The Effect of Mulch and Watering on Tomato Yields and Potential for Adoption During the Dry Season in Nanjara Village, Tanzania

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Thesis

Presented in partial fulfillment of the requirements

For the degree of

Master of Science
in Resource Conservation, International Conservation and Development

The University of Montana
Missoula, MT

May 2015

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ACNOWLEDGEMENTS

I am hugely grateful to the many people who were in instrumental in the success of this project.

First and foremost I would like to thank Dr. Irene and Mr. Isdory Tarimo for inviting me into their community, family, and home in Nanjara so that I could create a project. I relied heavily on the support and guidance from the people of Nanjara, which was facilitated by the powerful introduction from the Tarimo family. Thank you also for facilitating my good relations with the local and regional leaders and the acquisition of my research permit. Receiving such a warm welcome from COSTECH and the Tanzanian government was a very positive start to my research.

The entire community of Nanjara helped me to develop & implement my project by intimately including me in its activities, and the members of TECOSO merit special recognition for their devotion and commitment to me. They welcomed me with open arms I am eternally honored to have collaborated with them. I cannot sufficiently express how grateful I am for their hard work throughout my time in Nanjara.

Extra special thanks to Peter, Evodi, Maria, and Magdalena for their daily (and often hourly) help and attention. They remain loyal friends I am so grateful for all of their love and tireless guidance. Even as we chatted and laughed and cried together, Maria & Magda silently watched over me and quietly nudged me in the right direction so that I could easily assimilate into village life. Equally notable is the support and care I received from Joseph and Ester, who quickly claimed me as their own. I could not have succeeded at this project without Joseph's willingness to participate so extensively and his knowledge of plants and the ecosystem.

To all in Nanjara: *Asanteni, asanteni, asanteni, namshukuru sana*.

Many thanks to my committee members, Dr. Jill Belsky and Josh Slotnick, and to my advisor, Dr. Steve Siebert, for their invaluable advice as I worked in Nanjara. I heard their wise words continuously as I navigated developing and implementing my experiment. Thank you for encouraging me and for the immeasurable amount that I have learned from each of you.

Lastly, I would like to thank my family and friends for much more than I could possibly list here. I am so grateful to my parents and sister for their commitment to my education and their confidence in me, as well as their love and unwavering support.

And finally, to my husband Bruce: my new family, my biggest cheerleader and the love of my life. Words cannot express how lucky I feel to have your steadfast encouragement – celebrating my accomplishments and brushing away my setbacks. Thank you.

PREFACE

I met Dr. Irene Tarimo at the University of Montana in late 2011 when I was a first-year graduate student and she was participating in a student exchange during her Ph.D. studies. She asked about my course of study and suggested I contact her husband, Mr. Isdory Tarimo, who is the director of the Tanzania Ecological Conservation Society (TECOSO). Some emails and a year later I touched down at Kilimanjaro International Airport in northern Tanzania and eventually made my way to the hamlet of Nanjara, above the village of Kibaoni, one mile from the border town of Tarakea.

Figure 1: Nanjara's location (red dot) relative to the continent of Africa.

Figure 2: Satellite image of Mt. Kilimanjaro's peak (left). Dark green strip = cloud forest inside the national park boundaries & forest reserve land is immediately downhill. Yellow pins show the significant locations in Nanjara uphill of Kenya (yellow line).Figure 3: Nanjara's location (red dot) relative to the continent of Africa.

During my time in Nanjara I stayed in Dr. Tarimo's family house but she lives and works in Dar Es Salaam, some 700km away. I relied on the women living in the village to help me negotiate everyday life and we slowly but surely began to tell stories and secrets and open up to each other. I said yes to every event I was invited to and attended twice-weekly work parties at TECOSO's nursery site; we discussed our respective livelihoods as we planted, tilled, watered, harvested, and performed other farm work and I feel enormously grateful at how open and welcoming that community was. I described my life in the States and they taught me to carry buckets of water on my head and harvest beans with a huge stick. They fostered a remarkably intimate relationship with me by inviting me into their homes and families and encouraging me to visit whenever I wanted, and unannounced. And under the watchful eye of my self-assigned personal guards, I also attended Sunday homebrew parties where I met and chatted with other members of the community. After living in Nanjara for 4-5 months, the women who were my closest neighbors started inviting me over to tell "women's stories" and compare our lives as women. Eventually I moved into Joseph & Ester Tarimo's house and credit that experience for further understanding daily life in Nanjara. Ester and I got along like sisters and she gently included me in her decisions; we chatted and laughed constantly and her warm, friendly kitchen became a regular stopover for neighbors who wanted to chat with the foreigner.

I, meanwhile, was hoping to orient my project in an ecological direction but was unsure if I had the available time and resources. In my early conversations with TECOSO members, I asked them to describe their livelihoods, particularly what they deemed to be constraints to their access to natural resources relative to their farming. I was surprised that their answers were virtually unanimous. Less surprising was their intimate knowledge of ecological processes and how human activity has altered their ecosystem; even elders are perfectly aware that reducing cover in the cloud forest has led to changes in precipitation patterns, making life more difficult. As this experiment began to take shape, I asked TECOSO members almost daily if they agreed with the direction of my research and if they thought I would be of any use to them. They answered, "Go ahead, Emmy. Work on your work. We want to work but we want our hard work to lead to development."

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ABSTRACT

Approximately 90% of subsistence farmers in sub-Saharan Africa are dependent on rain for irrigation and face increasing water access challenges. Residents of the village of Nanjara in Rombo District, Tanzania, report limited vegetable consumption during the dry season, as they are unable to cultivate vegetables due to limited water availability. This study examined constraints to on-farm livelihood development reported by members of TECOSO, a local environmental restoration group, and other residents of Nanjara who identified lack of access to capital, lack of access to water, and the small size of household agricultural plots as the primary challenges. TECOSO farmers and elderly residents reported planting year-round with greater yields prior to the 1980s. Consequently, in this experiment I chose to assess the effectiveness of locally available mulch on the production of a locally-valued crop – tomato – for domestic consumption and sale. Experimental treatments were developed in consultation with TECOSO members and included a control treatment where plants were neither watered nor mulched, one treatment of mulched but not watered plants, one treatment of watered but not mulched plants, and one treatment of mulched and watered plants. Treatments were randomly assigned in a randomized block design and methods were chosen to be easily repeatable and affordable by village residents in Nanjara; TECOSO leadership recommended watering once a week during the dry season. Planting tomatoes with mulch and watering once a week during the cold, dry season (June-September) increased mean grams per plant by an average 165% times over the control (tomatoes planted conventionally: no mulch, no water) at p=0.05 confidence. Adding either water or mulch increased mean g/plant an average 56-92% over the control. Watering increased mean grams per fruit by 21% (p=0.05) over tomatoes receiving no water, regardless of mulch, and the number of fruits per plant increased by an average 49% when either mulch or water was added and by 95% when both were added (p=0.05). Mulching and watering once a week was considered a manageable labor investment by local residents and mulch is readily available, which make planting tomatoes during the dry season a feasible response to limited water availability. However, TECOSO members are smallholders who currently have little incentive to plant during the dry season due large volumes of produce imported from irrigated farms in nearby Kenya and limited market opportunities in larger Tanzanian markets. Planting with mulch during the dry season appears to be very appropriate for domestic consumption. Nevertheless, most TECOSO members and other residents of Nanjara are hesitant to adopt new cultivation practices.

