An Introduction to East African Smallholder Agriculture

ONE ACRE FUND

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CONTENTS

This introduction to East African smallholder agriculture will provide you with a basic technical understanding of the following:

Section #1: Conditions – *Where we work*

The conditions within which agriculture takes place are incredibly varied. Rainfall, soil, cultural preferences, and economic limitations can vary with both location and time. For a farmer to make a well-informed decision about what to grow and how to grow it, environmental, cultural, and economic conditions all play an important role. Low rainfall may mean a farmer should grow sorghum instead of maize. Cooking practices may mean they should grow red beans instead of black. Price volatility may mean they should grow a harder-coated maize variety for longer storability. While the East African agricultural landscape can be diverse and challenging to navigate, understanding its nuance is the foundation for improving farmer livelihoods.

WHY ENVIRONMENTAL CONDITIONS IN AGRICULTURE MATTER

A farmer can use the exact same inputs and manage her/his crop the exact same way every single season, but s/he will seldom get the exact same yield twice. The environment within which s/he farms can have as much of an impact on her/his yields as individual effort. Specific environmental conditions affect crop productivity in different ways.

Altitude and Temperature: A plant's ability to grow is determined partially by temperature, meaning that higher temperatures tend to cause a crop to mature more quickly, and lower temperatures cause it to mature more slowly. Lower temperatures can also affect how certain biological activities occur. For example, low temperatures reduce the ability of sorghum (which is adapted to dryer and warmer climates) to produce grain. As you climb up a mountain, you'll notice that temperatures fall. The same principles hold in agriculture but within a much narrower band. Farmers around Lake Victoria (around 1,100m above sea level) will typically experience hotter temperatures than farmers in the Rwandan Highlands (about 2,000m above sea level), although they fall on nearly the same latitude. For more on the effects of altitude and temperature, click here.

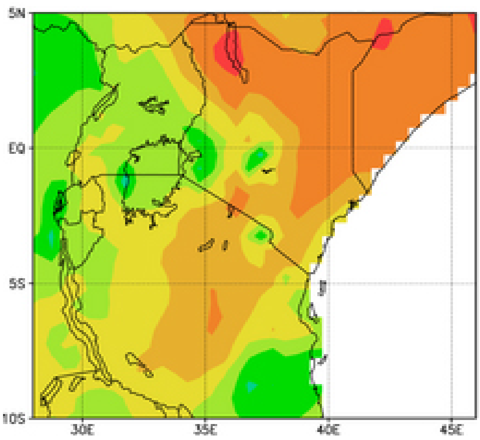
Sunlight: Most plants can't grow without light, and one of the main drivers of crop exposure to light is the length of the day. As East Africa straddles the equator, the length of the day is roughly the same year-round. This makes farming feasible during months when it would be impossible at latitudes further north and south. That said, there is still some amount of variability within East Africa. Southern Tanzania and Malawi, for example, have more daylight variability than Kenya and Uganda. This means that crops may need to be bred to tolerate lower amounts of sunlight depending on the timing of the growing season. For more on the effects of sunlight, click here.

Field Notes

Understanding the relationship between temperature and insect pests

One constant threat to food security is insect pests. Aphids, stalk borers, beetles, and other types of insects can be very damaging to crops, either by directly damaging leaves and stalks through chewing and burrowing, or indirectly by transmitting devastating diseases.

However, the timing of insect movements in a particular season is actually quite predictable. By using a simple formula for "growing degree days" -- or heat accumulated throughout the season -- we can determine when certain insects will hatch, spread, and reproduce. This is because their biology is strongly linked to the temperature of their environment. This means that in warmer seasons aphids may begin to attack maize plants earlier than in cooler seasons. Farmers can use this information to make pest management practices as efficient as possible. To learn more about growing degree days, click here.



High (green) and low (red) rainfall[ii]

Rainfall: Nearly all agriculture in East Africa is rain-fed, meaning that there is very little irrigation of staple crops like maize and beans. Rainfall quality is primarily a function of total volume within the season and its distribution throughout the season. A maize crop, for example, will perform well with around 800mm of rainfall during the season. However, if most of that rain falls in the first and last months of the season, it may wash the seeds away, the plants may experience significant moisture stress in the middle of the season, and the mature crop may not be able to properly dry in the field. This may also result in much higher levels of soil erosion. Research suggests that each day of moisture stress during the most sensitive parts of the season can result in a 7% yield loss.[1] For more information on the effects of rainfall, **click here**.

Soil Type: In addition to farmer management, soil characteristics can change depending on the geology of the rocks from which they were formed and the environments in which they developed (e.g., deserts vs. rainforests). Clay soils behave differently from sandy soils. Acidic soils behave differently from pH-neutral soils. A key point here is that different soil types have different natural fertility levels, and fertility strongly affects crop performance. This is one reason why two farmers in the same area, managing the same crops in the same way, may get different yields. For more information about soil types, **click here**.

Environmental Stress: Agriculture typically develops in areas where ecological stresses, particularly those associated with rainfall, are minimal. This is why in many of the dryer, more arid regions of East Africa, pastoralism is adopted over agriculture. The animals eat scrub bushes that people can't, and people eat the animals. However, environmental stress is ultimately unavoidable in variable climates, and this can be further complicated by climate change. Some farmers may experience drought or highly erratic rainfall. Some may experience the spread of large pest populations. Some may experience various yield-suppressing plant diseases. Resilience to these stresses is an important component of agriculture and a critical element of smallholder agriculture.

WHY HOUSEHOLD CONDITIONS MATTER IN AGRICULTURE

A farmer's environment may be perfectly suited to grow a particular crop, but that doesn't matter if there isn't a market for the crop or any interest in home consumption. Ultimately, agriculture is an activity that serves people. The preferences and limitations of those people are what drive agricultural decisions.

Consumption Preferences: Farmers in Rwanda grow a significantly larger amount of climbing beans than farmers in Kenya. This is partially a product of field space limitations from a higher population density. Nearly all farmers in Kenya prefer white maize because it makes better *ugali* (stiff maize porridge); they also do not like black beans because the color bleeds into their *githeri* (maize and bean stew), ruining the appearance. While many farmers mill their maize into flour, it is common to eat green maize, which is more a reference to the husk color than the maize itself. Green maize is harvested before completely maturing and drying in the field and is often roasted and eaten on the

[1] http://dirp3.pids.gov.ph/ACIAR/relatedresources/Impact%20of%20drought%20on%20corn%20productivity.pdf
[ii] http://www.catsg.org/cheetah/07_map-centre/7_3_Eastern-Africa/thematic-maps/east_africa_rainfall.jpg

cob. For green maize, farmers usually prefer "sweet" maize (different from sweet corn), which is felt to have better roasting qualities.

Farmer Perspectives

Taste preferences vs yield

Researchers developed a bean variety that is resistant to a major bean disease in Kenya (root rot) and therefore produces higher yields than local varieties when root rot pressure is high.

However, this particular variety of bean is a black bean and most Kenyan farmers strongly prefer either a red or a red mottled bean. Githeri, a dish of cooked and mixed maize and beans is said to become stained black if black beans are used. This has so far made this new bean variety fairly unappealing to farmers in spite of its yield advantage over local varieties. It is common for farmers to heavily weigh non-yield characteristics in their decisions. This makes sense – consumers select different varieties of crops on color and taste characteristics all the time. A lot of something that no one wants is not as good as some of something that everyone wants.

Economic Limitations: In addition to consumption preferences, agricultural economics strongly influence farmer decisions. Ease of market access, crop prices, storability, and timing of household expenses are also very important factors. As earning potential varies by crop, by variety, and by time of year, farmer decisions about what to grow and how to grow it may not be environmentally ideal, but they may be economically optimal. For more information about economic limitations, click here.

THE CONDITIONS OF ONE ACRE FUND FARMERS

One Acre Fund operates across a fairly wide range of conditions both within and between countries. While certain conditions are fairly similar – like temperature ranges and staple crops – others are different – like rainfall levels and disease pressures. Even within a particular country, the conditions significantly vary. This is the case between western and eastern Rwanda and between Dodoma and Iringa in Tanzania. However, generally speaking, we operate in areas of mid to high altitude (1,000 – 2,500 meters above sea level) with moderate to high temperatures (around 16 – 28 C depending on the time and season), and with moderate to high rainfall (600 – 1,200 millimeters per season). Maize diseases like Maize Lethal Necrosis (MLN), Maize Streak Virus (MSV), and Gray Leaf Spot (GLS) are common in East Africa. Bean diseases like Angular Leaf Spot (ALS), Root Rot, and Bacterial Blight are also common. As a general point, One Acre Fund clients tend to farm in areas that are good for agriculture and not too hot, cold, or arid.

Key Takeaways:

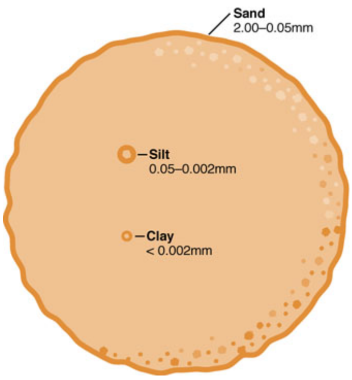
- The environmental conditions within which smallholder farmers work are quite varied, which can have a strong effect on productivity.
- Household conditions, such as cultural preferences or economic limitations, can play a strong role in farmer decisions.
- One Acre Fund operates across a wide range of environmental and household conditions, meaning that we must be very thoughtful in how we apply learnings from one country or region to another.

