Comparison of Cassava Yields and Water Infiltration Under Conservation Ag vs. Conventional Practice
Executive Summary

Eighty percent of Mozambique’s smallholders depend on rain-fed, non-mechanized and subsistence-based farming practices. Much-needed agricultural extension services and inputs such as fertilizers, pesticides and improved plant varieties are difficult to access. Increasingly irregular rainfalls, cyclones and higher temperatures are placing further constraints on farmers’ livelihoods, agricultural productivity and food security. In the Nampula region, poor soils, limited access to water, infrastructure and transport, reducing fish stocks and shortened fishing and farming seasons leave these communities in a highly vulnerable situation.

Since 2010, CARE International has been promoting Conservation Agriculture (CA) with small scale farmers in the coastal districts of Nampula Province in Mozambique as part of the CARE-WWF Alliance program in the Primeiras e Segundas, an Area of Environmental Protection declared in 2012 that permits subsistence use. Conservation Agriculture (CA) is an agriculture approach that focuses on soil conservation and improvement through the achievement and continual application three principles:

1. Minimum tillage;
2. Permanent organic soil cover;
3. Crop rotation and/or diversification.

Adoption of practices that support all three CA principles is around 28% for males and 32% for females that were former group members suggests that uptake of practices may be strongly influenced due to long term exposure to FFS activities, and that adoption seems to be relatively gender-balanced. Through a methodology called Farmer Field Schools (FFS), the CARE-WWF Alliance use CA to build the capacity of these farmers to sustainably produce sufficient foodstuffs to satisfy their own consumption needs in the face of both a decreasing soil base and increasingly erratic rainfall patterns. The FFS model provides a platform for learning that directly relates to the practices farmers depend on for their livelihoods. It strengthens links between different agricultural service providers and build farmers’ capacities in sustainable agriculture techniques, focusing on protecting and building soil fertility and introducing a wider diversity of crop varieties.

The CARE-WWF Alliance hired an external consultant to conduct trials on 8 FFS demonstration plots from 2014-2015 in Angoche and Moma Districts in Nampula Province, where CA had been practiced for over three years. The study was commissioned to compare CA and traditional practices to test:

1. The capacity of CA to improve infiltration of moisture in the form of rainfall from the surface of the soil into the soil profile.
2. Yields produced by the improved and local varieties of cassava under CA and conventional practices (CP).

In soil science terminology, infiltration refers to the process by which water on the soil surface moves into the soil. How fast or slow water enters the soil is known as the infiltration rate. These trials confirm that CA practices lead to the accumulation of soil organic matter. Therefore, under CA, there is a higher infiltration rate of water from the surface into the soil profile compared with soils where conventional practices were applied. Additionally, under CA practices, improved varieties of cassava out-produced both local varieties and the improved varieties grown under conventional practice. Moreover, cassava yields and water infiltration rates were higher where CA had been practiced continuously for a longer period of
time, suggesting that the effects of CA accumulate positively as practices persist longitudinally over successive seasons. This result is likely due to the lower incidence of disease, the higher levels of organic nutrients, improved soil moisture, and potentially higher populations of mycorrhizae in the soil that increase nutrient uptake by the cassava roots in soils.

These findings lead us to conclude the following:

- **Improved Varieties:** The Alliance should continue to promote CA in conjunction with promotion of Nziva cassava and other disease-resistant varieties.
- **Water Infiltration:** CA enhances the ability of coarse soils, like those in coastal Nampula Province, to infiltrate water.
- **Input Supply:** The Alliance should explore ways to scale the dissemination of improved varieties—not only of cassava, but also the diverse array of cover crops, cereals, and pulses—to better facilitate the adoption of CA methodologies.

There is strong evidence to suggest that CA practices are being adopted both within and outside of the Farmer Field Schools. Adoption of practices satisfying all three CA principles or a single CA principle is more likely by members (and former members) of an FFS. This implies that organizations like CARE and WWF have an opportunity to capitalize on this interest in and adoption of CA practice and should promote CA methodologies broadly.

**Background**

Mozambique’s Nampula Province, shaped roughly like a triangle, shares provincial boundaries with Zambezia Province to the south, Niassa Province to the northwest, and Cabo Delgado to the northeast. The province’s eastern boundary is defined by the Indian Ocean. Nampula is Mozambique’s fourth largest province, with a population of just under 4,000,000—of which nearly 500,000 reside in the eponymous provincial capital, Nampula.