I. INTRODUCTION

WATER ACCESS & AVAILABILITY IN NANJARA

Residents of the Tanzanian hamlet of Nanjara, Kilimanjaro Region, reported limitations in water access and availability despite the Tarakea River being replenished by the mountain's cloud forest. Farmers historically irrigated using a network of furrows that allowed for year-round water use. Furrows were traditionally built and maintained by village residents according to directions from the village council; each resident was able to divert water into a homestead as needed and diverted back into the river or stream when crops were properly irrigated (Vavrus, 2003). Today, water availability – or its physical presence in the river (Sullivan, 2002) – is diminished from its historical levels and small farmers have limited access to water; access to water is defined by a household's ability to afford or secure its necessary water supply (Sullivan, 2002, Calow et al., 2010). Labor and infrastructure can limit a household's access to water and availability can be limited by the demands of ecosystems processes and agricultural needs (Calow et al., 2010, Sullivan, 2002).

The government allowed private companies to build infrastructure throughout Tanzania to provide piped water to local residents; the cost per m^3 of piped water in Nanjara is low, but residents are responsible for installation costs that are often prohibitively expensive (personal communication, personal observation). Wealthier households are able to afford piped water, but non-wealthy households collect rainwater, pay for water by the bucket at a wealthy neighbor's tap, or collect water from the Tarakea River when the flow is sufficient – sometimes digging holes to reach underground flows; women and children are responsible for collecting water and this is a daily struggle (personal communication, personal observation). Small farmers lack access to water in Nanjara and could benefit from improved water use efficiency. Elderly residents reported using mulch on their farms when they were younger, which suggests that its use may be a feasible response to limited water access.

THE EFFECTS OF MULCH ON AGRICULTURAL PRODUCTIVITY

Using mulch in agricultural settings does not figure prominently in research in the sub-humid regions of Tanzania, but it has proven effective in increasing agricultural yields in many semi-arid regions on weathered, nutrient-poor soils subject to water shortages (Zake, 1993, Shemdoe et al., 2009). Yields in numerous studies were increased and plants exhibited better health when mulch was used. Farmers on Kilimanjaro are familiar with mulching practices; they collect farm residues and apply it to coffee and banana plants (Fernandes et al., 1984, Von Clemm, 1964, Misana et al., 2003, Soini, 2005a) but the potential use and efficacy of mulching on vegetable crop yields have not been studied. Mulching tomato crops has been studied in sub-humid areas with clayey soils in India; in that environment the application of straw mulch increased tomato yields by 30% compared to unmulched controls (Shrivastava et al., 1994). A similar experiment in another sub-humid Indian region with finely textured soils found that rice straw mulch positively affects barley yields (Sarkar and Singh, 2007). Experiments from other countries in East Africa report similar results; the addition of mulch to shallow tillage systems improves soil conditions and yields of a variety of crops (Gicheru et al., 2004, Biamah et al., 1993, Gicheru, 1994, Baijukya et al., 2006).

The soils in Nanjara are clay loams like those at Sokoine University of Agriculture Morogoro (SUA) where experiments assessed the effects of mulch on tomatoes during the hot, dry season (Sept-Dec) using 3 different treatments (John et al., 2005). Each of the 3 mulch treatments significantly increased yields compared to unmulched controls although mulch was also found to result in increased diseases and pests in some cases (John et al., 2005). Morogoro, in south-central Tanzania, has one long rainy season with June - August being dry and cold, and September-December hot and dry. The drought-like conditions in September make it difficult to establish tomatoes so market value soars; reducing water stress by adding mulch would allow farmers to benefit from the high market value of late-year tomatoes (John et al., 2005), which is similar to the needs of small farmers in Nanjara.

The field experiment at SUA addressed several problems related to tomato crops, including soil moisture content, yellow leaf curl, fruit cracks, weed infestation, and several other diseases (John et al., 2005). Three different types of mulch were applied– dry grass, rice husk, and sawdust – and the plots were watered once a week (John et al., 2005). The SUA experiment used two different varieties of tomatoes, one of which was bred to perform in cool, mountainous regions, while Morogoro is relatively low altitude (500m), and has a hot, humid climate; this discrepancy might account for some of the pest and disease infestation observed. Despite these challenges, mulching tomato plants in the dry season increased household earnings due to a significantly larger number of marketable fruits per m^2 and their larger weights (John et al., 2005). Nanjara would appear to have the same potential to increase tomato yields.

NANJARA: A CASE STUDY

This project addressed small farmers' lack of access to water in Nanjara by planting tomatoes with mulch. Project selection and methods employed were based on conversations with members of the Tanzania Ecological Conservation Society (TECOSO), elderly residents, and other residents of Nanjara who agreed to discuss their on-farm activities. Most of these conversations included a tour of the family's garden and fields and usually included discussion of off-farm and business ventures. TECOSO's members are small farmers so this project did not examine the livelihoods of either large-scale farmers or households without land; this decision was based on the project's available resources, including time and the potential for interactions with members of those socioeconomic groups. Final considerations for choosing methods developed from working once or twice weekly with TECOSO members at their nursery site. Encouraging communities to participate in developing methods and analyzing results creates more useful research and opportunities for capacity-building (Chambers, 1994, Pretty, 1995, Cornwall and Jewkes, 1995). Consequently, I used principles of participatory action research (PAR). A recent study showed that farmers in Ghana and Zimbabwe involved in PAR processes learned that soil fertility impacts the social cohesion of their communities and were more receptive to participating in adaptive activities (Mapfumo et al., 2013). One of my goals was to work with stakeholders and representatives of public and private sector entities and to encourage them to collaborate with the members of TECOSO.

Mr. Isdory Tarimo, director of TECOSO, extended a personal invitation to conduct a research project in conjunction with members based in Nanjara. My collaboration with TECOSO was aided by our mutual appreciation for ecological restoration and conservation efforts, but members have diverse reasons for participating in its activities: 4 members joined in the late 1990's to participate in environmental restoration and land conservation, 2 members are single mothers in Mr. Tarimo's close family who joined out of loyalty, 3 members want to profit from selling seedlings but do not otherwise enjoy garden work, 4 members are primarily interested in belonging to a social group, and the remaining members have no primary reason for joining (personal communication). Most members expressed concern for the environment and wish to participate in reversing degradation even if this is not their primary motivation for being members of TECOSO. Any resident of Nanjara is welcome to apply to join TECOSO but membership is contingent upon paying dues (payable in installments for the initial entry fee), presence at weekly work parties, and demonstrating commitment during a probationary period (Peter Shayo, personal communication). TECOSO members were eager to discuss their livelihoods and were amenable to experimenting with potential improvement strategies.

As previously stated, this research process started with conversations at TECOSO members' homes and included a tour of the property and farming activities and asking them to identify what they perceive to be the most important constraints to their livelihoods. Other social gatherings throughout the village provided the opportunity to ask these same questions to some residents of Nanjara who are not members of TECOSO. Nanjarans described themselves as very curious and they enjoyed asking me about my household and its activities, which encouraged me to reciprocate. The majority of Nanjara's households take turns preparing homebrew and hosting a Sunday party and those occasions were very appropriate settings for learning more about the community. Family, friends, and neighbors are traditionally invited so I was able to chat with people of different backgrounds by attending geographically scattered parties. I also sought elderly residents and asked them to describe changes in daily off- and on-farm activities, the environment, and the weather. All members of TECOSO and most other residents of Nanjara who participated in the conversations gave the same top 3 constraints to on-farm development: limited access to money/capital, small plot sizes, and limited access to water. I chose to focus on water availability for this project because it is potentially more readily addressed than limited capital or the size of land holdings.