Section #2: Introduction to Soil – *The fundamentals of soil science*

Soil is the product of weathered rock, decomposed organic matter, and the environment within which these processes occur. It contains 80% of the earth's land-based carbon and 3x the amount of carbon in the atmosphere[2]. Soil has profound effects on both the livelihoods of smallholder farmers and the environment within which we live. 95% of all food and fiber is produced out of the soil, and 99% of all freshwater passes through the soil[3]. Farmers' livelihoods are intimately tied to the soil; it is the source of most of the nutrients that plants use to become healthy and resilient against environmental stresses. Healthy soil drives agricultural productivity, which leads to greater yields.

HOW TO DESCRIBE SOIL

There are many ways to describe soil, but two of the most important characteristics are soil type and soil texture.



Soil Type: Soil on many farms in East Africa is quite red. Red soils are prevalent in tropical areas and are the result of various geological and environmental factors. Known as Ferralsols and Acrisols, these reddish soils often have low natural fertility compared to other soils. These soils are often acidic, low in plant nutrients, and respond poorly to fertilizer. In other areas, brown soils are common, likely Nitisols, which are typically more naturally fertile than Ferralsols and Acrisols. In a few places, dark volcanic soils known as Andosols may be found. These soils have exceptionally high natural fertility relative to other soils found in East Africa.

Field Notes

Quickly determine a farmer's soil texture:

A "ribbon test" enables anyone in the field to quickly evaluate soils based on feel. Place a small handful of soil in your palm. If it is dry add a bit of water until it is like modeling clay. Roll the soil into a cigar shape with about a 1/2-3/4 inch diameter. Place the cigar-shaped soil between your thumb and forefinger, and start to gently press the cigar into a flat ribbon shape. As the ribbon develops, let it extend over your forefinger until it breaks from its own weight. Depending on (1) how long the ribbon is and (2) how it feels you can determine the texture of a farmer's soil. If the soil breaks before you can start to form a ribbon it is considered sand.

One can use this skill to better understand the effect a particular farm's soil may be having on nutrient and moisture availability.

Soil Texture: Soil texture is the relative proportion of sand, silt, and clay found in a particular soil. Most soils contain some combination of all three of these materials and are described accordingly. Soil texture ranges from rough sand (think a beach) to slippery, sticky clay and includes everything in between. A soil's texture can mean a lot for how well it retains nutrients and moisture for plants to use. For example, water and nutrients pass through sandy soil very quickly; even with adequate rainfall and fertilizer, plants growing in sandy soils may not have all the water or nutrients they need. Alternatively, clay soils retain soil moisture and nutrients very well, and sometimes too well. Clay soils are more prone to waterlogging, and their

[2] http://www.nature.com/scitable/knowledge/library/soil-carbon-storage-84223790
[3] Weil, R. and N. Brady. 2007. The Nature and Properties of Soil. Pearson Prentice Hall, Upper Saddle River, NJ, USA.
[iii] http://www.nature.com/scitable/content/relative-sizes-of-sand-silt-clay-68243417
[iv] http://www.glencoelime.com.au/wp-content/uploads/2014/05/PlantFood-chart.jpg

The sizes of soil particles [iii]

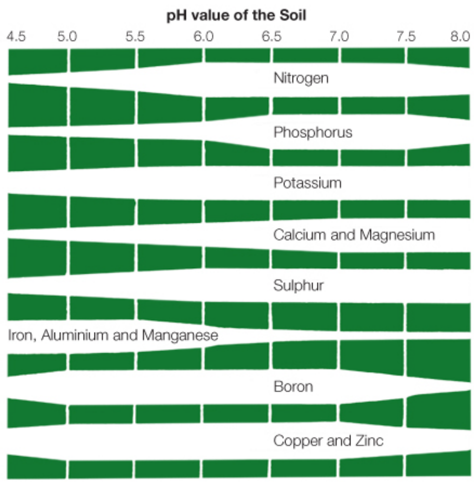
density makes it difficult for plant roots to expand and access nutrients. The most productive texture is typically loam, an ideal mix of sand, silt, and clay.

DEFINING SOIL FERTILITY

For soil to be considered fertile, it must meet a number of criteria. Generally, these fertility criteria can be classified as chemical, physical, or biological.

Chemical Fertility:

- Nutrients: There are 17 elements essential for plant growth, and 14 of these come from the soil (carbon, hydrogen, and oxygen come from the air). Nitrogen (N), phosphorus (P), and potassium (K) are required in the largest quantities. Though required in smaller amounts, the other elements are also essential for healthy plant growth; if one is missing or deficient, plants will not grow well. The role of each of these elements (also referred to as plant nutrients) in plant growth will be elaborated upon in Section #3. If present in the soil in sufficient quantity, the ability of plants to use them depends on soil type, texture, weather, farmer practice, and soil pH, among other things.



Nutrient availability at different pH levels [iv]

Farmer Perspectives

Competing uses for organic materials

Farmers typically want to improve the fertility of their soil. This means spending less on fertilizer and producing sufficient amounts of food. However, improving soil fertility is not quite as simple as "add more compost" or "cover the field in mulch."

After harvest, a farmer may have a field of maize stalks and leaves, bean stems and leaves, and other plant materials. S/he may decide to combine the stalks and stems with some livestock manure and make compost. S/he may decide to use some of the plant materials as livestock feed instead. In some situations s/he may decide to use them to fuel her/his cook stove.

Since these are all important uses for plant materials produced on the farm, it can be difficult for smallholders to make large amounts of compost, or cover significant portions of their fields with mulch. It's a challenge that requires a long-term solution.

- Acidity: Soil pH is another crucial contributor to chemical fertility. A soil with low pH (below 7) is considered acidic; if the soil pH is high (above 7), it is considered basic. Soil pH influences how soil nutrients are expressed, meaning that some nutrients become less available as pH decreases, and other nutrients can become too available (white space in the above chart). Acidic soil can result from soil erosion, weathering, loss of soil organic matter and is often a product of soil type. However, soils can also become acidic from agricultural intensification (e.g., heavy fertilizer use) in the absence of pH-correcting practices like the use of agricultural lime. One Acre Fund actively promotes and sells lime to smallholder farmers and regularly runs several trials to improve its use. As a bulky, sometimes expensive, and not widely available product, lime is an important focus.

- Carbon: In the soil, carbon (C) is mostly found in organic matter. Organic matter is the product of decomposed plant and animal material, such as maize stalks and cow manure. It directly contributes to the soil's ability to retain nutrients and moisture and positively affects a soil's pH. Organic matter degrades more quickly under heavy soil tillage and in warm, moist climates such as those found in East Africa. It is an essential contributor to soil fertility and a focus of many of our long-term impact efforts. To find out more about chemical fertility, **click here**.

Physical Fertility: One easily observable indicator of soil fertility is its physical characteristics – specifically soil structure. Soil structure is the degree to which soil forms *aggregates*, or small clumps of soil, between which roots can grow and oxygen and water can flow. Good soil structure is typically a product of good texture and minimal soil tillage. When farmers till the soil, aggregates are destroyed. This reduces the structural quality of the soil. Additionally, when farmers excessively walk on saturated soil or heavy machinery is used the soil can be compacted, reducing soil structure quality.

Biological Fertility: In one gram of soil, there are over 1 million species and over 1 billion individual organisms. In one handful of soil, there are more organisms than the total number of humans that have ever existed[4]. These organisms do everything from improving soil structure to creating compost to helping bean plants turn atmospheric nitrogen into fertilizer. Bacteria known as rhizobia attach to legume roots (like beans) and act as micro-scale fertilizer factories, directly supplying each plant with nitrogen – this is known as biological nitrogen fixation. Fungi known as mycorrhizae attach to plant roots and extend deep into the soil. The plant feeds the fungi and the fungi provide the plants with greater access to nutrients and moisture they otherwise may not be able to reach. While these microorganisms can positively affect chemical and physical soil fertility, they have a difficult time surviving in chemically and physically infertile soil. Maintaining a balance between chemical, physical, and biological fertility is key to ensuring a sustainable soil ecosystem. To find out more about biological fertility, **click here**.

Key Takeaways:

- Soils are very diverse. They are the product of both agricultural practice and the environment within which they were formed.
- Different types of soils affect crop productivity in different ways. To most effectively serve farmers, it's important to understand the types of soils with which they are working.
- Soil fertility includes chemical, physical, and biological components, all of which are critically important to sustain agricultural productivity.

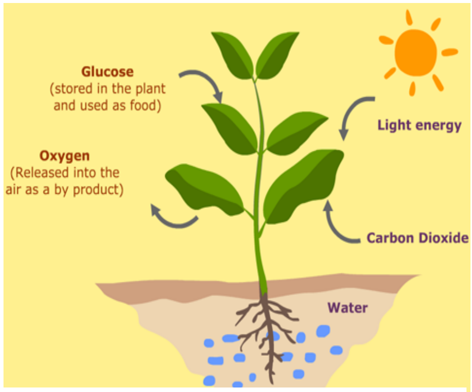
[4] http://extension.psu.edu/business/start-farming/soils-and-soil-management/soil-quality-introduction-to-soils-fact-sheet

Section #3: Introduction to plants – *The fundamentals of crop science*

Plants are the primary producers of biological energy on earth. They convert solar energy and carbon dioxide into the oxygen we breathe and the food we eat. Plants are found on every continent of the globe except Antarctica. While there are an estimated 300,000 plant species in the world, just 10 species are responsible for over 90% of the world's food supply, two-thirds of which comes from just three species and one family: wheat, maize, and rice. In African agricultural systems, two plant families dominate: Poaceae (the grass family – maize, rice, sorghum, and millet) and Fabaceae (the legume family – common beans, green grams, and groundnuts).