Nampula Province has a significant agricultural presence, with sisal farmed as commercial commodities, often on industrial scales. However, as is the case throughout Mozambique and much of southern Africa, 81% of the nation’s population relies on small-scale cultivation of food crops at or slightly above subsistence level. Key crops—maize, cassava, groundnuts, sorghum, sweet potatoes—are usually grown by smallholders cultivating around than 1.2 ha of land (FAO 2010).

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1 The vast majority of single-technology adopters practiced crop diversification/rotation techniques or a combination of minimum tillage, permanent soil cover, and/or crop diversification. The high number (33%) of the total sample practicing crop diversification and rotation only suggests that farmers are more likely to test with practices such as intercropping, inclusion of new crops, etc., that are easiest to practice without changing the fundamental aspects under CA of either tillage or soil cover.
The Mechanics of Low Productivity

Small-scale farmers in Nampula lack: 1) control over soil moisture; and 2) the ability to appropriately replace soil nutrients. As described below, the root causes of both of these problems are varied and can be dramatically different depending on the agroecology of a particular region. Looking at the underlying reasons for low crop productivity in Nampula Province, the best options for agriculture interventions to build long term resiliency to climate shocks are targeted at altering small-scale farmers’ fundamental practices.

Crop Productivity: Crop productivity levels are generally considered to be low for the following, non-exhaustive list of reasons:

- Small-scale agriculture is entirely reliant on rainfall, which can vary greatly from season-to-season, particularly with global events such as el Nino and la Nina. This is further complicated by the continuing effects of climate change, which has resulted in changing rainfall patterns that lead to a decrease of soil water recharge, impacting ground water resources and the water table in wells.
- Use of external sources of soil nutrients such as animal manure or mineral fertilizers is extremely low; less than 4% of smallholder farmers in Mozambique utilize fertilizers (FAO 2010). This means that the replacement of soil nutrients utilized to grow the majority of food crops, particularly nitrogen, is virtually non-existent;
- There are extremely low levels of improved planting materials which are bred for disease resistance, drought tolerance, higher productivity, etc. In lieu of these improved planting materials, farmers rely heavily on continuously recycled varieties that may be vulnerable to disease outbreaks;
- Small-scale agriculture practices are characterized as “extensive”4, briefly defined as clearing new land for cultivation whilst leaving depleted fields fallow for natural processes to restore soil fertility. The increase in population has resulted in far less open land to clear, and less time, if any, for fields to rest. Extensive practices are also threatening important biodiversity, such as the unique miombo woodland of Eastern and Southern Africa, which is home to some 8,500 plant species, including over 300 trees, and provides food and cover for diverse wildlife of global and local importance.

Access to Fertilizer: Unfortunately, there is neither the agri-business market infrastructure available nor the profusion of animals in Nampula Province to supply fertilizer or manure in sufficient quantities to replace soil nutrients that would allow for a more intensive farming system. Fertilizer availability is proscribed by the quality of infrastructure to supply fertilizers, the ability of the population to purchase these relatively-expensive fertilizers, and the know-how to utilize them properly. Concurrently, the low productivity of small-scale farmers and their subsequent limited financial capacity severely proscribes their ability to purchase expensive, imported mineral fertilizers in sufficient quantities to replenish their fields. Nutrients can be supplied through animal dung, but levels of livestock ownership in Nampula, particularly in the coastal districts, is not at levels sufficient to supply those nutrients.

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2 Clay- or salt-based compounds that largely supply macronutrients such as nitrogen (N), phosphorous (P), and potassium (K).
3 Planting materials include seeds (maize, beans, groundnuts, etc.), cuttings (cassava), vines / slips (sweet potatoes), corms (bananas and onions), tubers (Irish potatoes), rhizomes (ginger), etc.
4 Often characterized rather poorly as “traditional” agriculture.
Further limitations on the effectiveness of mineral fertilizers is the sheer diversity of soil types within limited spatial areas and their capability to respond to uniform blends of either basal- (N-P-K) or top-dressed (urea) fertilizers, resulting often in either insufficient or excessive supply of individual nutrients. In the case of the coastal regions of Nampula Province, soils have high sand fractions; where they have been continuously cultivated, acidity levels in the soil have reached levels where, without upwards correction of soil pH through expensive applications of either lime or gypsum, fertilizer does not boost yields sufficiently to be economically justifiable for low-value, staple crops, such as maize and cassava.

**Water Infiltration:** With the exception of carbon captured from the atmosphere, plants absorb the remainder of their nutrients through their roots in liquid form. On one hand, the lack of soil moisture from limited rainfall can reduce the availability of nutrients to plants; one the other, an excess of rainfall can wash nutrients laterally off the field (erosion) or down through the soil profile (leaching), both of which deplete the soil nutrient pool.