I asked TECOSO members and other residents of Nanjara how they would use more water and they unanimously declared that they would "plant during the dry season." I explored potential readily available, low-cost means to improve water use efficiency since additional water is not available. Homegarden tours provided the opportunity to observe near-universal mulching of coffee-banana plantations and that farmers are familiar with the effects of mulch. But using mulch in vegetable gardens is not a common practice because households either plant with the rains (most) or are sufficiently wealthy to have access to irrigation (few households). This experiment was developed on 3 on-farm sites and at TECOSO's nursery to evaluate improving water use efficiency through methods adaptable to current farming practices and that can potentially increase yields during the dry season; planting methods required little capital and labor investment and used only locally available materials so as to be easily repeatable by Nanjara residents.

Figure 4: Satellite image of Mt. Kilimanjaro's peak (left). Dark green strip = cloud forest inside the national park boundaries & forest reserve land is immediately downhill. Yellow pins show the significant locations in Nanjara

HISTORY & BACKGROUND

AN INTRODUCTION TO NANJARA & THE CHAGGA PEOPLE

Nanjara is in Rombo District in Northern Tanzania (Figure 2) at approximately 1740m in altitude on Mt. Kilimanjaro's northeastern slopes. Above Nanjara are government-controlled forest reserves which eventually give way to the cloud forest and then the rock and ice of Africa's tallest peak (Figure 3). Two miles downhill from Nanjara is the border town of Tarakea where the slope begins to flatten into the Kenyan savanna.

Residents of Nanjara are almost exclusively members of the Chagga tribe, a Bantu people who have lived in the Kilimanjaro Region for centuries. The Chagga originally retreated to the mountain's resource-rich slopes to escape land-tenure conflicts with Maasai agro-pastoralists several centuries ago (Håkansson et al., 2008, Tagseth, 2008). Homegardens were developed as part of a broader household farming system to respond to increasing market demand from traders – perhaps as early as the 17th century; this system includes the homegarden plot as well as combinations of lowland fields for maize and beans, livestock (either in lowland fields or stall-fed next to the homegarden), high-altitude forest products, tree crops, and off-farm business ventures (Fernandes et al., 1984, Soini, 2005a).

Figure 5: Satellite image of Mt. Kilimanjaro. The National Park encompasses the rock & ice of the summit and the cloud forest in the dark green band; Chagga homegardens in the lighter green band. Tarakea marked by red pin. Kenyan border marked by yellow line.

The complexity of Chagga household livelihood systems provides numerous advantages; the diversity of livelihood activities reduces household vulnerability[1]. The diversity in agricultural endeavors has provided a buffer against total crop failure – an event that has never been reported in either oral or written Chagga history (Hemp, 2006a). Despite these advantages, Chagga farmers are increasingly subject to constraints and challenges that limit profits, agricultural yields, and the opportunity to invest in activities that might improve livelihoods (Soini, 2005a). Coping mechanisms and adaptation strategies employed can also sometimes exacerbate existing constraints to agricultural production (O'Brien et al., 2008).

Tarakea Division suffers from geographic remoteness due in part to the access road having been paved only in the last few years. The southern and western slopes of Kilimanjaro are located on the Arusha-Moshi corridor and have experienced greater affluence, including the majority of research attention. Very few studies have included locations in Rombo or those that have were broad comparative studies. For example, although Meena's 2007 & 2008 research included locations in Rombo, the study relied on a broadly distributed household survey and did not include District-level analysis of livelihoods. Agricultural and marketing conditions, opportunities and constraints among households in Rombo are likely different from the more developed southern slopes and the district would benefit from further research.

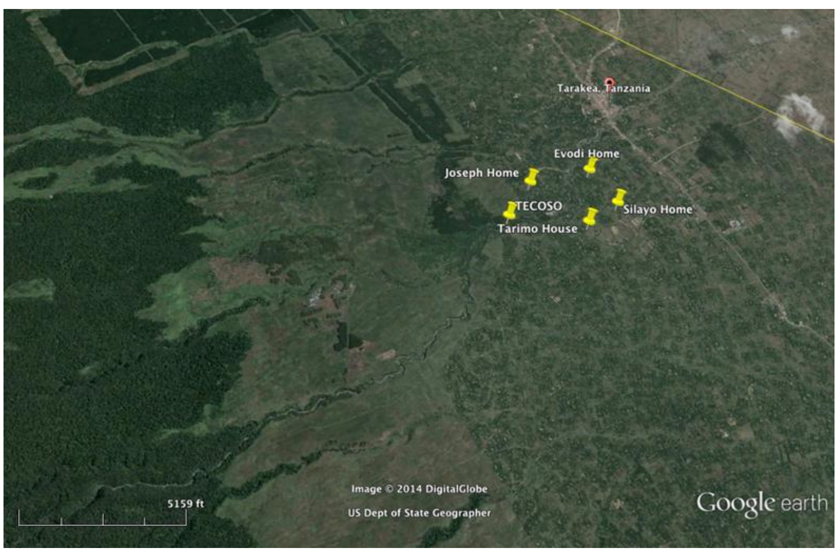

Figure 6: Satellite image of Nanjara (yellow pins) & Tarakea (red pin). Dark green cloud forest on left side, land cleared for use as a forest reserve in middle, and homegardens (spotted light green) on the right.

[1] "Vulnerability" as defined by Adger: "the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt." Adger, W. N. (2006) 'Vulnerability', *Global environmental change,* 16(3), pp. 268-281.

The Kilimanjaro Region & Tanzania: A Brief History

Tanzania has been stable, peaceful and free of civil strife that has affected most countries in sub-Saharan Africa. Nevertheless, it has had little socioeconomic development due to post-independence policies that failed to invest in general infrastructure, such as roads and energy (Tagseth, 2008). Consequently, Tanzania remains one of the poorest countries in the world. Agriculture accounts for approximately half of its GDP, yet only 4% of the land was considered arable at the beginning of the 21st century (Agrawala et al., 2003); the World Bank estimates current arable land to be 15%. Average per capita GNI in Tanzania is about $700 with approximately 30% of the population estimated to be below the poverty line (World Bank, 2013, United Nations, 2012). By comparison, the average per capita GNI for all of sub-Saharan Africa is $1,600 (World Bank, 2013, United Nations, 2012). Economic development policies in Tanzania have favored large-scale agricultural production for export while poor and small-scale farmers have not experienced poverty reduction (Pauw and Thurlow, 2011). In fact, small farms throughout Tanzania and Sub-Saharan Africa have struggled to increase production despite significant investment from both local and international lenders (Jayne et al., 2010).