HOW PLANTS GROW

One of the most important biological events in history was the evolution of photosynthesis – the process in which plants use light energy (from the sun) to convert CO_2 into sugars. With a few exceptions, photosynthesis is the sole means of sustaining all life on Earth. For plants to function properly they require light, water, gases (CO_2 and O_2), and nutrients. If all of these things are supplied in sufficient quantities photosynthesis works efficiently and plants produce good yields.



Photosynthesis

Light: Visible light is part of what is known as the electromagnetic spectrum. This spectrum ranges from gamma rays (high energy) to radio waves (low energy). Most of the spectrum is totally invisible to the human eye; in the middle is a very narrow range that our eyes can see. This is called visible light. The visible light spectrum (all the colors of the rainbow) ranges from far-red (low energy) to blue (high energy). Of this spectrum, plants only use the blue and far-red wavelengths for photosynthesis (called photosynthetically active radiation). This is partially why the color blue is very rare in plants, as plants use most of it for photosynthesis.

Water and gas: All living things need water to survive. Plants are no exception. Plants get most of their water through the soil via roots. Water movement into roots is also the primary method plants use to acquire nutrients. Once in the plants, water travels up tiny tubes (xylem) and then evaporates through tiny holes in the leaves (stomata). This process is called evapotranspiration and is the principal mechanism for water movement in plants. CO_2 and O_2 also enter and leave the plants through the stomata.

Nutrients: As noted in the previous section, there are 17 essential nutrients for plant growth. If any one of these nutrients is missing the plant will die. Of these nutrients, three come from the air (C, H, O) the rest come from the soil. The table below summarizes all of the nutrients and what they do in plants. For more information about the roles of different nutrients in plant growth, click here.

Nutrient	Role in plants	Expression
N – Nitrogen	The backbone of all proteins	Overall plant growth
P – Phosphorus	DNA and ATP (energy)	Overall plant growth
K – Potassium	Osmotic regulation	Water regulation and seed development

S – Sulfur	Needed for some proteins	Overall plant growth
Ca – Calcium	Cell wall structure	Strong stems and leaves
Fe – Iron	Cofactor in chlorophyll synthesis	Overall plant growth
Mg – Magnesium	Central element in chlorophyll	Root and shoot growth; disease susceptibility
B – Boron	Cell wall structure	Good growth of growing points
Mn – Manganese	Cofactor in photosynthesis	Overall plant growth
Cu – Copper	Photosynthesis and respiration	Overall plant growth
Zn – Zinc	Cofactor in many plant hormones and chlorophyll synthesis	Growth and development of the plant
Cl – Chlorine	Osmotic regulation	Overall plant growth
Mo – Molybdenum	Cofactor in nitrogen cycling in plants	Overall plant growth
Ni – Nickel	Nitrogen metabolism	Overall plant growth

PLANTS AS PARTS OF ECOLOGICAL SYSTEMS

Natural plant systems can be very productive when biological and environmental cycles are coupled. This allows forests and savannas in East Africa to support an incredible number and diversity of animals. If agricultural systems emulate the synergies found in natural ones, smallholder farmers can benefit from maximum social, economic, and environmental sustainability.

> **Field Notes**
>
> **Determining maize growth stages**
>
> Plants go through different biological stages throughout the course of their lives. In the case of maize, some are easy to spot like germination and cob formation. However, there are important stages that are a bit harder to see. That's where "leaf counts" come in to play.
>
> Different maize growth stages correspond with the number of leaves on the plant. For example, when the plant has 6 fully formed leaves it is beginning a stage of rapid leaf and stalk growth. This happens until about the 12-15 leaf stage when a tassel emerges from the top of the plant and silks emerge from the ear (the beginning of the reproductive stage). Since nitrogen fertilizer is important for leaf and stalk growth farmers are encouraged to apply their topdress fertilizer at the six and ten leaf stages (referred to as V6 and V10). For more information about maize growth stages click here.

Integrating annual and perennial plants: Irrespective of plant families, plants can be categorized into two broad groups: annuals and perennials. Annual plants (like maize and beans) are highly adapted to seasonal variability in climate; in Africa, this principally means rainfall. They germinate quickly, grow, set seed, and die within one season in order to take advantage of the seasonal rains. These plants typically invest most of their energy into a shallow root system and are sensitive to drought. Perennial plants (like bananas and pigeon peas) germinate slowly and mature over several seasons before setting seed; once mature these plants can produce seed for several years or more. Initially, these plants invest most of their energy into establishing a deep root system that allows them to access water even in the dry seasons. In nature, perennial plants are integrated with annual plants. Picture the East African savanna – perennial acacia trees (legumes that fix nitrogen!) are scattered throughout a sea of annual grasses. During the rains, the grasses feed huge herds of animals. During the dry season, the acacias provide food for giraffes, elephants, rhinos, and other larger animals. Similar strategies exist within the context of East African smallholder farming. For more information about perennial plants, click here and for annual plants, click here.

Farmer Perspectives

Perennial pigeon peas in Malawi

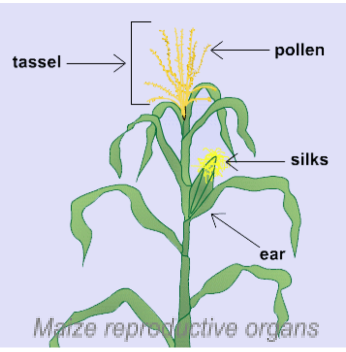
Malawi has a very short rain season and a long dry season. Farmers have adapted to this environment by incorporating a perennial legume crop, pigeon peas, into their cropping system. Pigeon peas are planted at the same time as maize. While the maize is growing tall the pigeon pea is developing a deep tap-root. During the start of the dry season, after the maize has been harvested, the pigeon peas grow and produce a harvest throughout the dry season. By using deep groundwater, pigeon peas allow smallholder farmers a nutritious food and income source to take them through the long dry season.

Integrating legumes and grasses: Most legumes can convert atmospheric nitrogen into biological nitrogen; in a sense, they produce their own nitrogen fertilizer. In addition, legume crops grow relatively closer to the ground and can grow adequately with some shade. Grasses need a lot of nitrogen and sunshine to grow well. By incorporating legumes (like beans or desmodium) in between grass crops (e.g. maize), farmers can use the legumes to partially "feed" maize with biological nitrogen. There are other benefits too. Some legumes produce chemicals that repel insect pests, kill weed seeds, or smother emerging weeds; these systems are often called "push-pull". To find out more about push-pull systems click here.

HOW PLANTS PRODUCE FOOD

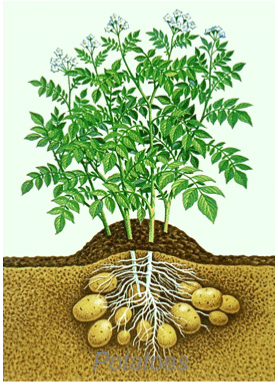
When farmers grow crops, they typically do so to produce one of three things – food, fuel, or fiber. Fuel may refer to wood to burn or turn into charcoal and fiber may refer to products like cotton. For East African smallholder farmers, however, the primary focus is food. When we refer to food produced from crops, we mean a few different things, including leafy greens from plants like collards, grains from maize or sorghum, fruits from avocado trees or tomato plants, and starchy vegetables and tubers like carrots or potatoes. Here we'll briefly explain how plants make these different food products.

Seeds and Fruits: Meals that include maize, sorghum, millet, rice, wheat, beans, tomatoes, and avocados all have something in common; they all include the fruiting bodies of the plants that produced them. Taking maize as an example, maize grains are produced when pollen is blown in the wind from the tassel (the male side of the equation) and lands on the silks (the female side) of another plant. The male genes then make their way through the silks to the ear – inside the husks – to make the fully developed maize grains that farmers will eventually eat. The "flowering period" is the time around the middle of the season when the tassels and silks emerge. In maize, and in all flowering and fruiting plants, this is the part of the season when the plant is most sensitive to low rainfall, disease, and nutrient deficiencies. That's why, for example, topdress and chemical spraying are supposed to occur prior to flowering. For more information about seed and fruit development, click here.



Leafy Greens: When you eat leafy greens such as collard greens, lettuce, or indigenous greens with ugali, you are eating the vegetative part of the plant rather than the seeds or fruits. For some plants, that is the main food source; for others, it's a mix – like cowpeas – where you can eat either the leaves or the seeds. For other plants like maize, humans don't eat the greens though livestock certainly do. The vegetative, leafy parts of plants require a lot of nitrogen to develop. That's why if you were to apply a lot of nitrogen fertilizer to bean plants they may become bushier than you'd like, spending more nutrients growing leaves than producing healthy grains. For more information on the growth of leafy greens, **click here**.

Collard greens



Tubers and Root Vegetables: Crops like Irish and sweet potatoes, cassava, and carrots all have something in common – the starchy part of the plant we eat grows underground. When a potato plant is in the early stages of growth, it extends its roots out like most other plants. However, around the midpoint of the season, the roots curl in on themselves. From this point on, large amounts of water and nutrients are sent to the ends of the roots, producing the starchy tissue that farmers ultimately harvest and eat. Tubers typically use large amounts of potassium to grow, meaning that they either draw it heavily from the soil to develop or require potassium fertilizer. This is one of the reasons why NPK fertilizers are typically used by farmers growing potatoes. For more information about the growth of tubers and root vegetables, **click here**.