**Access to Improved Inputs:** The improvement of planting materials is an easier task than improving nutrient supply because planting materials can be propagated. For example, if someone plants a cassava (*Manihot esculenta*) cutting from an improved plant variety, that cutting will grow into an identical clone of the other plant, and more stems can be harvested from it in the subsequent year that can be planted with the same qualities. Furthermore, an improved plant variety of a species already familiar to a farmer does not carry with it a significant readjustment of knowledge. A good example of this is the advent of white dent maize as a market crop in Northern Rhodesia (Zambia) during the 1920’s; farmers familiar with growing older flint maize derived from the Columbian Exchange quickly adapted their best practices to the new variety to benefit from the market for the latter (Vickery 1986, McCann 2005). However, the physical presence of planting materials at scale in a remote geography such as Nampula requires significant logistics, as will be discussed later.

To summarize, the intervention with the lightest financial cost is improvement of how small-scale farmers practice agriculture independent of external resources. The goal is to give farmers the knowledge and tools to change their agricultural practices quickly enough to build and preserve overall soil health, such that the same plot is productive enough to feed that farmer’s household year-in and year out, supplying them with sufficient livelihood without resorting to ecologically or socially damaging livelihood pursuits to survive. It is an appealing prospect for sustainable change, but the transmission of abstract ideas is far more complex than the delivery of a handful of seeds or a bag of fertilizers.

**Conventional Practice (CP)**

It is important to preface any discussion of small-scale agriculture in sub-Saharan Africa with a caution against normative definitions. Some conventional agricultural practices have been referred to as “backwards”, “primitive”, or “traditional” when practiced by small-scale farmers; however, similar practices under commercial-scale agriculture are referred to as “industrial” or “modern”. In describing CP,

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5 With the exception of seeds, most planting materials are effectively genetic copies or clones of their mother plant. Open-pollinated seeds (OPVs) and landraces, when grown in a single variety with isolation from other similar species typically have very similar characteristics to their mother plants. Hybrid seeds, esp. maize, do not have similar characteristics with regards to grain yield, resulting in a decline in yield from one generation to the next.

6 Hickory King, an American variety whose descendants now make up the majority of hybrid seed grown in Southern Africa.
we must recognize that methods are fluid and have shifted due to external drivers, such as colonialism, taxation, war, and economic conditions. Simultaneously, so-called “traditional” practices in many cases date back 50 years or less to the introduction and wide-scale promotion of Green Revolution technologies across the African continent. Therefore, it is essential to have a general understanding of CP and why it is so widely practiced, as well as understanding its impact on soil health.

In very general terms applicable to the spatial majority of southern Africa, CP is a series of events that are based around the specific times in the seasonal calendar.

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Table 1 – Agricultural Seasonal calendar for coastal regions of Nampula Province, Mozambique

Clearing: Before the beginning of the rains in mid-to-late November, farmers typically clear the field of any flora, such as trees, shrubs, grass, and the previous crops residue. In most cases, this work is done by hand with either hoes or axes. Cut material is left to dry for a period, then gathered in heaps and set on fire because:

1. The removal of residues reduces the habitat available for rodents that act crop predators, as well as the attendant snakes that prey on the rodents;
2. Burning of trees and shrubs converts nutrients in the wood and leave biomass into nutrients available for plant uptake in subsequent crops, such as potassium and phosphorus. In addition, the burning of larger tree biomass (e.g., trunks and branches) produce large quantities of calcium carbonate (CaCO₃) which helps neutralize soils with inherently low pH levels;
3. The heat from fires often kills weed seeds in the upper layers of the soil, reducing weed competition during the critical early growth of food crops;
4. In denser clay soils, hot fires loosened the soil surface to the extent that little digging was necessary;
5. Removal of surface residues eases later digging or ploughing operations; and
6. Agriculture extension from the colonial period through Independence and into the present day copied European farming conventions that emphasized so-called the preparation of “clean” fields.

7 The miombo woodlands region is home to 86 of the 98 major tree species known in Africa. WWF is working on the ground with local communities, organizations and governments in the region to promote the use of natural resources in a more sustainable way, such as through conservation agriculture, sustainable charcoal production and reduction of water pollution from mines and industries.
**Digging:** Following the clearing of flora from the soil surface, farmers then proceed to manually turn over the entire soil surface using hoes, usually to a depth of 10 to 15 centimeters. In most cases, the inversion of the soil is done as soon as the rains begin, as heavier soils are often too hard to work when dry; also, the high temperatures at the height of the dry season in September and October often preclude hard physical labor. Turning the soil surface is largely done for the following reasons:

1. To prepare the soils for planting by loosening the topsoil, which is a necessity in often well-used, compacted soils. This allows easier growth of young plant roots and increases infiltration of rain into otherwise-compact soils;
2. To bury the weeds that would germinate with scant early rainfall and compete with young crops; and
3. As above (see 6), agriculture extension often emphasizes the inversion of the soil surface as inherent to modern agricultural practices.