From a historical perspective, the Kilimanjaro Region has been impacted by global markets and economic trends since pre-colonial times (Håkansson et al., 2008). Prior to Tanzania's (then Tanganyika) colonization by Germany, resources such as ivory, iron, and timber, were highly sought and the northeastern part of the country became an important route for traders moving products from inland East Africa to the Indian Ocean in the 17th -19th centuries (Håkansson et al., 2008). The beginning of German colonialism at the very end of the 19th century brought widespread landscape manipulation and regulation; in addition to introducing the cultivation of coffee and sisal, forest preserves were created and a land tax instituted (Tagseth, 2008). Local populations were subjected to land alienating practices that helped to solidify German power (Håkansson et al., 2008, Sunseri, 2005, Tagseth, 2008). The new crops required increased labor that resulted in men being forcibly removed from their homes. This labor shift resulted in changes in household food availability and contributed to changes in the regional landscape (Håkansson et al., 2008).

Tanganyika came under British rule following the end of World War I and was subject to "economic restructuring" and the introduction of new land-use regulations (Håkansson et al., 2008). The appropriation of lowland areas for colonial farmers in Kilimanjaro Region worked in concert with newly created high altitude forest reserves to confine Chagga farmers to a narrow strip of land on the mountainside. This appropriation put additional pressure on the land resources (Tagseth, 2008, Håkansson et al., 2008) and denied Chagga their historical complex of lowland fields, midland homegardens, and highland grazing areas. Households with small tracts of land on the mountainside found themselves in direct economic competition with colonial farmers who had benefited from British land alienation policies (Håkansson et al., 2008). Chagga men were forced to seek employment outside of their homes in response to this land appropriation; the subsequent loss of labor resulted in poor land management practices and adverse ecological effects (Håkansson et al., 2008). Poor land management led to decreased farm output, increased household income disparities, and further off-farm employment (Håkansson et al., 2008).

The British assigned each of the approximately 120 tribes present in Tanganyika to a role and a region (Tagseth, 2008), such as providing farmland for the Chagga and pastureland for the Maasai. Maize replaced finger millet as the main carbohydrate staple, and cotton, rice, beans, and sunflowers were among the cash crops the British ordered farmers to grow (Tagseth, 2008). In Kilimanjaro Region, these new crops increased irrigation demands and the carrying capacity – already impacted by the "land squeeze" – further declined as water became less available for subsistence crops (Tagseth, 2008). Farmers, seeking respite from these pressures, were forced to choose how they might expand their earning potential; potential options included education, crop intensification, participation in agroforestry activities, long distance migration, salaried work, or increased involvement in trade activities (Tagseth, 2008).

Tanganyika's independence in 1961 was peaceful compared to neighboring Kenya's struggle and the country was renamed Tanzania with the inclusion of Zanzibar in 1964. Julius Nyerere was the only person in the country with a university degree so he became the first post-independence president; he embraced socialist principals and sought to unify people by relocating rural populations into villages in a bid to avoid the tribal conflicts of Kenya (Tagseth, 2008). This scheme was called *ujamaa* and one of its goals was to create infrastructure through which the government could provide services such as health care, education, and trade opportunities (Tagseth, 2008). There were few *ujamaa* villages in the Kilimanjaro region and thus little economic restructuring but the government's price-setting measures were far-reaching; they drove down crop prices and reduced agricultural production (Putterman, 1995).

Geography of Mt. Kilimanjaro

Mt. Kilimanjaro, an ancient volcano whose slopes are entirely located in Tanzania, is the tallest freestanding mountain in the world and the highest point in Africa. The steep slopes rise from the savanna plains at 700m in altitude to Uhuru Point at 5,895m. The mountain's proximity to the equator at around 3° S and its high altitudinal gradient create distinct ecological zones including alpine, subalpine, and cloud forest – each with unique flora and fauna.

Current management of the Mt. Kilimanjaro ecosystem is divided according to the altitudinal gradients with the area above 2700m designated a national park. Below 3000m and extending downwards to approximately 1800m is the "forest belt," a cloud forest managed for timber and as water catchment (Soini, 2005b, Hemp, 2006a). Farmers have developed homegardens focused on banana-coffee systems between 1800m and 1000m (Fernandes et al., 1984, Hemp, 2006a, Soini, 2005a). At 900m the mountain slope gives way to a savanna plain used for crops that require hotter and drier conditions (Hemp, 2006b, Soini, 2005b).

Northern Tanzania's proximity to the Equator results in a bi-modal rainfall pattern: "short rains" occur in October and November, and the "long rains" are in April and May. May to October is the coldest and driest part of the year and December to March experience the warmest temperatures (Hemp, 2006b). Rainfall data is patchy and incomplete but available data suggest an average of 1500mm at 1900m altitude and 2700mm at 2200m for the southern slopes, and 1000-1800mm for the northern slopes (no altitudinal distinction available) (Hemp, 2006b, Mbonile et al., 2003). The mountain's northern slopes are hotter and drier than its southern counterparts (Hemp, 2006b)

Water on Mt. Kilimanjaro

The cloud forest located between 1800m and 3000m (Fernandes et al., 1984) provides a continuous supply of water for the mountain's river network (Newmark, 1991). Nevertheless, TECOSO members reported access to water is a major constraint to on-farm activities (personal communication). They reported reduced output in the streams and rivers, difficulty in paying for piped water, and degradation of traditional irrigation systems (personal communication). Reports from a late 19th century British expedition described an extensive network of irrigation channels or furrows (Grove, 1993) that were essential to Chagga livelihood and allowed for year-round use of Kilimanjaro's water (Grove, 1993, Vavrus, 2003, Fernandes et al., 1984).

The arrival of British colonialism began a trend of government regulation of furrows as the British feared that crucial water resources were being diverted from colonial settlers' farms in the lowland plains (Grove, 1993); this regulation was revised when the colonial government realized that this area of irrigated agriculture was a crucial component of the local economy and the local populace might protest (Grove, 1993). Seventy percent of the region's population had converted to Christianity by independence in 1961 and historical, pre-Christian spiritual connections to springs and streams disappeared (Grove, 1993). The mid 1970's brought *ujamaa* villages and programs and water resources were nationalized; piped water was provided free to village residents (Grove, 1993).

Adult residents of Nanjara enthusiastically recalled when they had to swim across the river or tote their younger siblings on their backs and jump from one strategically placed boulder to the next (personal communication). By the 1980's the river was often dry, even during the rainy season, and residents would sometimes walk 15km to a neighboring watershed in search of water. Almost all TECOSO members and all elderly informants stated that deforestation and overpopulation are responsible for the reduced river flow (personal communication). The competition for land and the economic hardships of the 1970's and 1980's led village residents to convert forest into arable land, including in river corridors (personal communication). Population expansion also increased competition for firewood and other wood products and significantly increased deforestation in the forest reserves and in the lower reaches of the National Park (personal communication).

The ecological impact of land clearing was sufficiently significant to attract political attention. Tanzanian president Ali Hassan Mwinyi publicly acknowledged in 1990 that there is a connection between deforestation in mountainous regions and atypical flood and drought events in surrounding lowland areas (Bjørndalen, 1992). TECOSO was founded in 1996 to combat environmental problems and its first project was to plant trees in the river corridor. Perennial flow returned to the Tarakea River within 10 years of the tree-planting initiative according to members of TECOSO and persists today (personal communication). The water output is very limited in volume and spatial extent; water retreats underground in areas where trees were not planted or were removed along the riverbanks. Experience from Mt. Kenya demonstrates that communities adjacent to the intake systems experience water restrictions and shortages as competition for water grows and intake systems are built in the upper reaches of rivers (Wiesmann et al., 2000); intake infrastructure may result in further restrictions in water access for residents of Nanjara as water demand continues to increase throughout the watershed.