Key Takeaways:

- Plants are not created equal. Different plants are adapted to a variety of ecological conditions. Despite the existing diversity, humans rely on very few species for their diet.
- Understanding diversity in crops can enable farming systems to mimic the synergies found in natural environments. Biodiversity is one of the most critical elements for creating resilience in cropping systems.

Section #4: Inputs – *What One Acre Fund delivers*

The agricultural inputs One Acre Fund primarily works with fall into two categories: improved seed and mineral fertilizer. These inputs are the practical extension of crop and soil science. While high-quality agricultural inputs are a necessary part of a productive farming system, they are not sufficient on their own. Farmers must also know how to use these inputs properly to fully unlock their potential. Best practice agronomy is, however, covered in the next section; this part will focus on the seed and fertilizer that we deliver and why we deliver it.

WHAT IS IMPROVED SEED AND WHY DOES ONE ACRE FUND PROMOTE IT?

Seeds are not created equal. Certain varieties of particular crops produce higher yields than others under different conditions. Certain varieties taste better and are more easily cooked. These differences are a product of the genetics of a seed and how those genetics came to be there. Improved seed is an important part of sustainable and productive farming systems and has been shown to increase farmer yields by up to 59% even in the absence of fertilizer[5]. In 2020, One Acre Fund sold and distributed over 5,000 metric tons of improved seed across all countries; this number grows each year.

Seed Types: Regardless of the crop, there are generally three types of seed to consider: (1) local or open-pollinated varieties, (2) hybrid varieties, and (3) genetically modified varieties. Each of these names is primarily an indication of the way the seed was produced and, more specifically, the degree of precision humans had over its creation.

- Local or open-pollinated varieties are the result of a genetically diverse male pollinating a genetically diverse female. In the case of “local” seed, this happens in farmers’ fields either intentionally (via farmer selection) or unintentionally. In the case of “improved” open-pollinated varieties, this happens under the care of a trained breeder who is looking to select specific traits from genetically diverse plants.

- Hybrid varieties are the result of a genetically pure male pollinating a genetically pure female. Each of the two “parents” has been “inbred” over the course of a number of seasons to isolate specific traits. Those genetically pure parents are then cross-pollinated to produce a “hybrid” seed. A phenomenon known as “hybrid vigor” results from crossing two genetically pure parents, meaning that the seed produces a particularly vigorous and high-yielding plant. However, if you re-plant seed harvested from a hybrid it will not perform as well due to the lack of “hybrid vigor” in that generation of the seed. Due to long breeding, release, and production timelines, it can often take 5-10 years to develop and introduce a new hybrid seed.

- Genetically modified (GM) varieties are the result of highly controlled selective breeding like that found in the development of hybrid varieties. The key difference is that rather than controlling which genes are transferred through pollination (hybrid production) a breeder selects specific genes either from the same crop or another crop and selectively inserts those genes into the DNA of the crop of interest. The result is faster and more controlled breeding than can be achieved with conventional methods. Typically, GM varieties are bred to perform particularly well under drought, disease, or pest pressure. **GM seed is illegal in many countries of One Acre Fund operation, and we do not sell GM seed**. For more information about the different types of seeds, **click here**.

[5] *Potential effects of the imposition of value added tax on agricultural inputs and sifted maize meal.* Tegemeo Institute. 2012

Farmer Perspectives

Choosing which maize variety to grow

Each season, farmers must choose which seeds they will plant. Some will recycle seeds harvested from the previous growing season, selected because of their performance in that season. Some will choose to purchase improved OPV and hybrid seed.

Additionally, a farmer must decide which characteristics are most important. S/he may speak to family and neighbors, rely on her past experience and personal observations, or depend on the guidance that her/his One Acre Fund field officer provides.

Many of the most commonly purchased hybrid seeds in Kenya were developed in the 1980s and 1990s. They've performed reasonably well over the seasons for many farmers and this may provide a reason to not adopt newer, often higher-yielding varieties. Change in farmer perception of new varieties can take time and first-hand experience.

Seed Characteristics: When farmers are deciding what seed to grow and when One Acre Fund is deciding what seed to offer, we take into consideration myriad varietal characteristics. A few of the most important characteristics are color, taste, yield, and maturity period. At a minimum, farmers typically want (1) the type of food they like to eat (2) produced in the highest quantity possible, and (3) within the shortest time possible. However, there are a number of additional characteristics that come into play here. Many varieties have been bred to resist particular diseases. If a farmer's crop is strongly affected by bean root rot, for example, that farmer would benefit from growing a variety that is resistant to bean root rot. Additionally, a farmer may use maize stalks and leaves as feed for her/his cows. If that's the case, they may prefer a variety that produces lots of biomass – e.g. big stalks and leaves. Alternatively, a farmer may experience strong winds and prefer a slightly shorter-height variety that is less prone to being knocked over by strong gusts (referred to as "lodging"). A variety may have all the characteristics a farmer is looking for, but if s/he can't afford it, then it doesn't matter. Price is another key characteristic, as not all seed costs the same to produce. Some types of hybrids, such as "single cross" hybrids are more expensive to produce (and typically higher-yielding), making them less affordable to smallholder farmers. Other types of hybrids, such as "three-way cross" hybrids, yield slightly less but are also less expensive to produce. The result is that "three-way crosses" are the most common type of maize hybrid sold in much of East Africa. On a seasonal basis, we evaluate and update our seed offering to best reflect the needs of the farmer clients we serve. For more information about seed characteristics, **click here**.

WHAT IS MINERAL FERTILIZER AND WHY DOES ONE ACRE FUND PROMOTE IT?

Crops draw nutrients from three sources – air, soil, and fertilizer. Fertilizer provides nutrients that the soil and other organic, on-farm inputs are not able to provide in sufficient quantities. Applying small amounts of fertilizer, even in the absence of improved seed, has been shown to increase yields by 95%.[6] In 2020, One Acre Fund sold and distributed over 70,000 metric tons of fertilizer across the program. This number grows each year.

A One Acre Fund scoop used to microdose fertilizer.

[6] *Potential effects of the imposition of value added tax on agricultural inputs and sifted maize meal.* Tegemeo Institute. 2012

Organic and Inorganic Fertilizer: Organic and inorganic fertilizers are not substitutes; rather, they are complements. Organic fertilizers are low in nutrient value but high in organic matter, while inorganic – or mineral/chemical – fertilizers are high in nutrient value but do not contain organic matter. One Acre Fund trains farmers on how to produce compost on the farm using plant residues, animal manure, and other materials. However, this practice alone is typically incapable of supplying the nutrients needed to produce a healthy crop each season. By pairing inorganic fertilizer with organic inputs, farmers are able to get the benefits of both increased organic matter and increased nutrient availability each season. For more information about the differences between organic and inorganic fertilizer, click here.

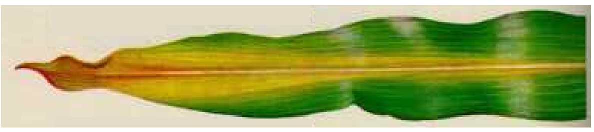
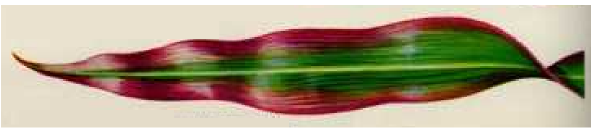
Using Fertilizer: There are four ways to think about appropriate fertilizer use – blend, rate, timing, and placement:

- Blend: This refers to the nutrient content of the fertilizer (e.g. DAP 18:46:0). Different crops, soils, and growth stages require different proportions of plant nutrients. For example, if a maize plant shows visual signs of zinc deficiency, a blend that includes zinc would be appropriate.

- Rate: This refers to the amount of fertilizer used (e.g. 50kg per acre). Similar to selecting a blend, different crops, soils, and growth stages require different quantities of plant nutrients. For example, maize uses a lot of nitrogen relative to other crops, and will therefore benefit from the use of greater nitrogen rates than other crops.

- Timing: This refers to when fertilizer should be applied. There are typically two points during the season when fertilizer is applied – at planting, and in the middle of the season (referred to as "topdress"). However, exactly when topdress application should take place is typically dependent on both the environment and on plant biology. For example, a maize plant will use about 40% of its nitrogen between the 30th and 60th days. Therefore, farmers should time their nitrogen topdress application based on this heavy usage period.

- Placement: This refers to the distance that the fertilizer is applied from the seed or plant. This is a balancing act. If you apply certain fertilizers too close to the seed at planting, it can harm the seed. However, if you apply fertilizer too far from the seed, the seedling will not have access to the nutrients provided by the fertilizer. For more information about using fertilizer, click here.

Nutrient	Deficiency Symptoms
Nitrogen (N)	
Phosphorus (P)	
Potassium (K)	

Plant Nutrients: Plants, like humans, need certain nutrients to grow and each nutrient plays a specific role in a plant's development. If any one of these nutrients is deficient, a plant's health and yield will suffer. It's actually quite simple to visually identify certain nutrient deficiencies in plants. In the figure above are a few examples of common maize nutrient deficiency symptoms. We focus on the three "macronutrients" here, though it is important to remember that there are 17 different nutrients that are essential to healthy plant growth. Crop yields will be limited by any deficiency, no matter the nutrient. For more information about the roles of different plant nutrients and visual symptoms their deficiencies present, **click here**.