Though not characterized as a reason by small-scale farmers, digging the soil surface immediately prior to planting also exposes soil organic matter to oxygen, significantly boosting mineralization of soil organic matter by soil microbes into the plants available nutrients.

**Planting:** Planting occurs immediately after, or often simultaneous to, digging the soil surface. Priority is placed on cash crops (cotton, tobacco, and sesame) and/or carbohydrate-laden food crops, such as cassava or maize, which form the bulk of foods consumed by local households. It is key to note that in coastal Nampula, cassava planting usually precedes the rains, as cassava has the interesting capability to germinate and root in dry soils. Early planting of the cuttings accomplishes two things:

1. Cassava field preparation and planting can be carried out prior to planting of most other field crops such as maize, groundnuts, beans, etc. The farmer thus avoids splitting labor between crops; and
2. Cassava planted prior to the rains can fully utilize the nitrogen flush, resulting in greater growth of the plant and subsequent energy storage in the roots.

**Weeding:** Immediately following planting, farmers undertake the first weeding of their fields. This is necessary to keep weeds from overcrowding and starving the emerging crops of sunlight, moisture, and nutrients. Following these critical operations, crops like groundnuts, beans, and cowpeas are planted in small quantities, either separate from or intercropped with the maize or cassava plants. Other farmers may plant additional portions of maize in the hopes that the rains will last long enough to realize greater harvest, or to spread risk away from reliance on the first planting. Typically, crops that are judged to be well-performing may be weeded again later.

It is difficult to understand the amount of hard physical labor that accompanies the tasks described above; suffice it to say that every able member of the household, inclusive of children, engages in that labor daily for a period of nearly four (4) months, often to the point of exhaustion. Ironically, just as labor demands begin to climb, food supply for households typically drops. January through March is dubbed “the hunger season,” which also coincides with the rainy season. Very little can be harvested in this period, families

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8 This emphasizes what some agronomists refer to as the “nitrogen flush”, where large amounts of nitrogen from organic decomposition are available early in the rainy season.
have less variety in their diet, and the resulting physical weakness and susceptibility to sickness disrupts and delays the execution of tasks, leaving farmers even more vulnerable to climate shocks.

**CP Effects on Soil Health and Staple Crop Production**

It is critical to understand that extensive agriculture in sub-Saharan Africa relies on low population densities and correspondingly high availability of wooded landscapes, like miombo, that can be cleared and put under cultivation, whilst previously used fields are left to fallow under tree and shrub regrowth. This allows the restoration of soil organic matter through leaf litter, as well as the replenishment of soil nutrients through biological nitrogen fixation and nutrient cycling, provided that the fallow period is sufficiently long. However, the high population growth rates of Mozambique, estimated at 2.45% (CIA 2016) on a fixed land base has resulted in conversion of and pressure on miombo woodlands, a critical resource for subsistence livelihoods and habitat for wildlife. Moreover, small-scale farmers are experiencing diminished capability to shift fields and shorter fallow periods that have not permitted soils to regain their former fertility. The continuous cycle of burning of plant residues and the later digging of the soil surface repeatedly on the same field has in the first case removed organic matter sources (leaves, grass, crop stalks, etc.), and in the second mineralized the organic matter in the soil profile. In other words, soils have become severely depleted of soil organic matter (SOM).

**Water Infiltration Under CP:** Infiltration is the function of two factors:

1) Gravity, which pulls the water downwards through the soil profile via macropores (spaces between soil aggregates of size greater than 0.08 millimeters in diameter); and

2) Capillary action, in which water is pulled laterally or vertically into micropores due to differences in water potential (attributable to surface tension and the attraction of water molecules to soil particles).^9

Rain and other water infiltrate into a soil surface as long as the rate of supply (e.g., how hard it is raining) does not exceed the soil’s infiltration capacity. As such, it is desirable for soil to have a high infiltration capacity so that water moves down, into, and through the soil profile, rather than ponding on

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^9 Matrix potential through the soil or $\Psi_m$ (“psi m”) is best described as the movement of water from areas of higher matrix potential (wetter) to areas of lower matrix potential (drier) along a wetting front. The simplest example of this is putting a dry sponge (e.g., the low matrix potential) on top of a small pool of water (e.g., the high matrix potential).
a flat soil surface (flooding) or running off laterally on a sloped soil surface (erosion). A soil’s texture\textsuperscript{10} is a major contributor to its infiltration capacity due largely to the quantity and size of pores between soil mineral particles. Soils with a higher percentage of sand particles tend to drain faster than soils with a lower percentage of sand particles. SOM can also play a significant role in both gravitational and capillary water infiltration, often in subtler, long-term ways.