Continued perennial flow in the Tarakea River will depend on management decisions made by the National Park and managers of the forest reserve. Global climate change has contributed to the noticeable loss of Mt. Kilimanjaro's glaciers, but is not expected to significantly impact stream hydrology since glacial melt is responsible for only minimal stream flow (Newmark, 1991). The rivers and streams are fed primarily by the cloud forest (Bjørndalen, 1992) and later congregate to form the Pangani River Basin which provides much of northern Tanzania with water and hydropower (Rockström et al., 2004). The conversion of the cloud forest, whether precipitated by climate change or deforestation, would likely result in reduced water in catchments (Agrawala et al., 2003).

The glaciers on Mt. Kilimanjaro have been retreating for at least 150 years and global warming trends in the latter half of the 20th century have accelerated melting (Agrawala et al., 2003). The mountaintop's once extensive glaciers have seen an 85% reduction in volume since 1912 when they were first measured (Sebastien, 2010, Thompson et al., 2009). The present melt pattern is unique in the last 11,700 years and the glaciers on Kilimanjaro are both thinning and shrinking due to warming temperatures (Thompson et al., 2009). Historical droughts captured in ice core samples have demonstrated that reduced precipitation and decreased cloud cover do not account for the melting of the once extensive ice fields (Thompson et al., 2009). Rather, warming trends in surface temperatures are responsible for the widespread melting (Agrawala et al., 2003, Thompson et al., 2009). Current estimates predict that the glaciers will be completely gone by 2020 (Agrawala et al., 2003).

Homegardens

Chagga homegarden plots in Kilimanjaro include up to 15 varieties of banana, multiple species of fruit trees, vegetables, living fences, and ornamentals, as well as trees for timber, fodder, shade, water retention, and medicinal value (Fernandes et al., 1984). German missionaries first introduced coffee to the area in the late 19^{th} century (Mercer, 2002) and the British colonial government later expanded coffee production from 3,300 to 87,000 coffee farmers between 1923/4 and the late 1960's (Grove, 1993). The inclusion of coffee into homegardens has persisted and coffee is typically planted under the shade of banana trees that are seminal to Chagga identity (Fernandes et al., 1984, Bender, 2009, Hemp, 2006a). The colonial-era income generated from coffee allowed children in the Kilimanjaro region to attend school; the region's literacy rates remain above average for the country (Meena and Sharif, 2008).

Current Livelihood Constraints in Kilimanjaro Region & Rombo District

The most frequently reported primary constraints to Chagga livelihood on the southern and eastern slopes are fluctuating market prices, poor quality of housing, restricted access to forest products (timber and non-timber), and limited access to loans and credits for household development (Fernandes et al., 1984, Hemp, 2006a, Sebastien, 2010, Soini, 2005a, O'Brien et al., 2008, Grove, 1993, Kessey and O'Kting'ati, 1994). Key constraints to on-farm activities include limited access to "farming materials" and insecure land tenure (Soini, 2005a), followed by limitations in labor, water shortages, and limited knowledge of alternative agricultural techniques for more resilient farming systems (Fernandes et al., 1984, Hemp, 2006a, Sebastien, 2010, Soini, 2005a, O'Brien et al., 2008, Grove, 1993). "Farm materials" includes such items as seeds, fertilizers (both chemical and natural), farm tools (both mechanized and hand tools), and water (Soini, 2005a, Sebastien, 2010).

Rombo District has received much less research attention than the more accessible southern districts but reported land tenure, gender issues, declining coffee prices, changes in precipitation due to climate change, access to firewood, and declining soil fertility as the primary self-identified livelihood constraints (Meena and Sharif, 2008). TECOSO members and some other residents of Nanjara describe their production as focusing on subsistence crops (bananas, maize, beans, potatoes) with some cultivation and sale of tomatoes and maize by wealthier farmers; they also report that coffee was until recently the most significant source of income for the majority of households (personal communication). The sale price for 1kg of raw coffee beans was about $1 in

Nanjara in 2012-2013 and average production is 50-100kg per year for the families who agreed to homestead tours (personal communication).

Elderly residents reported that families did not experience food shortages prior to the 1970's and were not adversely affected by limited integration into the cash economy (personal communication). The elderly perceive Tanzanian independence in 1961 and the country's subsequent entrance into a cash economy as the time when they began to experience hardships (personal communication). The 1970's were a period of rapid intensification of household struggle and military action against Idi Amin in neighboring Uganda in 1978-79 had devastating effects on the Tanzanian economy (Pauw and Thurlow, 2011, Putterman, 1995). Similar economic struggles exist for smallholders throughout sub-Saharan Africa and issues regarding land tenure, market integration, and the need to improve the productivity of low-input agricultural systems are also widespread while most agricultural research has focused on increasing yields in large farms (Jayne et al., 2010).

Land Tenure

Land tenure is complex in Kilimanjaro Region but the primary tradition is for fathers to divide land holdings amongst sons (Tagseth, 2008, Soini, 2005a). Traditions prohibit women from owning land[2] and shame men who are financially obligated to sell land (Tagseth, 2008). Land sales must be approved by an all-male village council that encourages selling to male members of the same clan (Vavrus, 2003). These traditions persist in Nanjara with some exceptions; married women who have problems with their husbands may plead their cases to the male members of their families and are sometimes granted land by their fathers or brothers so they can return home and live peacefully as single women (personal communication). Single women might also be granted inheritance rights when they are deemed to have taken good care of their ailing parents or have shown "obedient behavior"(personal communication). Population growth has led to repeated subdivision of land holdings thereby reducing the average plot size to 1.25 acres, approximately half their mid-20th century size (Soini, 2005a, Håkansson et al., 2008). Lack of cash prevents land-poor households from acquiring land in rare instances where plots in the 1200-1800m belt are available for purchase, (Tagseth, 2008).

Many families in Nanjara do not have a lowland field but instead plant maize, potato, and bean crops next to their homegardens; the average homestead plot is 0.5-1 acre (Peter Shayo, personal communication, personal observation). Some well-connected families are able to secure plots in forest reserve clearings to plant maize and beans, an

[2] According to male residents who have served on the Rombo Village and Rombo District councils, Tanzania's constitution explicitly allows women to own land, but defers to tribal traditions and local councils unless pressed to intervene. Women would likely win the right to purchase land in Rombo if they pursed the matter in a court of law, but would be ostracized and made to feel unwelcome.

activity that is only possible if labor is available (meaning there are a sufficient number of young, able-bodied adults in the household).

Past Research Efforts

Rombo is poorly represented in research studies in general and particularly so for agriculture. One study by the CEEST Foundation analyzed livelihood adaptations to the impacts of climate change in Rombo District, but failed to specify household characteristics (Meena, 2007). The authors argued that sampling approximately 1,000 households over the course of two months (using checklists and physical markers to complement their surveys) was sufficient to produce conclusive results.