Fertilizer and the Environment: Excessive or wasteful fertilizer use can have negative environmental effects. This is why it is incredibly important that care be taken to train farmers on best fertilizer use practices. Fortunately, there is an alignment of incentives because efficient fertilizer use is good for both the environment and the farmer's bottom line. There are a few specific ways in which fertilizer use can be harmful to the environment:

- Leaching: This occurs when nitrogen and other nutrients that have been applied to the soil as fertilizer are not used by the plant. Rather, these nutrients are pushed deep into the soil by rainwater and eventually into groundwater, rivers, lakes, and oceans. In the same way that plant nutrients spur rapid crop growth, they can also lead to rapid algae growth. When heavy leaching occurs, "algae blooms" may form in water bodies and out-compete other water-dwelling organisms for resources. However, with appropriate rates of fertilizer use and application methods, the rate of leaching is fairly minimal among One Acre Fund clients and smallholder farmers more generally.

- Acidification: This occurs when nitrogen undergoes a state change in the soil, which produces hydrogen ions. An increase in soil hydrogen ion concentration is the direct definition of a soil pH decrease or acidification. This process occurs most significantly with the application of ammonium-based fertilizer. For example, the application of 1kg of DAP fertilizer requires the application of 0.74kg of agricultural lime in order to offset its acidity effect.[7] It is important for farmers to adopt acidification-mitigating practices like lime application when they use ammonium-based fertilizers.

Field Notes

Reading a Fertilizer Bag

Fertilizer bags are typically labeled with three numbers. These numbers represent the % content of nitrogen (N), phosphorus (P), and potassium (K) in the fertilizer, always in that order.

However, this is a bit misleading. 17% N does actually mean that the bag is 17% nitrogen by weight. However, 17% P does not mean the bag is 17% phosphorus by weight. 17% actually refers to the molecular form of the phosphorus, which is only 44% phosphorus. Therefore this bag is actually only 7.5% P by weight. The same goes for potassium, for which the molecular form is only 83% K. Therefore, this bag is actually only 14% K by weight. **As such, this 50kg bag of NPK 17 fertilizer contains 8.5kg of nitrogen, 3.8kg of phosphorus, and 7 kg of potassium.** An average One Acre Fund client farmer's maize crop will use 32kg, 9kg, and 32 kg of N, P, and K respectively throughout the course of the season, meaning that if this was the only fertilizer applied to the crop more nutrients would be drawn from the soil than from the fertilizer.

- Greenhouse Gases: These are emitted both during the production of nitrogen fertilizer and after its application to the soil. Production of 1 ton of nitrogen fertilizer can result in 3.6 tons of carbon dioxide released into the atmosphere.[8] Additionally, when that ton of nitrogen fertilizer is added

[7] http://extension.psu.edu/agronomy-guide/cm/sec2/sec28
[8] http://yara.com/doc/122597_2013_Carbon_footprint-of_AN_Method_of_calculation.pdf

to the soil, if not properly managed, it can release nitrous oxide into the atmosphere. The impact of one molecule of nitrous oxide on global warming is about 300x that of one molecule of carbon dioxide. However, with limited quantities and microdosing, nitrous oxide releases in East Africa are minimal. For farmers who are moving from very low to reasonably high levels of production by applying small amounts of fertilizer, the increased plant photosynthesis can, by some measures, offset the carbon dioxide emitted by the production of nitrogen fertilizer.[9] For more information about fertilizer and its effect on the environment, **click here**.

Key Takeaways:

- There are many differentiating characteristics of seeds, including how they are bred, how much they can yield, how they taste, what they look like, how long they take to mature, and what they can resist.
- Organic and inorganic fertilizers are complements, not substitutes. Organic matter and plant nutrients are both necessary to produce healthy and sustainably productive crops.
- Smart fertilizer application is critical. Maximizing farmer profits and minimizing environmental harm often go hand in hand.

[9] https://openknowledge.worldbank.org/bitstream/handle/10986/11868/673950REVISED000CarbonSeq0Web0final.pdf?sequence=1

Section #5: Practices – *What One Acre Fund recommend to farmers*

Seeds and fertilizer are the primary inputs that go into smallholder agricultural farming systems in East Africa. These two components are the backbone of the One Acre Fund input supply program. However, they only partially contribute to a successful harvest. There are a number of other necessary tasks that are important for food plants to maximize their yield potential. These tasks include tillage, planting practices, weeding, biotic stress management, and harvesting. Together, these practices are referred to as agronomy. Individual components of agronomy may have marginal effects on yields. However, when aggregated, the synergies of good agronomy with improved seeds and fertilizer create high yields and farmer profits. Agronomic practices are not universal; there is considerable variability in what is appropriate both within and between countries. This document outlines the general categories of agronomic practices.

PREPARING FOR THE SEASON

There is no universal consensus on tillage. Some research has shown that no-till systems are beneficial while other studies have shown that tillage systems are beneficial. However, there is agreement that tillage should be minimized as much as possible. At One Acre Fund, we primarily view tillage as serving two purposes – weed control and ease of planting.

A farmer uses a hand hoe to till land.

Tillage: At the end of the dry season, farmers in East Africa till their soils. This practice serves a couple of functions. Primary tillage breaks up the hardness of the soil that has developed over the previous year through compaction. Any weeds that have become established are killed and worked into the soil during primary tillage. Primary tillage is usually done when the soil is dry, before the rains. Near the beginning of the rain, farmers till the soil for a second time. This tillage is usually done after it has started to rain and just before planting. There are two objectives for tilling at this time – to kill any weed seeds that have germinated and to break up the large clods that are left from the primary tillage. This makes the soil fine and loose to facilitate good contact with the planted seeds – often called the "seedbed." For more information about tillage, click here.

DURING THE SEASON

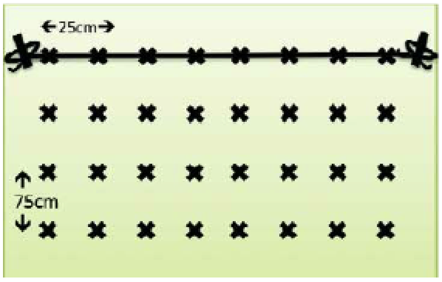
Once the soil has been tilled and the rains have started, it is time to plant! The question is, when is the best time to plant?

Planting Timing: Ideally, planting should happen as early as possible during the rainy season. However, farmers are generally discouraged from planting immediately at the onset of the rains. The rainfall in eastern and southern Africa typically starts erratically. If farmers plant at the first rain there is a risk that the rain will stop for a few weeks or a month before starting in earnest. If this happens, the plants will die. At One Acre Fund, we recommend that farmers plant after three days of steady rainfall to reduce the risk of planting based on the so-called "false rains."

Country (One Acre Fund HQ)	Rains begin	Rains end	Total annual rainfall (mm)
Ethiopia (Bahir Dar)	April	November	1400
Uganda*† (Kamuli) & Kenya*† (Kakamega)	January	December	1300 (UG) & 1500 (KE)
Tanzania (Iringa) & Malawi (Zomba)	November	April	750 (TZ) & 730 (MW)
Zambia (Kabwe)	September	March	900
Rwanda† (Rubengera) & Burundi† (Muramvya)	September	May	1200 (RW) & 1300 (BU)

* In eastern Uganda and western Kenya there is usually a mid-season low rainfall period around July/August and a dry season from November to February. † In these countries, there are two planting seasons per year.

Planting depth and spacing: The two principal variables to consider at planting are planting depth and spacing (both within and between rows). With planting depth, seeds need to be placed deep enough so that they do not dry out, but not too deep as to deprive them of the energy to emerge. A good rule of thumb is that any seed should be planted at least as deep as twice the length of its widest axis.



Common planting spacing for maize

Farmer Perspectives

Using a hand hoe

Jembe, khasu, and isuka are all local words for the hand hoe. The hoe is the most ubiquitous farm implement; it is found across eastern and southern Africa. Unlike the western-style hoe, the African hoe is relatively thick, wide, and heavy. The weight and angle on the handle make it effective at tilling and digging holes. When well sharpened, it is also an effective weeding tool. In skilled hands, the hand hoe is a very versatile tool. The size and shape of the blade and the angle of the blade on the handle can change depending on the use. For example, a hoe that is spade-shaped and set at a 45° angle to the handle is ideally suited to quickly harvest groundnuts buried deep in the ground.

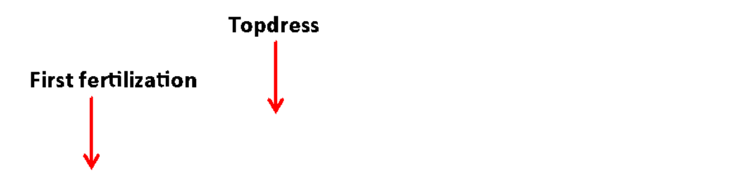
Planting spacing is more variable. Ideally, the plants should be spaced so that there is minimal root and leaf overlap, to minimize competition for light, water, and nutrients. There should also be enough space between plants to allow for optimal airflow – poor airflow can cause diseases. One of the principal determinants of planting density is water. In drier areas (e.g. Tanzania, Zambia, and Malawi), the planting spacing should be wider to maximize the soil water available to the plants. In wetter areas (e.g. Rwanda and Kenya), the planting spacing can be smaller – more water in the soil means competition between plants is not as great. For more information about plant spacing, click here.

