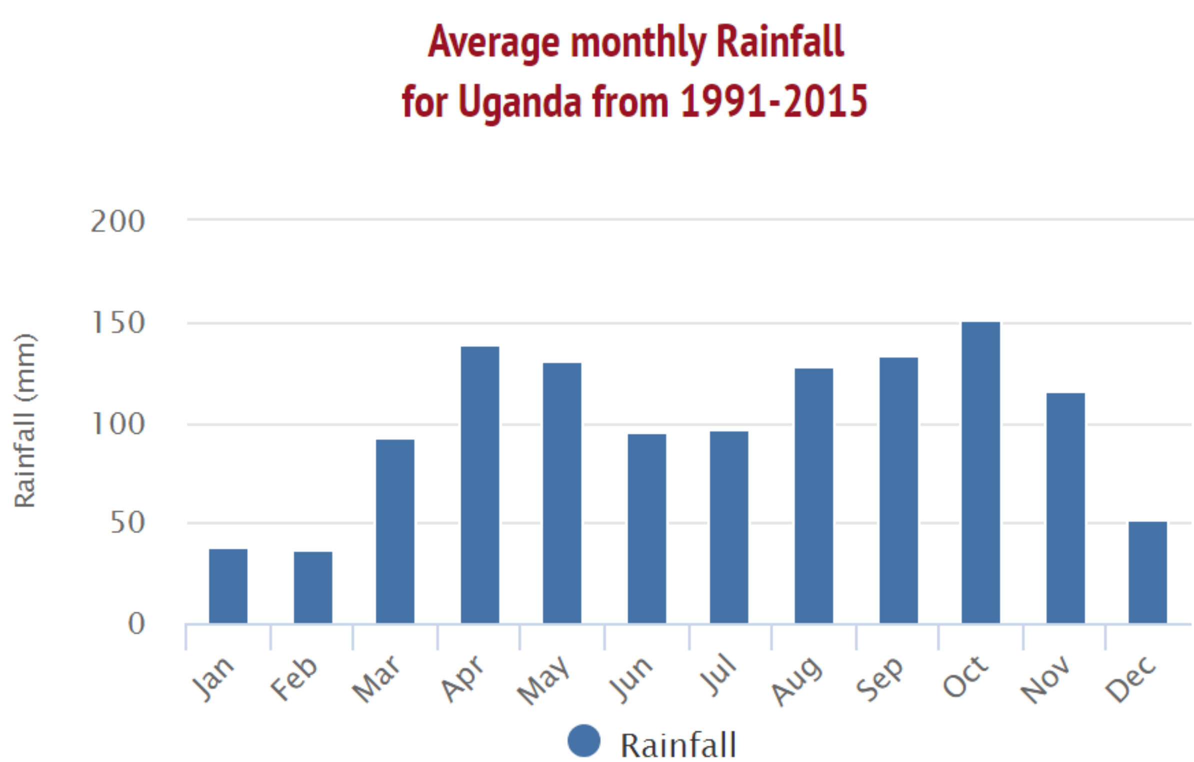
8.4 | Kasejjere Test Results and Context

8.4.1 | Growing notes for crops found in Kasejjere

Crop	Soil	pH Level	Growing Notes
Maize	Loamy	Neutral	Needs large amounts of nitrogen and phosphorous in the soil. Nitrogen fixing plants, like beans; can be grown together with maize; composted farmyard manure can be added to the soil before planting to enrich the soil for better production.
Cassava	Well-drained	All levels	Uses very few minerals in the soil; good crop on less fertile lands, or during dry periods, before resting soil. Prefers full sun with mulch or ground cover to protect moisture in the soil.
Tomato	Loamy	Acidic	Tomatoes prefer well-drained soil with lots of organic material and compost. To help tomatoes through periods of drought, place flat rocks next to each plant; they pull up groundwater and stop it from evaporating.
Beans	Loamy	Slightly Acidic	Beans prefer well-drained soil which has been mixed with compost. They need lots of nitrogen for planting, but less as they mature or the plants will grow lots of leaves but few beans. Beans should not be grown in the same area every season.
Sweet Potato	Loamy	Neutral	Sweet potatoes prefer full sun and a lot of water for the first few days after planting. Vines should not be trimmed. Pile loose, well-drained soil into 6-8 inch tall beds.
Irish Potato	Sandy	Acidic	Irish potatoes need loose, loamy soil with organic matter. Planting should be done in trenches about 2-3 feet apart. Once the plants reach 10-12 inches tall, the soil should be piled over the roots to protect the potatoes. Irish potatoes need consistent watering as they grow.
Groundnuts	Sandy	Slightly Acidic	Groundnuts need loose, well-drained soil, and full sun. They should be planted in the same manner as potatoes; piling the soil over the roots of the plant as it grows.
Eggplant	Sandy	Slightly acidic to	Eggplants prefer sandy, slightly acidic soil with full sun.