Previous studies in Kilimanjaro Region have used random sampling methods to estimate the prevalence of agricultural constraints throughout the entire population of Chagga homegardeners. These efforts provided insight into the types of limitations affecting farmers but the spatially broad sampling frames do not provide site-specific information. The highly variable constraints to household and farm development limit the utility of such studies. A detailed, village-specific study that builds upon locally identified needs and opportunities could provide more useful information and identify specific constraints and potential adaptive responses. Soini (2005) used a multivariate analysis of self-identified constraints and responses from a survey of 45 households throughout Kirua Vunja Division, but did not find any statistically significant correlations between constraints, responses, or agricultural yields (Soini, 2005a). The complexity of the farming system and inter-household variability were cited as responsible for limiting correlative analysis.

CONVERSATIONS WITH TECOSO MEMBERS & OTHER RESIDENTS OF NANJARA

Working and socializing with members of TECOSO provided the opportunity to become familiar with the village, household needs and resources, and agricultural practices. They and other village residents were eager to dispense invitations to weekly *mbege*[3] sampling parties in their homes and those of their friends and neighbors, all of whom are stereotypically Chagga: warm, friendly, and extremely sociable. TECOSO's members all agreed to host a tour of their homesteads and to discuss their livelihoods and perceived constraints; every member participated with the exception of one elderly male member who is divorced and felt ashamed to host a guest without providing an adequate

[3] Mbege is the name for a traditional Chagga drink brewed from bananas and millet. It is allowed to ferment for two weeks and is served in traditional 1L calabashes. It is often referred to as "food" and "medicine" and is central to Chagga culture.

meal. Homestead tours also gave insight into which characteristics could be used to determine relative wealth and social status. Signs of wealth and higher social status appear to include the presence of solar panels, piped water, a motorcycle, a brick house (instead of wood or mud), college-educated children, lineage that descends from chiefs and village leaders, leadership positions in local councils, and adult children with stable income (personal communication, personal observation). Wealthier families appear to have larger plots, but stable employment and business ventures also appear correlated to wealth (personal observation). Local signs of poverty include a mud house (instead of wood), children with little to no secondary school education, single women with children, and families who do not belong to or participate in a council/organization. The number of farm animals (cows, sheep, goats, chickens, and pigs) is probably not a reliable marker so it was not considered an important factor in determining relative wealth: some families choose to invest their labor differently, other families have physical labor constraints, but other sources of income, and animals are subject to disease (personal observation, personal communication). Some village residents, including TECOSO members, confirmed these factors as signs of relative wealth (personal communication).

The members of TECOSO appear to be similar to average residents of Nanjara when these markers are used to compare them to other village residents (personal communication, personal observation). They also appear similar to average members of most socio-economic groups relative to gender, age, and family composition. Six out of 7 male members are married and 1 is divorced; most men receive their plots when they marry so single men contribute to their fathers' farming operations and are not considered an individual household. Seven of the 12 women are married, 3 are single and live on their own plots (2 on 1/10th acre of land given to them by their brothers and 1 on a 3-acre plot inherited from her parents) and 1 is divorced and lives on a 1/10th acre plot on her brother's land. Approximately one third of the members are in their 30's with small children, one third are in their 40's with children as old as secondary school, and one third in their 50's with some older children contributing to other households.

Members also vary in their socioeconomic status as measured by the size of their land, their employment status, and the highest level of education achieved by their children – this last marker is not a strong correlation as some children fail out of school or elect to stop studying, but college education is a sign of a family's relative wealth and forcibly stopping school prior to completing secondary school is often a sign of poverty (personal observation, personal communication). Some TECOSO members have sent their children to medical school or to complete a four-year degree, most members have educated their children through secondary school or an apprenticeship, and some have been unable to pay for any secondary school (personal communication, personal observation).

Some other residents of Nanjara invited me to visit their homes and we discussed many of the above topics. The Tanzanian custom is to ask questions about a new acquaintance's background immediately after greetings and then offer tea or a meal (personal observation, personal communication). This inviting atmosphere encouraged me to ask questions and become familiar with some village households not belonging to TECOSO members; they appeared to exhibit similar characteristics to those described above (personal observation, personal communication).

ADDRESSING SELF-IDENTIFIED CONSTRAINTS

The most common self-identified constraints to increasing agriculture production by TECOSO members were land tenure (especially plot size), money, and water. Money was cited most often and many individuals complained of not having access to capital for business and entrepreneurial ventures such as expanding their farm operations or to purchase land.

TECOSO members reported that land tenure and water are equally complex constraints rooted in both local and national politics. The unanimous answer was "plant more vegetables" for consumption and for "selling at the market" when asked what they would do with more water; most families plant with the rainy season due to limited water availability. Elderly residents reported that they "never saw a month without rain" until the 1980's and it was previously possible to grow crops year-round (personal communication). Increasing agricultural productivity is a prevalent need throughout sub-Saharan Africa (SSA); the livelihoods of 90% of the population living in rural areas of SSA depended on agriculture in 2003 and increasing agricultural yields has been identified as crucial to poverty reduction (Asfaw et al., 2012).

IDENTIFYING AGRICULTURAL NEEDS AND RESEARCH OBJECTIVES WITH TECOSO FARMERS

TECOSO farmers in Nanjara identify being unable to grow vegetables in the cold, dry season as a significant constraint to their livelihood development despite historically being able to plant year-round; older residents recount planting year-round as they "never stayed more than one month without receiving rain." Families reported in late 2012 being unable to buy vegetables during the dry seasons due to high market costs, low or lack of income, and low availability (personal communication). Residents of Nanjara understand the nutritional importance of eating vegetables and an increasing incidence of diabetes diagnoses has caused a surge in outreach campaigns to promote a balanced diet (personal observation, personal communication).

Tomatoes (*Solanum lycopersicum*) are highly valued in Nanjara due to their high market value and use in local cuisine. I elected to evaluate the potential to increase tomato yields through mulch application and regular watering on the advice of Joseph Tarimo and Peter Shayo. Members of TECOSO agreed that improving tomato productivity could be a valuable asset to household livelihoods in Nanjara during the dry season.

This decision considered the increased labor requirements and whether mulch may have a better use elsewhere on the homestead; maize residues are used in

Figure 7: Looking uphill at the summit of Mt. Kilimanjaro, from Nanjara. Mawenzi Peak, on the left, appears taller than Uhuru Peak, on the right, due to proximity. TECOSO is located at the peak of the brown field.

homegardens under coffee and banana trees, but Joseph stated that dried maize often carries insects so is not an appropriate mulch for tomatoes (personal communication). Woody material and leaves from trees on or adjacent to the planting site would provide mulch that is both safe for the plants and does not have other uses (Joseph Tarimo, personal communication). TECOSO members agreed that collecting mulch in close proximity to the field is a feasible labor investment in exchange for greater yields (personal communication);

OBJECTIVES & HYPOTHESIS

This experiment's primary research objective was to measure the effect of mulch on tomato yields during the dry season. Secondary objectives were to use methods requiring minimal labor, resource, and capital investments and that are similar to current farming practices in Nanjara: tomatoes were watered minimally and planted without store-bought fertilizers and pesticides. Watering once or twice a week is considered an acceptable labor investment by TECOSO members (personal communication).

Developing and testing an all-natural pesticide was a secondary objective to make methods easily repeatable. TECOSO members believe that chemical pesticides and fertilizers sold locally are harmful to their health and they are prohibitively expensive (personal communication). An all-natural alternative made from cow urine and locally available plants could facilitate tomato planting by families unable to afford commercial products; if successful it may also have potential as a business venture.