Weeding: Weeds are a major management constraint in farming systems worldwide. Smallholder farming systems typically manage weeding through hand tools. If left unchecked, weeds can reduce yields by up to 100%[10]. In addition, the act of weeding is one of the major recurring labor expenditures for smallholder farmers. A good understanding of weed ecology can

[10] http://eu.wiley.com/WileyCDA/WileyTitle/productCd-0471370517.html

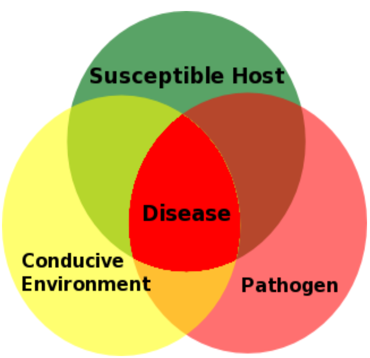
help develop innovative ways to enable farming communities to successfully manage weeds. There are two principal strategies for weed control – (1) reducing the seed bank and (2) controlling weeds early in the season. The weed seed bank is reduced by letting the weed seeds germinate and then killing the weeds before they can flower and produce seed. One of the major reasons for primary and secondary tillage is to control weeds before planting maize or other crops. The first couple of months (5-6 weeks) after planting are one of the most critical times to weed. If weeds establish at this stage, they will compete with the young plants for nutrients. Once the plants are mature and established (3-4 months) and the leaf canopies have closed, the crops are less sensitive to weed pressure. After the crops have emerged, it is common to weed the fields two or more times. During in-season weeding, how weeding is done is as important as how many times the field is weeded. The objective of in-season weeding is to cut the weed shoots from the roots just below the soil surface, usually using a hand hoe. The objective is to kill the germinated weeds and reduce new weed seeds from germinating. Because the weed seed bank goes deep into the soil, digging deep in the soil to kill the weeds on the surface will bring up new weed seeds from below, which will germinate and, in turn, need to be controlled. For more information about weeding, click here.

Fertilizer timing and placement: To be effective, fertilizer timing and placement must correspond to the needs of the plant. When the plant is small, not much fertilizer is needed. However, as the plant grows bigger, particularly just before flowering, the demand for plant nutrients increases. This is the reason fertilizer application is split into two or more applications: at planting and as topdress once the crops reach a certain age. By so doing, farmers get the most out of their fertilizer investments. Importantly, when fertilizer is applied, it is best buried a few centimeters in the soil. Burying fertilizer keeps it close to the plant roots and prevents it from washing away or reacting with air and sunshine and evaporating as a gas. For more information about fertilizer timing and placement, click here.



Maize N uptake throughout the growing season. Image from Virginia Tech.

PEST AND DISEASE MANAGEMENT



The disease triangle

During the cropping season, other living organisms may cause harm to food crops. Common harmful organisms include bacteria, viruses, fungi, parasites, insects, and/or weeds. When a living organism causes crops harm, the event is referred to as a "biotic stress" – different from an "abiotic stress" such as drought. Not surprisingly, managing biotic stresses like pests and diseases can be challenging. The prevalence and severity of biotic stresses can vary from season to season even on the same farm. There are a few key principles to understand when developing biotic stress management strategies.

Disease Management: The "disease triangle" (pictured above) is a framework for thinking about disease emergence, prevalence, and persistence. Three components – a pathogen, a susceptible host, and a conducive environment – are needed for a disease to emerge and persist. Consider these three factors in the context of the bean disease Angular Leaf Spot (ALS), which is endemic in many areas of East Africa:

1. The Pathogen: A fungi called *Isariopsis griseola*

2. The Susceptible Host: Principally common bean plant (both bush and climbing) in East Africa, though a number of other crops can be hosts as well (e.g. cucumbers)

3. The Conducive Environment: Warm and humid conditions

To develop an effective disease management strategy, a farmer must consider the best way to reduce or remove at least one of these variables. Fungicides may reduce the pathogen presence and therefore the disease expression. The susceptible host may also be removed through crop rotation or through the inclusion of resistant varieties; in this scenario, despite pathogen presence, the disease is prevented. In some instances, diseases may be managed by targeting incubatory environmental conditions. For example, opening up plant spacing may increase airflow and reduce the relative humidity between plants – for some pathogens, when the relative humidity is reduced the favorable growth environment is also reduced. While targeting one of these variables can provide temporary relief, the most effective disease management strategies follow Integrated Pest Management (IPM) practices. These strategies deploy a broad range of tactics (such as those noted above) aimed at multiple elements of the disease triangle.

Insect Pest Management: Certain insects are a critical part of agricultural systems; they play important roles such as pollination and reducing the population of harmful insect pests. However, there are also many insects that directly damage crops through chewing/destroying leaves, stems, roots, and grain. Some also act as pathogen vectors. For example, aphids and thrips carry the component viruses of Maize Lethal Necrosis (MLN), a major maize disease in East Africa. Management of insect pests should, like disease management, follow an IPM approach. In the case of insect pests, the following approaches are frequently employed:

1. Resistant Seed: Some varieties have been bred to be less susceptible to damage caused by particular insects. In the case of maize pests, resistance to stalk borer damage has been bred into some maize varieties.

2. Environment Manipulation: Changing environmental conditions may reduce pest pressure. Examples include planting rows of crops along prevailing winds. The wind may prevent certain pests (e.g. thrips and aphids, who are not strong flyers) from establishing.

3. Biological Controls: These can be products that introduce beneficial living organisms to the agroecosystem in an effort to combat harmful organisms. These may include beneficial fungi like Trichoderma or insects like wasps and ladybugs. Other methods include diversifying farms to include resistant crops and/or include crops that exude certain chemicals that repel insects that may otherwise damage crops.

4. Chemical Controls: Some chemicals are potent short-term controls of pest pressure. These are products that contain an active ingredient(s) that is toxic to the target pest. These methods are preferably only used if the other three approaches have proven unsuccessful.

AT THE END OF THE SEASON

Harvest: There are two possible harvest periods for maize. The first is during the "green stage" before physiological maturity. This maize is harvested to be eaten fresh as a vegetable. The second harvest period is at physiological maturity when the maize plant stops investing resources in grain development. This maize is harvested for grain. If a maize plant is harvested in the green stage it will not produce a harvest at the end of the season. This bimodal harvesting cycle is partly why maize farming is so popular.

Drying: When mature maize grain is harvested, the moisture content typically ranges between 25 – 30%. However, to prevent rot during long-term storage, the moisture content in the grain needs to be below 13%. Farmers typically achieve this by either spreading the grain out in the sun to dry or by hanging the unshelled cobs from the rafters of their house/store.

Storage: For long-term storage, it is important to dry the maize grain thoroughly. Maize will store for over 10x longer if at or below 13% moisture. If the maize grain is too moist during storage it may develop mold, which can contain toxic compounds such as aflatoxin. Apart from rotting, insect pests are a major problem for stored grain. Insecticides and improved storage bags are some of the ways insect pests are controlled.

Field Notes

Determining maturity: the black layer

After pollination in maize, the plants funnel water and nutrients into the developing maize grain on the cobs. This stage is called "grain filling". When this process is complete, the maize is ready for harvesting, called "physiological maturity." No matter how much longer the grain stays on the plant it will not get bigger. Judging when this occurs can be difficult. However, there is a good visual indicator. Nutrients are transferred to the grain at the point where the kernel attaches to the cob (a sort of umbilical cord). When mature, this attachment place turns black and is referred to as the "black layer." Presence of the black layer can be used as an indicator to determine when to harvest.

No black layer → Black layer

Key Takeaways:

- Tillage, planting, weeding, fertilizer application, biotic stress management, and harvest are the major components of basic agronomy.
- While there are many similarities in practices between countries, agronomic practices have to be contextualized to the local environmental and cultural conditions.

Section #6: Yields – *Perspectives in the African agricultural landscape*

What is a good yield? This is a common question for anyone working in unfamiliar agricultural environments or for new members of any agricultural community. Most smallholder farmers served by One Acre Fund know this intimately. However, while yields are highly variable by crop species, variety, and agro-ecological zone, their knowledge is limited to nearby farms. In addition, there is no universally standard unit for yields. All of these complexities make it difficult to quickly answer this question. The objective of this section is to provide a bit of context and perspective to crop yields in the regions where One Acre Fund operates.

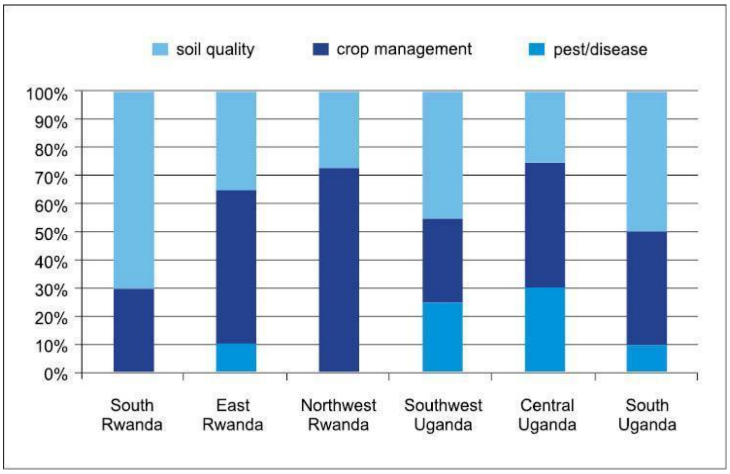
THINKING ABOUT CROP YIELD GAPS

Yield comparisons can be a fascinating thing. We often think of yields by comparing the harvests of One Acre Fund farmers with those of non-One Acre Fund farmers. We need to go a step further and consider the actual yields of program farmers against their "potential" yield. This is essentially an assessment of the gap between what farmers are getting and what they could achieve with ideal management and input selection. For more information about the effects of yield gaps in smallholder farming, **click here**.