		Neutral	
Bananas	Well-drained	Acidic	Bananas prefer moist soil with good drainage, hot temperatures, and consistent rainfall. Dig ditches every 15 meters in the direction of the slope.
Amaranth	Well-drained	Neutral	Amaranth needs rich, well-drained, soil and compost, and prefers high levels of nitrogen and phosphorus. They prefer full sun.
Cabbage	Loamy or Sandy	Neutral	Cabbage prefers sandy soil and full sun, but cooler temperatures. They need a lot of nutrients. Soil should be kept moist with mulch, and cabbage should not be grown in the same area every season.
Robusta Coffee	Well-drained	Slightly acidic	Robusta coffee prefers well-drained, fertile soils rich in organic material. Mulching or legume cover crops will improve results. The plants need a lot of rain and are best grown at altitude 1,500 meters above sea level. Can be grown with banana trees for shade.

8.4.2 | Precipitation measurements for nearest weather station to Kasejjere



(Image source: World Bank Climate Portal)

8.4.3 | Soil and Water Kit Testing Results

Farmer Number	Farmer Name	Location	Crop Sample Area	Unsuccessful Crops	POTASSIUM	ppm	PHOSPHORUS	ppm	NITROGEN	ppm)	pH Description	pH Number
1	Alideki Frank	Banda	Beans		Sufficient	600	Deficient - Adequate	10 - 20	Surplus	80	Acid - Slight Acid	6.0 - 6.5
2	Tamale Rogers	Banda	Banana	Cabbage, Right Plot	Surplus	900	Sufficient	50	Sufficient	40	Slight Acid	6.5
8	Salongo Kakembo Ziboyimu	Kasejjere	Coffee Tree, Right Plot	None	Adequate	400	Surplus	100	< Adequate	20	Slight Acid	6.5
8	Salongo Kakembo Ziboyimu	Kasejjere	Cabbage, Right Plot		Sufficient	600	Surplus	100	> Adequate	25	Slight Acid	6.5
9	Leonard	Kasejjere	Beans	Beans	Sufficient	600	Adequate	20	Adequate	20	Slight Acid	6.5
10	Kaganga John	Kasejjere	Banana, Uphill, Better		Surplus	900	Deficient	10	Adequate	20	Slight Acid	6.5
7	Bam	Kasejjere	Cassava, Uphill		Sufficient	600	Adequate	20	Deficient - Adequate	10 - 20	Acid - Slight Acid	6.0 - 6.5
10	Kaganga John	Kasejjere	Banana, Low Slope, Wilt	Some Banana Wilt	Sufficient	600	Deficient - Adequate	10 - 20	Deficient - Adequate	10 - 20	Neutral	7
4	Kikandwa Environmental Association	Kasejjere	Mix		Adequate	400	Deficient	10	Deficient	10	Neutral	7
6	Nakanwagi Correti	Kasejjere	Coffee Tree	Maize	Depleted	50	Deficient	10	Deficient	10	Slight Acid	6.5
9	Leonard	Kasejjere	"Poor" Soil Area		Sufficient	600	Adequate	20	Deficient	10	Neutral	7
13	Kiranda Steven	Kasejjere		Soybeans, Unsuccessful Areas	Sufficient	600	> Adequate	20	Deficient	10	Slight Acid	6.5
14	Katsushaba Simon	Kasejjere	Passionfruit	Banana, Maize (would wash away), Pineapple,	Surplus	900	Surplus	100	Deficient	10	Acid	> 6.0

				Sugarcane								
3	Omolo Postiano	Banda	Cabbage	Tomatoes, Eggplants	Sufficient	600	Adequate	20	Depleted	0	Slight Acid	6.5
7	Bam	Kasejjere	Coffee Tree, Low Slope	Banana; Beans in "Poor" Area	Sufficient	600	Deficient	10	Depleted	0	Acid - Slight Acid	6.0 - 6.5
11	Bukya Joseph	Kasejjere	Cassava		Sufficient	600	Adequate	20-Jan	Depleted	0	Acid	6
12	Margaret	Kasejjere	"Poor" Soil Area	Unsuccessful Area	Adequate - Sufficient	400 - 600	Deficient - Adequate	10 - 20	Depleted	0	Slight Acid	6.5
15	Kizito Geofrey	Kasejjere	"Poor" Soil Area		Adequate - Sufficient	400 - 600	Sufficient	50	Depleted	0	Acid	> 6.0
16	Salongo Kamya Jackson	Kasejjere	Coffee Tree, "Poor" Soil	Oranges, Some Banana Wilt	Sufficient	600	Sufficient	50	Depleted	0	Neutral	< 7.0

Water Sample	Location Description	Bacteria	Pesticide	Nitrates, Nitrites	Alkalinity (mg/l)	pH	Hardness	Lead	Copper	Chlorine
1	Community (KEA) Well)	Positive (slowest response)	Negative	Negative	40	6	9	>1.0 ppm	1.3 ppm	0
2	Natural Spring (Northeast of School)	Postive	Negative	Negative	40	5	6	0.3 ppm	< 1.3 ppm	1
3	Natural Spring (Katsushaba Simon Property)	Positive (fastest response)	Inconclusive / Negative	Negative	60	5	3	0.5 ppm	1.3 ppm	0

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