The formation of micropore space resulting from the accumulation of SOM can also signify an improvement in a soil’s capacity to hold moisture. Though this may appear contradictory, recall that infiltration describes the movement of water through a soil, not its capacity to hold water. If we were to imagine a deep sandy soil with a high sand particle percentage, its infiltration rates will unlikely vary significantly with greater or lower SOM levels (due to the inherent macropore space between individual particles that allow for rapid percolation of water downwards through the soil). However, in a clay soil, infiltration rates will likely increase as soil aggregation increases, allowing for greater unimpeded percolation through the soil profile. In either case, the increase in SOM will allow for greater water-holding capacity, meaning the soil’s capacity to supply water to plant roots for longer periods of time is increased.

*Cassava Performance under CP:* Cassava is considered to be the best crop of last resort. Relative to plants that produce carbohydrates, it is by far the most tolerant of drought, low soil fertility, and excessive heat. As such, it is the ideal candidate in a climate picture that is both erratic and extreme, as it continues to produce when other crops fail. However, in light of the labor intensity of cassava, its proneness to disease and local cultural practices, the actual return on investment is very low for poor farmers.

\textsuperscript{10} Soil texture is the relative proportions of sand, silt, and clay particles in a soil. Sand particles are the largest (0.05 – 2.0 mm in diameter), followed by silt particles (0.002 – 0.05 mm in diameter), with the smallest being clay (less than 0.002 mm in diameter). Soil textural types are classified according to their relative proportions of these mineral sizes using the USDA’s Soil Texture Triangle as “sand”, “loamy sand”, “sandy clay loam”, “sandy clay”, “loam”, “silt loam”, “silt”, “silty clay loam”, “silty clay”, “clay loam”, and “clay” (see annex 03).
Cassava’s ability to grow on fields with poor soil nutrition that are often a result of high acidity levels has often worked to its disadvantage. Farmers, recognizing that plants like maize that are more sensitive to soil nutrition, often plant cassava as the last crop in a field that has been effectively depleted of nutrients by preceding crops. Though cassava is an amazing effective accumulator of both potassium (K) and nitrogen (N), the usually low levels of either remaining in the soil following previous crops severely constrains cassava production. The availability of moisture in the soil further limits plant growth; storage of energy and indeed, the part most desired by farmers cultivating cassava are the roots of the plant. Low moisture levels in the soil decreases the capacity of the plant to transfer energy resulting from photosynthesis (in the form of starch) to the roots of the plant.

CP also works against cassava in that the practices of clearing and burning surface residues followed by a complete inversion of the soil surface causes the soil to be depleted of organic matter through mineralization. Though this provides a short-term burst of nutrients, loss of SOM degrades the soil structure’s capacity to supply either nutrients or moisture to the plant. This results in an inherently less-productive plant that is more susceptible to insect-borne disease or pest attacks. Therefore, cassava production across Mozambique is very low, estimated at 14.7 million metric tons annually. By comparison, the largest producer of cassava is Nigeria, producing close to 45 million metric tons annually.

Diseases affecting Cassava Production

Cassava is susceptible to several diseases that are spread through whiteflies. Most common are Cassava Mosaic Disease and Cassava Brown Streak Virus. Infection in spatial scale is typically achieved through the collection and planting of cuttings from infected plants. This is rarely intentional, as farmers often collect cuttings when there are fewer leaves on the plant and disease identification (via the stem) is less apparent. Most local varieties of cassava are susceptible to either disease. However resistant varieties are uncommon and difficult to access at scale.

**African Cassava Mosaic Virus (ACMV)** – ACMV (cassava mosaic disease (CMD)) is a widespread virus transmitted by whiteflies that suck sap from leaves and hence, provide the vector of transmission for ACMV. Depending on the scale of the infection, the chlorosis impedes the ability of the leaves to photosynthesize, consequently limiting the plant’s ability to produce starches for storage in the roots. A variant of the virus in Uganda during the 1990s, forced farmers to abandon cassava outright and small outbreaks of famine resulted. In Mozambique, 51% of households growing cassava reported CMD as a major issue with cassava production (IITA 2010).

**Cassava Brown Streak Virus (CBSV)** – CBSV is similar to ACMV in that the major transmission vector for the disease is the whitefly, which transmits the virus from infected to non-infected plants. However, CBSV is slightly more insidious in that it is often harder to detect, but it has arguably worse impacts due to its rot and subsequent ruination of below ground roots.