Yield potential: One way to compare different crops, varieties, and geographic areas is on their "yield potential." There are some specific ways this is looked at, but the general idea is that crops in a particular environment (temperature, elevation, soils) under ideal management are expected to produce a specific yield level. This is typically referred to as "genetic yield potential" – the yield potential when the environment is not a limiting factor, only the genetics of the seed used. "Water-limited yield potential" is another way researchers and breeders think about yield potential.

Attainable yield potential: Understanding that some environments are not ideal (e.g. rainfall limited) and that resources are limited (e.g. fertilizer amount) we must also consider what is "attainable." This is the yield potential of some One Acre Fund farmers. Attainable yield potential will vary by location. For example, attainable yield potential for farmers in drier areas (e.g. Malawi) is not expected to be the same as wetter areas (e.g. Rwanda). Additionally, in some cases it may not be profit-maximizing to reach "genetic yield potential"; "economically optimum" yield may be sought after instead.

Actual yields: The yields that farmers produce under current practice, with all environmental limitations in place, are referred to as "actual yields." These yields are lower than the potential yield for a variety of reasons, including rainfall variability, soil infertility, poor agronomic practice, and lack of access to/use of high-quality inputs. These yields would typically be what we see from some One Acre Fund farmers as well as others outside the program.



How to think about the gap: The difference between potential and actual yield is referred to as a "yield gap." This is basically the amount of yield that is unrealized because of sub-optimal practice or inputs. Figuring out how to "close" a yield gap is complicated. Different factors contribute to a yield gap, with different degrees of severity depending on the region. For example "soil quality" could contribute anywhere from 30-70% of the Rwandan banana yield gap depending on the region. It is important to investigate yield gaps on a geography-specific basis because distributing more fertilizer may boost yields in one area, but do nothing in another area. For yield gap data for various crops in Africa, **click here**.

MAIZE YIELDS IN PERSPECTIVE

Maize is one of the most important food crops in the world, with over 1 billion metric tons produced globally. Some 65 million tons of maize are produced in Africa (around 6.5% of global production), which serve as a staple food for over one hundred million people. Maize has seen a profound transformation over the past 60 years. Pre-1950s, the global maize harvest was below 1.5 tons per hectare (t/ha). Global averages for maize production are now upwards of 4 t/ha. This has largely been the result of hundreds of millions of dollars invested in maize genetic improvement, nutrient management, and agronomy. The USA and Brazil are world leaders in maize production, with an average yield approaching 10 t/ha. Maize production in Africa has the lowest current productivity at 1.5 t/ha on average.

The current genetic yield potential for long-maturing maize is above 12 t/ha while genetic potential for short-maturing varieties is around 8 t/ha. In smallholder systems of Africa, attainable yield (rain-fed with moderate fertilizer use) is between 8-10 t/ha for long-maturing varieties and around 4-5 t/ha for short-maturing varieties. For more information about maize yields in sub-Saharan Africa, **click here**.

COMMON BEAN YIELDS IN PERSPECTIVE

Common beans (*Phaseolus vulgaris*) are the second most important crop in eastern and southern Africa. Beans are a staple food for more than 200 million Africans. Continental production is estimated at 2.5 million tons. While common beans are a critical source of nutritional protein for much of the world's poor, investments into improved varieties are only a small fraction of that of maize.

There are two primary types of common beans: bush and climbing. Bush beans mature rapidly and all at once while climbing types mature over a longer period of time and produce seed throughout the season. The genetic yield potential for bush beans is over 2 t/ha, while the genetic potential for climbing beans is over 4 t/ha. Achievable yield potential is estimated to be around 1.5 t/ha for bush beans and around 3 t/ha for climbing beans. The actual yield for smallholder farmers is currently around 0.5 t/ha for bush beans and 0.8 t/ha for climbing beans. For more information about common bean yields in sub-Saharan Africa, **click here**.

Field Notes

Converting between different yield measurements

Crop yields are commonly measured in units of weight or volume of grain per unit land area. Unfortunately, there is no universal standard of measurement — it all changes from country to country. The closest universal measurement system is the metric system; however, many African countries use different mixtures of metric units and imperial units. Here is what is common in the various country programs:

kg/acre – Kenya and Uganda

kg/are – Rwanda and Burundi

kg/hectare – Ethiopia, Tanzania, Malawi, and Zambia.

However, it is more common for farmers (who do not have scales) to measure in volume (bags) per land area. This is also what is done in the USA (bushels – a basket – per acre). Below are some useful conversions:

1 hectare = 100 ares = 2.47 acres

1 metric ton = 1000 kg = eleven 90 kg bags of maize.

OTHER CROP YIELDS IN PERSPECTIVE

Millet, sorghum, and cassava are often referred to as "minor" crops. Both millet and sorghum are native to Africa, drought-tolerant, and among the most nutritious grains known. While cassava is not native to Africa, it is highly tolerant to drought and poor soil fertility. Few crops have a yield potential as high as cassava. However, despite the notable benefits of these crops, very few resources have been invested in their genetic improvement. In fact, the genetic yield potential of sorghum is not known. Experts believe it may be much higher than that of maize!

The current genetic potential for finger millet is 6 t/ha, achievable yield stands at 2 t/ha, and actual yield at around 1.8 t/ha. The current known genetic potential for sorghum is around 8 t/ha, and its genetic potential may be as high as 16 t/ha[11]! Achievable yield for the currently available varieties is around 3.5 t/ha, but smallholder farmers typically harvest around 0.75 t/ha. Clearly, there is untapped potential with sorghum. On the other hand, the genetic potential for cassava is above 30 t/ha, achievable yield is in the range of 20 t/ha, with current varieties and management practices. Africa's smallholder farmers typically harvest around 10 t/ha.

Farmer Perspectives

Post-harvest food loss

When we think about yields, we often think about "tons per hectare" or "bags per acre." While this is an important number, it's important to consider that this yield is not necessarily what makes its way to a farmers' table. Post-harvest losses to pests like weevils and rats, to mold, and to physical loss can quickly reduce a farmer's yield by more than 10%.

If that harvest is not stored properly it can disappear within 3-6 months. The fear of post-harvest loss can push farmers to sell early at lower prices. This is why practices like proper drying and the use of strong storage bags and insecticidal dusts are so important to smallholder farmers.

Clearly, all of these crops have a high potential for development. They are some of the most drought-tolerant crops and produce decent yields in the most degraded soils. Many of these crops sustained indigenous smallholder production for thousands of years. With increased awareness of their nutritional benefits, perhaps commensurate research efforts can be placed on these crops in the future. For more information about general crop yields in sub-Saharan Africa, click here.

	Finger Millet	Sorghum	Cassava
Genetic potential	6.0 t/ha	8.0+ t/ha	30+ t/ha
Achievable yield	2.0 t/ha	3.5 t/ha	20 t/ha
Actual yield*	1.8 t/ha	0.8 t/ha	10 t/ha

** From FAOSTAT, not 1AF farmer data.*

Yield is not the only outcome that matters, but efficiently achieving high yields is one of the best ways that farmers can both positively impact the environment and earn the money they need.

[11] *Lost Crops of Africa. Grains. 1996. National Academies Press*

Key Takeaways:

- There exist substantial yield gaps between what farmers harvest and what they could harvest.
- Addressing these yield gaps needs to include local adaptation of inputs and agronomic practices.
- The largest yield gaps are found within the least developed crops.

Section #7: Recommended reading

This primer provides only a simple surface-level overview of very complex subjects. Please refer to the "click here" links within the document to explore specific topics in greater depth; additionally, below are links to a few other reference materials that are particularly helpful.

ONLINE RESOURCES - SOILS

Soil Atlas of Africa: In this three-part download, the European Commission Joint Research Centre renders a visually striking guide to the soils of Africa. In addition to soil maps, the atlas provides thoughtful information about the state of African soils.

ONLINE RESOURCES - CROPS

CABI Crop Guides: This is an online resource library with free, downloadable agronomy and biotic stress management guides for 22 different crops including bananas, coffee, maize, common bean, sweet potato, cassava, millet, pigeon pea, rice, and groundnut. These guides are translated into 25 different languages including English, French, Kiswahili, Chichewa, and Bambara.

Seed Business Management in Africa: Written by John MacRobert – one of the most respected African seed systems researchers – this guide provides an in-depth introduction to how seed is bred, regulated, and made commercially available in many African countries. It also dives into seed company marketing and financials.

Atlas of Common Bean Production in Africa: A general CIAT overview of common bean agriculture in Africa. This resource covers everything from the environmental factors that influence bean productivity to the use of different types of seed to counter pests and diseases that affect African bean production, and their relative impacts depending on the exact country and region.

Insect Pests of Maize: A Guide for Field Identification: A CIMMYT guide that provides both written and visual identification support when determining which maize pests are most prevalent in a given area. This resource also provides recommended management strategies for each specific pest.

BOOKS AND PUBLICATIONS

Biology of Plants, 7th Edition: The definitive text in the introduction to botany, *Biology of Plants* contains extensive coverage of plant diversity, chemical interactions, evolution, ecology, taxonomy, genomics, and plant hormones. This book relies extensively on visual depictions of plant biology.

Principles of Field Crop Production: Introduces over fifty species of crops and the most current principles and practices used in crop production today. Learn the botanical characteristics, economic importance, history, and adaptation of various species and how science and technology impact their production.

The Nature and Property of Soils, 14th Edition: Takes an ecological approach that effectively explains the fundamentals of soil science. It covers soil erosion and its control, soil acidity, chemical pollution, and soil ecology.