Planting tomatoes with mulch and watering once or twice a week during the dry season was expected to increase yields and potentially provide Nanjarans with a new agricultural option; surplus may not be available to sell at the market but yields may be sufficient for home consumption. Tomatoes planted without mulch and never watered were expected to die before producing fruit due to the intensity of the sun; water and mulch were tested as separate variables to isolate their independent effects. Tomatoes were conventionally planted in October-November and received rain almost daily for approximately 2 months; consequently, treatments watered once a week without mulch were not expected to increase yields. Mulch alone was not expected to significantly increase yields since water is reportedly the limiting factor and there is little to no rain during the dry season (TECOSO, personal communication).

II. METHODS

PHASE 1: JANUARY – MAY 2013

Experimental trials were planted in four sites in early 2013: the TECOSO demonstration field, and on the farms of Evodi Tarimo, Joseph Tarimo, and Edwin Silayo. The fields were planted using a randomized block design; each row was divided equally into 8 treatments with numbers drawn from a hat to randomly assign treatments to plants within the rows. The total number of rows and plants per row varied from field to field according to the plot size, but the number of plants per row was consistent among the different rows in each field. Rows were planted according to local cultivation practices: 1 foot spacing between plants and 2 feet in between rows.

Residents complained that seeds purchased locally were sometimes non-viable so improved varieties were obtained from the AVRDC – The World Vegetable Center just outside of Arusha, Tanzania. The seeds are available at no cost to local farmers but their acquisition would require a trip to Arusha. Farmers in Nanjara were asked if this would be too costly or burdensome but they were adamant that the investment would be feasible and worthwhile if the improved varieties were more productive and resilient. The AVRDC staff provided an appropriate variety based on the altitude, aspect, and climate of Nanjara; it was tested with the same treatments as the locally available variety (Rio Grande).

TREATMENTS

Eight treatments for 3 variables – seed variety, water, mulch – were used in each of the sites; each variety (locally sourced and an AVRDC/improved variety) was planted either with mulch or without and was either watered or not watered throughout the experiment. Control for this phase was locally available seeds planted without mulch and not watered past the 1st week post-transplant; AVRDC-acquired seeds also received a treatment of no water & no mulch. Locally available seeds and AVRDC seeds each received a mulched but not watered treatment and a not mulched, watered once a week treatment. For the last 2 treatments each seed type (locally available, AVRDC) was mulched and watered throughout the experiment. The number of individuals per site and per treatment was based on the size of the site and shown in Table 1.

The seeds were planted in an in-ground nursery at the beginning of January 2013 and seedlings were transplanted a month later. Harsh weather resulting from a monsoon event in the Indian Ocean destroyed 90% of those transplants as well as many of the seedlings in the nursery. Plants destroyed by heavy winds and rains were replaced with healthier seedlings and the young transplants were protected using a shelter fashioned from tree branches with leaves and upright posts; this shelter remained in place for one week to provide shade and a cooler setting as the plants adjusted to their new environments. But the unpredictable weather and extreme events continued throughout the season and most of the young plants experienced blight.

Site name	**# of rows**	**Plants in each row / total number of plants**	**# of treatments**	**# of plants per treatment per row**
TECOSO	5 rows	24 plants per row / 120 total experimental plants	8	3 plants
Evodi Tarimo	3 rows	24 plants per row / 72 total experimental plants	8	3 plants
Joseph Tarimo	3 rows	16 plants per row / 48 total experimental plants	8	2 plants
Edwin Silayo	5 rows	8 plants per row / 40 total experimental plants	8	1 plant

Table 1: Number of plants in each experimental site.

Figure 8: Phase 1 tomatoes planted at TECOSO, taken during the first week when the shade system was in place to protect the newly transplanted seedlings.

Mulch

Mulch was collected at each site and consisted of a combination of dried leaves and twigs, grass, and dried corn residue. Joseph Tarimo has mulched past plantings, is knowledgeable about local plants and was consulted on which plants might be toxic or have other adverse effects. Mulch was applied to individual plants according to their randomly assigned treatment at a thickness of approximately 3 inches; finer materials such as dried grass were used were used in conjunction with other materials and applied sparingly to not suffocate the soil.

Figure 9: Mulch applied to half of the experimental plants and all of the outer, non-experimental plants at TECOSO.

Watering

Watering was planned for 1-2 times per week for slated treatments; this schedule is considered a feasible labor investment by TECOSO members and reasonable for plants in an average week with a normal amount of sunshine. Weeks with exceptionally hot days or when the sun felt exceptionally intense would result in watering a second time. However, abnormal rain events in January, February and March of 2013 exceeded weekly watering and all plants received the same amount of water throughout most of the experiment.

Edge Effect

Each site was planted with outer, non-experimental rows on all four sides at the same spacing as the experimental ones. These rows served as guard rows and were not used in data analysis.

Pesticide

A pesticide was developed for this experiment based on a recipe Joseph Tarimo was given at an agricultural workshop in south-central Tanzania a few years ago; he had observed its production but had been shy to test its efficacy (personal communication). It is produced from locally available organic materials. The leaves of "mbangi porini" (*Tagetes minuta*), "utupa" (*Tephrosia vogelii*), and "tumbaco" (*Nicotania spp.*) are beat in a large mortar and pestle for a few minutes with minced hot peppers (*Capsicum frutescens*) and chopped "ndulele" (*Solanum incanum*). The mixture is added to a 20L bucket of cow urine for one week and then diluted in a backpack pesticide sprayer – approximately 1L of mixture to 14L of water. Application was 1-3 times per week and its water-solubility required application following rain events. It was applied to all of the plants in each field and not tested in a controlled experiment; all of the plants in a field were sprayed within the same half hour, but different fields were sometimes sprayed on different days. This pesticide was an important part of this research and its use and effectiveness are reviewed anecdotally in the discussion.

Figure 10: Evodi Tarimo preparing pesticide; utupa in the lower left corner, tobacco to the right, hot peppers, and ndulele fruit in the upper right corner of the tarp.

Fertilizer

Store-bought fertilizers (usually NPK pellets) are relatively expensive for residents of Nanjara and are not used with less valuable crops, such as leafy greens (personal communication). Many residents of Nanjara have 1-5 cows, 2-5 goats, and chickens, and invest in a piglet to fatten and sell after 6 months (personal observation, personal communication). These animals are stall-fed and their manure collected for use as fertilizer – either placed in its raw form at the base of banana and coffee trees or rarely aged >6 months for use in vegetable gardens (personal observation, personal communication). This latter form is also sold or bartered and some households have fertilizer available for purchase (personal observation, personal communication). Most households generate at least some manure-based fertilizer throughout the year so it was deemed an appropriate input for this experiment. Its effects as relates to this experiment are discussed anecdotally in the results.

PHASE 1 CROP FAILURE

The first phase of this experiment began in January 2013 to coincide with the hot, dry season. However, excessive precipitation caused widespread blight, which resulted in extremely low yields: less than 30% of the plants in the TECOSO site produced fruit and yields were insufficient for statistical analysis. Cultivation trials on the three on-farm sites also failed. Moles killed approximately half of the plants on Evodi's field, blight claimed 80% of the plants at Silayo's field, and lack of sun prevented maturation of tomatoes on Joseph's field. TECOSO farmers were disappointed in the results and asked me to repeat the experiment during the upcoming cold, dry season (June – September) after the seasonal rains. Seeds were planted in May 2013 and seedlings transplanted in July of 2013.