Conservation Agriculture (CA) and Farmer Field Schools (FFS)

CA is an agriculture approach that focuses on soil conservation and improvement through the achievement and continual application of three principles:

4. Minimum tillage;
5. Permanent organic soil cover;
6. Crop rotation and/or diversification.

Though CA is relatively easy to understand theoretically, CA implementation often proves difficult, as CA practices often contradict CP.

**Cultural Norms** – Farmers in rural Mozambique experience an inherent difficulty in implementing new practices that run counter to his or her community’s. The fear of being socially ostracized within rural
communities carries potentially dangerous consequences to an individual or a household, ranging from disenfranchisement from social networks to suspicion and accusations of witchcraft. Likewise, the adoption of a new, seemingly complex system such as CA that displaces an established system learned from ones’ trusted parents and/or peers over the course of a lifetime requires a similarly trusted learning environment.

Given the power of cultural norms, the CARE-WWF Alliance began implementing in 2010 CA interventions in the coastal districts of Angoche, Larde, and Moma in southeast Nampula Province utilizing Farmer Field Schools (FFS) approaches in partnership with AENA (the Associação Nacional de Extensão Rural or National Association for Rural Extension. The fundamental idea behind the FFS approach is to gather groups of people with a common interest to study the “how and why” of a specific agricultural approach. Per its name, FFS are largely centered around a field utilized as a learning space, where FFS facilitators and farmer members design, set up, monitor and evaluate different agricultural practices. This creates a safe environment for farmers to collectively learn and adapt practices such as CA to local condition for adoption on their own fields nearby. It can also act as an entry point for further group formation, such as village savings clubs, farmer associations, or producers’ cooperatives.

The value of FFS are both obvious and subtle. FFS viscerally demonstrate differences between crops and practices. An observer who is not a member of the FFS can see the difference between characteristics of local and new varieties of crops during casual visits, field days and farmer to farmer visits. Sometimes such differences between CA and CP also visible to casual observers; for example, in a dry year, a farmer observing maize grown with heavy organic residue on the soil surface vs. maize grown with no surface residue will note a marked difference between the plants. The subtle value, which is harder to grasp from one-off visitations and more apparent to members, are improvements in soil structure that lead to better soil moisture and nutrient retention, reductions in pest and diseases incidences, and adjustments to intercrops to suit localized soil conditions.

Adapting Cultural Practices to Improve Agricultural Productivity – Alliance CA work in coastal districts of Nampula Province has used the FFS approach so farmers can compare CA to CP for staple crops, particularly maize (Zea mays) and cassava. These comparisons incorporate a number of technical approaches that fit within the framework of CA, such as the intercropping of both food and green manure legumes11 with cassava to both grow organic matter in situ, biologically fix nitrogen from the atmosphere into the soil, and sometimes recycle soil nutrients that have leached deep in the soil profile back to the soil surface. It provides a platform for farmers to observe and evaluate new varieties of existing crops like cassava and cowpeas (Vigna unguiculata). It also provides a means for farmers to experiment and evaluate new, nutritious crops such as jack beans (Canavalia ensiformis), lab-lab (Lablab purpureus), Pigeon peas (Cajunus cajan), or mung beans (Vigna radiata).

CA is so effective at rebuilding and maintaining SOM that it’s often described as “organic matter farming” because the first two CA principles directly address the drivers of SOM loss. Maintaining permanent organic soil cover and promoting minimum tillage also critically minimizes SOM loss. Overtime, the

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11 Food legumes are legumes that provide edible foodstuffs, but are usually do not fix large amounts of nitrogen in the soil; these include groundnuts, cowpeas, beans, soybeans, lab-lab, etc. Green manure legumes are legumes that produce significant amounts of biomass and fix greater amounts of nitrogen, but generally do not produce an edible seed; these include velvet bean, jack bean, sword beans, etc. A handful of crops provide both services, such as pigeon pea.
application of these two principles contributes significantly to restoring biological processes in the soil to a natural soil under grassland or forest, improving overall soil health and resilience.

CA use to improve SOM in crop fields is thus paramount to the long-term health and resiliency of the soil in light of frequent intra- and inter-seasonal climate shocks. Measuring soil resiliency requires understanding its capacity to both absorb and retain rainfall. As such, the Alliance has utilized basic technologies to both demonstrate to farmers and scientifically measure water infiltration into the soil.