Agricultural Experimentation: Design and Analysis 1st Edition: Introduces principles of experimentation and explains common experimental designs, and offers detailed, step-by-step procedures showing the logic and reasoning behind each analysis. It also includes sections on correlation and regression, analysis of counts, and mean separation, with especially thorough coverage of transformations and ANOVA.

Good Statistical Practice for Natural Resource Research 1st Edition: This book provides a practical approach to applying statistics to a wide variety of studies or projects. The topics covered include types of study in natural resource management, planning, data management, and analysis. The book has been written for professionals in all disciplines in agriculture, forestry, rural development, environmental, and related sciences.

Weed Science: Principles and Practices, 4th Edition: Provides a detailed examination of the principles of integrated weed management, with important details on how chemical herbicides work and ought to be used. Other topics include the use of conservation-tillage systems, environmental concerns about the runoff of agrochemicals, soil conservation, and herbicide resistance.

Maize Agroecosystem: Nutrient Dynamics and Productivity, 1st Edition: Includes the history of maize growing, the kinds of soil that best support maize farming, nutrient dynamics, the use of soil organic matter, the physiology, and genetics of maize, and integrated nutrient management. It also highlights the impact of crop genotype on soil nutrient dynamics and productivity.

Bananas and Plantains (Crop Production Science in Horticulture) 2nd Edition: Provides a review of the scientific principles of banana production and how these relate to field practices. It also includes world trade statistics and policies, breeding new cultivars in relation to disease resistance and markets, and prospects for genetically modified bananas.

Lost Crops of Africa: Volume 1: Grains: Covers available information on where and how various grains are grown, harvested, and processed, and lists their benefits and limitations as a food source. Specifically, this resource covers African rice, finger millet, fonio, pearl millet, sorghum, and teff.

Maize and Grace: Africa's Encounter with a New World Crop, 1500-2000: Explains the history of the introduction of maize to Africa and how it spread across the continent over the past 500 years, replacing more traditional grains like sorghum, millet, and rice. Today, maize accounts for more than half the calories people consume in many African countries.

Crops and Man, 2nd Edition: Explains how human activities have shaped the evolution of crops used for food, feed, and fiber. The world food supply now depends largely on only 12 to 15 plant species owing to the continued erosion of diverse gene sources from ancient landraces.

Section #8: Frequently Asked Questions

How does One Acre Fund distribute agricultural inputs?

One Acre Fund is a nonprofit social enterprise that equips smallholders with the tools to significantly increase their farm productivity, improve their climate resilience, and build lasting pathways to prosperity. We offer farmers a holistic bundle of products and services, including key agricultural inputs such as natural hybrid seeds and fertilizer. Farmers receive these high-quality inputs on credit, as an in-kind loan (Inputs are accompanied by services such as delivery and technical trainings; please see our model for a full description.)

On average, 97%+ of One Acre Fund clients successfully repay their input loans in full each year [as of 2020, these repayments cover 77% of our core program costs; donor support covers the remainder]. We offer flexible repayment schedules to accommodate all farmers. We also provide crop insurance that delivers partial or full loan forgiveness when yields are meaningfully below a geography's historical averages.

What are we doing to ensure environmental sustainability? Do we promote organic farming techniques?

One Acre Fund's top priority is long-term soil health and productivity. Our work is informed by a deep understanding of and respect for the limits and cycles of agroecological systems – particularly soil, the farmer's most important asset. In many areas where we work, years of widespread practices such as monocropping and crop residue removal have 'mined' soils of key nutrients, creating a downward cycle for resource-constrained smallholders. One Acre Fund is dedicated to enabling clients to reinvest in their land and re-establish healthy, rich soil that can support sustainable agricultural production for generations to come.

As part of this effort, we have developed extensive in-house soil testing capabilities and undertaken longitudinal studies of measuring the soil health of thousands of Kenyan and Rwandan farmers, which we are looking to expand to other country programs. The resulting data helps ensure that our program 'does no harm' to client soils, and underpins our design of agronomic and behavior-change trials to rigorously explore specific soil health interventions; we only scale practices that demonstrate strong impacts on soil fertility and robust farmer adoption.

At present we take a multi-pronged approach to enabling clients to increase their long-term soil fertility:

- Land management – We train and encourage practices that build organic matter in the soil and reduce erosion. These include composting (with plant residues and animal manure), mulching (covering the soil with plant residues), contour tillage (making rows perpendicular to the slope of the land), and on-farm tree-planting (which reduces erosion, improves soil retention, strengthens local biomes, and provides natural mulch).
- Smart fertilizer use – To drive up food production and achieve food security, we believe that some amount of mineral fertilizer is generally necessary. But we also understand that too much inorganic fertilizer can affect soil structure, so we employ a number of measures to minimize the potentially negative effects of fertilizer on soil health. One of these is microdosing - applying small quantities of fertilizer onto the seed during planting, or close to the seedling when topdressing. Through farmer trainings, we actively promote using the smallest amount of fertilizer possible using fertilizer scoops (these deliver less than a thimble-full of fertilizer to the roots of a crop, reducing the risk of runoff).

- Fertility products – Additionally, we proactively offer products that allow farmers to restore otherwise degraded soil. This includes agricultural lime, which addresses soil acidity, and legume seed inoculants which restore critical soil microorganisms to the soil. We are actively trialing a number of other products that fit this same bill.

Overall, within our operating context, we have found that a careful and sustainable blended approach of organic inputs and inorganic fertilizers enables farmers to increase both the organic matter and nutrient availability of their soil — a position widely supported in the sustainable agriculture research community. For more on this subject, **click here**.

What is the difference between "regular" seed and hybrid seed?

Local or open-pollinated varieties are the result of a genetically diverse male pollinating a genetically diverse female. In the case of "local" seed, this happens in farmers' fields either intentionally or unintentionally. In the case of "improved" open-pollinated varieties, this happens under the care of a trained breeder looking to select specific traits from genetically diverse plants.

Hybrid varieties are the result of a genetically pure male pollinating a genetically pure female. Each of the two "parents" would have been "inbred" over the course of a number of seasons to isolate specific traits. Those genetically pure parents are then cross-pollinated to produce a "hybrid" seed. A phenomenon known as "hybrid vigor" results from crossing two genetically pure parents, meaning that the seed produces a particularly vigorous and high-yielding plant. However, if a farmer re-plants seed harvested from a hybrid crop, it will not perform as well due to the lack of "hybrid vigor" in that generation of the seed. Due to long breeding, release, and production timelines, it can often take 5-10 years to develop and introduce a new hybrid seed.

One Acre Fund offers hybrid seeds because they enable larger yields, offer other benefits such as drought or pest resistance, and encourage farmers to embrace diversification instead of monocropping; in sum, these advantages make farmers less susceptible to crop failure and maximize their return on investment. We continue to innovate within the seed space. For example, in Kenya, we are increasingly investing in seed recommendations optimized for specific agro-ecological zones; in Rwanda, we have collaborated with public-sector partners to establish local hybrid seed production and processing capacity. Organization-wide, we are continually trialing and scaling up new seed varieties.

**Note that One Acre Fund does not sell genetically modified (GM) seeds. GM seed is illegal in most of One Acre Fund's countries of operation.*

How do we select the inputs we sell?

The products that we sell go through a multi-phase evaluative process before ever reaching the farm. First, we actively engage with world experts in various fields of study as well as industry leaders developing products for smallholder farmers. We then determine which products are most likely to both deliver impact and allow scalability. Second, we test our hypotheses at our research stations and on trial-farmer fields. If a new innovation (maybe a new seed, fertilizer, or agricultural practice) shows a clear improvement over current practice controls and farmers want it, we begin to offer the product at scale. This whole process typically takes 1-2 years. Lastly, we source mass-scale inputs on commodity markets to optimize prices for our clients.

Why do we work with the crops that we work with?

To a large extent, we work with crops that farmers in the areas we work are already growing. These are mostly cereals like maize and sorghum, legumes like bush and climbing beans, and tubers and root vegetables like potatoes and cassava. Our goal is to make sure these crops are grown as profitably and sustainably as possible. In some cases, we sell crop packages that aren't particularly prevalent (e.g. soybean in Kenya) with the goal of stimulating demand for a crop that we believe is (1) agro-ecologically suitable for the area, (2) marketable and profitable, and/or (3) a promising crop for rotation and soil fertility.

What are the primary drivers of yield gaps for the crops we work with?

There are a number of drivers that may contribute to a crop's yield gap in a particular area and/or in a particular year. The exact degree to which each of these drivers contributes is often both geographically and seasonally variable. However, in general, the following factors often contribute to yield gaps to some extent:

- Soil infertility – low soil carbon and pH levels may contribute to low yields. This is addressable with the use of compost and agricultural lime.
- Inappropriate fertilizer use – using too little fertilizer, the wrong fertilizer, or applying it incorrectly may contribute to low yields.
- Inappropriate seed use – using an unimproved seed or a seed that is not well-suited to particular growing conditions may contribute to low yields.
- Inappropriate agronomic practices – planting at the wrong time, using the wrong plant or row spacing, and poor timing may all contribute to low yields.
- Strong insect, weed, and/or disease prevalence – insect damage, nutrient competition from weeds, and the presence of crop disease may contribute to low yields.

Who do we work with externally on agricultural research?

We work with a number of national and international research institutions and universities. These include KALRO (Kenya), RAB (Rwanda), ISABU (Burundi), and SARI (Tanzania). We also work with a number of CGIAR research centers such as CIMMYT, CIAT, ICRAF, and IITA. A number of private research institutions, such as IFDC and IPNI, are also involved in our work.