However, maintaining permanent soil cover has proven difficult in many regions due to: 1) Traditional practices, including in Nampula, surrounding the burning of fields to clear off surface residues; and 2) Communal grazing of livestock on crop residues, a practice more prevalent further in southern Mozambique’s Inhambane Province. 3) Crop rotation, the annual cycling of different crops on the same land, is also a challenging proposition for farmers limited in land and labor resources: because it requires displacing staple crops that produce filling carbohydrates and/or have more market value with less common grains or legumes that have less food value or market potential; and due to lack of access to seed supply for alternate crops.

FFSes have thus tested innovative solutions to persistent problems that constrain CA adoption. For example, early efforts to manually create permanent soil cover via carrying dry biomass onto the soil surface proved too labor-intensive. Starting in 2013, the Alliance introduced different green manure / cover crops that grew the bio-mass on the field, removing the burden of building adequate levels of bio-mass on the soil surface.

Research Methodology

In 2014, the Alliance and FFS members set up eight (8) trials to compare the improved variety of cassava (Nziva) in CA plots, adjacent to CP plots. In all 8 FFS, CA had been practiced for over three years utilizing green manure / cover crops intercropped with cassava. In parallel, trials were set up where eight (8) individual farmers practicing CA with local varieties of cassava were to be compared with eight (8) other farmers practicing CP with the same local varieties of cassava. Trials were split equally between Angoche and Moma Districts for both FFS (four trials per district) and individual farmers (eight trials per district).

In 2015, the Alliance also conducted a series of infiltration tests in Angoche and Moma Districts. These tests were conducted on FFS and local farmer plots in four communities in each district (eight communities total). Following data collection, infiltration rates (in liters per second, L/s) were determined by dividing the amount of water used in the tests by the time it took for the water to completely infiltrate the soil surface.
Findings

Cassava Yields under CA vs. CP

The data clearly shows that the improved variety of cassava grown under consistent CA practices in FFS yielded more than the three other trials. As can be seen in the figures below, yields varied significantly for both the FFS trial of improved cassava variety under CA (blue bar). Looking specifically at the comparison of the improved Nziva variety under CA vs. CP, Nziva (blue bar) clearly performs much better under CA.

Without specific nutrient analysis, it is difficult to assess whether the yield can be attributed to increased moisture in the soil under CA or increased availability of nutrients. Should the improved yields be attributable to the latter, this may have a number of underlying reasons:

1. The intercropping of legumes with cassava has increased available nitrogen in the soil, something that appears to be borne out by the increased average height of the plants under CA.
2. Soil under CA typically have higher pH values\(^\text{12}\), meaning nutrients like phosphorous (P) are more readily available than they would be under CP. Soil acidity measured in similar coarse-grained soils of Western Zambia in 2013 showed inherent pH levels below 5.0. Given the importance of phosphorus to root development, this could significantly increase yields.
3. Soil microbial activity is enhanced by the greater availability of soil organic matter in the soil, and organic plant material shading the soil surface. This creates an environment more favorable to fungi (infesting plant roots in a symbiotic relationship) that increases uptake of plant nutrients, particularly phosphorous (P), in the rhizosphere (Vaidya, et al. 2008) (Okon, Solomon and Osonubi 2010).

In the case of the trials in the farmers’ fields, note that CA practices do not preclude the incidence of disease in the plots, though the use of CA may reduce the negative impact of these incidences, resulting in generally higher yields.

Water Infiltration in Soils under CA vs. CP

Comparing the average infiltration rates of all the FFS and individual farmers CA and CP sites in ascending order, 14 of the 16 highest rates (the top 50%) were observed under CA sites, whereas CP accounted for

\(^{12}\) pH is a measure of the acidity or alkalinity of a solution on a logarithmic scale on which 7 is neutral, lower values are more acid (down to 0), and higher values (up to 14) more alkaline.
14 out of the 16 lowest rates (the bottom 50%). Indeed, infiltration rates averaged between FFS CA, FFS CP, Individual farmer CA, and individual farmer CP trials show that infiltration rates are higher under CA on both FFS and farmer plots.

<table>
<thead>
<tr>
<th>Field / Practice Type</th>
<th>Duration of CA Practice prior to test (years)</th>
<th>Average infiltration (L/s):</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFS – CA</td>
<td>4</td>
<td>0.00597</td>
</tr>
<tr>
<td>Individual farmer – CA</td>
<td>2</td>
<td>0.00509</td>
</tr>
<tr>
<td>FFS – CP</td>
<td>0(^{13})</td>
<td>0.00449</td>
</tr>
<tr>
<td>Individual farmer – CP</td>
<td>0</td>
<td>0.00416</td>
</tr>
</tbody>
</table>

Table #3 – Average Infiltration rates based of duration of CA practice.

Though site variations may have played a significant role in comparisons within FFS plots and between individual farmers, the much higher rates of infiltration where CA was practiced confirms that water infiltration rates in CA soils will generally be higher than those under CP. Data also suggests that the longer CA is practiced, the greater the soil’s water infiltration rates. Given that adjacent test sites within the same FFS had lower scores, and that individual farmers’ CA practices also showed higher infiltration rates, there is a strong implication that CA practices make the soil more capable of absorbing moisture and therefore, more resilient to more variable and extreme precipitation experienced in a changing climate.

**Recommendations**

**Improved Varieties:** It is readily apparent that the improved Nziva cassava variety grown under CA conditions can yield a greater quantity of edible roots. However, yield increases of local varieties under CA were less noticeable at larger scales, suggesting that benefits of applying CA alone may be diluted when applied to large scale production of improved cassava yields. That said, yields for the improved Nziva variety under CP revealed that it does not out-perform local varieties through disease-resistance alone (i.e., without CA practice adoption). As such, the foremost recommendation is that the Alliance should continue to promote CA in conjunction with promotion of Nziva cassava and other disease-resistant varieties.

**Water Infiltration:** The ability of the soil to both transfer and hold moisture is a significant indicator of that soil’s resiliency to the increasing number of climate shocks seen across sub-Saharan Africa. A soil that can transfer water can better withstand heavy rainfall events, while a soil that can hold moisture can better withstand dry spells. Alliance infiltration data demonstrates that CA can improve soil infiltration, with greater effects the longer it’s practiced. Practiced in combination with organic matter on the soil surface to slow both lateral movement of water (runoff) and evaporation of moisture from the soil surface, CA enhances the ability of coarse soils, like those in coastal Nampula Province, to infiltrate water. Though we don’t know how much of the soil’s water holding capacity is attributable to CA practices, greater infiltration suggests CA significantly improves soil structure.\(^{14}\)

\(^{13}\) The plot had had CA practiced on it before, but in the season prior to the test (2014/15), CA was not practiced, representing a restart of the duration.

\(^{14}\) Specific determination of the effects of CA on the soil represent a considerable undertaking, but with the refinement of existing tests, addition of a few additional tests and higher numbers of replicates, it is entirely possible for a scientifically sound model of data collection to be established that can inform farmers, practitioners, and
Input Supply: This final recommendation addresses the logistical challenges of sourcing improved planting materials and inputs like cassava cuttings and legume seeds. Although research and development (R&D) of improved planting materials, including disease-resistant cassava, has been underway for some 20 years, dissemination of these planting materials is abysmal given the unrealistic reliance on NGOs to distribute and disseminate these planting materials at scale. The system largely requires NGO collection and bulking of material from sources such as research centers or proximate farmers at a distance and shipping the material hundreds of kilometers over challenging infrastructure to awaiting farmers. For planting material such as cassava cuttings, which has an extremely limited shelf life and is inordinately bulky, this presents a major challenge to scalable distribution, especially when considering that farmer-to-farmer stock replication can be extremely slow. Further, within the current development discourse, NGOs are often encouraged to somehow monetize planting materials in order to develop inputs markets through the private sector. Though nominally effective for a handful of crops such as hybrid maize seed, most food crops in southern Africa are difficult to monetize for a myriad of reasons, including: private sector hesitancy to engage with cash-strapped small-scale farmers; and farmers’ low return on investment for various crops due to limited market access. The unattractiveness of deferring spending of limited funds on immediate household needs like education, health and food make less productive, unimproved varieties without costs more attractive than more productive and costly varieties.

Therefore, the recommendation, and in this case appeal, to donors and research agencies is to seriously and radically reconsider ways to scale the dissemination of improved varieties—not only of cassava, but also the diverse array of cover crops, cereals, and pulses—to better facilitate the adoption of CA methodologies. It must be recognized that the current R&D model, with limited to non-existent provision for upscaling seed supply across a country the size of Mozambique, puts an often insurmountable burden on NGOs and farmers that effectively obviates the usefulness of the R&D.

Despite efforts of NGOs like CARE, farmers are not accessing improved materials, and continue to languish in abject poverty. Programming around development of improved planting material must be designed with a much stronger component of dissemination so that stakeholders’ interventions around sustainable agricultural improvements for small-scale farmers are not constrained through logistical supply.

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15 A bundle of 100 cuttings, each with a length of 50cm, is approximately 30 cm in diameter. A five (5) ton truck can carry roughly 600 of these on tarred road. At a spacing of 1m x 1m between plants, this represents a plated area of 100m². It serves to note that even the poorest farmers may plant 0.5 ha or 5,000m² of cassava.