PHASE 2: MAY – OCTOBER 2013

TECOSO farmers stated that the improved seed varieties obtained from the AVRDC were not desirable due to their larger fruit size and perception as being "less sweet" (personal communication). Tomatoes are often sold at the market by the unit so more small tomatoes are preferable to fewer large ones. Selling by the crate and shipping to other regions garners a better price and smaller, firmer tomato varieties better withstand the rigors of transport. Thus, Phase 2 used only locally available seeds (CAL J variety) but retained many of the same methods from Phase 1 as noted below.

Sites were again planted using a randomized block design with numbers drawn from a hat. Plants per row and per treatment again varied according to the size of the field and is shown in Table 2. Only Joseph, Evodi, and TECOSO's fields were used due to difficulties working in Silayo's field. Silayo is 65 years old, suffers from diabetes and was unable to provide any assistance; working in his field required either Evodi or Joseph to be present and the time commitment was burdensome for them. In addition, Silayo's wife was not amenable to hosting an experiment; Joseph and Evodi stated that she did not want to experiment in Silayo's field (personal communication).

Site name	# of rows	Plants in each row / total number of plants	# of treatments	# of plants per treatment per row
TECOSO	12 rows	26 plants per row / 312 total experimental plants	4	variable[4]
Evodi Tarimo	2 rows	24 plants per row / 48 total experimental plants	4	variable[5]
Joseph Tarimo	2 rows	6 plants per row / 12 total experimental plants	4	variable[6]

Table 2: Distribution of Phase 2 plants by site.

Figure 11: Tilling Phase 2 plants at TECOSO.

[4] The original planting scheme planned for an equal distribution of treatments; error on the part of the farmers resulted in an unequal number of individuals per treatment.
[5] See Footnote 5
[6] See Footnote 5

Figure 12: Joseph at Evodi's field with Phase 2 tomatoes.

Figure 13: Looking uphill to Kilimanjaro's summit from TECOSO's Phase 2 field.

TREATMENTS

Four treatments with 2 variables (water, mulch) were used at each site; plants received one of 4 treatments: a control planted without mulch and not watered after the 1st week post-transplant. The 2nd treatment was planted with mulch, but not watered past the 1st week and the 3rd treatment was watered throughout, but not mulched. The 4th treatment was planted with mulch and also watered throughout. The number of individuals per site and per treatment was again determined by the size of each site and is shown in Table 2.

Seeds for this phase were planted in a mixture of soil, fertilizer, and ash (40:40:20 ratio) in individual polypot containers to protect them during the colder months of May and June and to "keep them warm so they don't get blight" (Joseph Tarimo, personal communication). The nursery was planted in late May 2013 and the seedlings were transplanted in mid-July 2013 to protect the young plants during June's period of heavy fog. The nursery was located at Joseph's house and he shielded the seedlings during extreme weather events using temporary tarp installations.

The farmers were given an elaborate diagram of the planting scheme and they planted the experimental fields in late July 2013; color-coded stakes were used to designate which plants would be watered and mulched throughout the experiment (blue= no water, no mulch; yellow= no water, mulch; red= water, no mulch; green= water, mulch). Treatments were assigned using randomized block design.

Mulch and water treatments were the same as Phase 1; all mulch was collected from locations adjacent to each field and laid at a thickness of approximately 3 inches. Designated plants were watered usually once, but sometimes twice per week depending on the intensity of the sun. It was impossible to water all 3 experimental sites at the same time on the same day, but the time between site visits was consistent from site to site. To elaborate: if TECOSO's site visits occurred on Wednesday morning and Saturday morning then Evodi's field was visited on either Wednesday afternoon and Saturday afternoon or Thursday morning and Sunday morning or afternoon (to accommodate his church schedule).

The all-natural pesticide developed during Phase 1 was used 1-2 times per week during Phase 2. Sites were sometimes sprayed during different days of the week but all plants within each site received pesticide during the same half hour.

Watering during Phase 2 began similarly to Phase 1 with all members of TECOSO working to bring water from the river during Wednesday morning work events. Organizing two dozen farmers delayed watering to late morning and prompted concern for general plant health so two reliable women were paid to water the designated plants at TECOSO in the late afternoon. Their work was always supervised but they easily learned to distinguish watered plants by their color-coded stakes.

PHASE 2: DATA COLLECTION & ANALYSIS

Tomatoes were harvested prior to being completely ripe and when greenish-yellow in color to minimize theft by people and pests; this schedule was consistent across all sites. A digital kitchen scale was used to weigh the fruit harvested and weights were recorded with the date and the total number of individual fruits harvested from that plant; time constraints did not allow for fruits to be weighed and recorded individually. Harvest occurred as often as necessary to prevent fruits from ripening and becoming vulnerable to theft. Some theft did occur and fruits browsed by pests were weighed and recorded separately. The number of browsed fruits and their estimated weights (based on similar individuals on the same or neighboring plants) were less than 1% of total grams per plant for each treatment.

Data for the TECOSO field were normally distributed but subjected to a Kruskal-Wallis test due to the unequal number of individuals per treatment. With 3 degrees of freedom and at 0.5% level of significance, the critical value is $X_o{}^2 = 12.838$ (Chi-Square Distribution Table). The approximation of the variance of the rank sums H is equal to 69.304, which is in the rejection region and thus rejects the null hypothesis. The null hypothesis for this experiment is that there is no difference between the means for each treatment and rejecting the null hypothesis means that there is a difference in the mean g/plant yield for each treatment; the assignation errors resulting in different sample sizes per treatment were not significant at TECOSO and the data can be analyzed statistically.

The results from Evodi Tarimo's field could not be analyzed statistically due to inconsistencies in treatment methods. Evodi planted color-coded stakes designating treatment uphill of some plants and downhill of others creating some discrepancies in the first two weeks of the experiment. This error was rectified, but low river levels created water availability problems and prevented the watering scheme from being implemented correctly; consequently, data from Evodi's field are considered anecdotal and will be discussed only as an example of possible on-farm expectations.

Data from Joseph Tarimo's field are not statistically valid as too few total individuals (n=12) were planted. These results are used anecdotally to discuss on-farm conditions and challenges.

This experiment used methods easily repeatable by average residents of Nanjara. Purchase materials were limited to a pressure sprayer for dispensing pesticide, a watering can, chicken wire to build a fence, fertilizer, seeds, and labor. Watering cans and pressure sprayers can be borrowed from neighbors and most farmers can either source or barter fertilizer. Seeds are readily available from the market in Tarakea Town – 1-2 miles from Nanjara – and are not expensive. Labor is a more complicated matter, but the average resident is a capable farmer and extended families often work together to plant each other's plots (personal communication, personal observation).

III. RESULTS

PHASE 1

Results for Phase 1 could not be analyzed statistically due to low yields caused by inclement weather. In the months of January, February and March of 2013 it rained at least once a week in Nanjara. Consequently, water was not a limiting factor. Fungal blight was also widespread: every plant showed some level of infestation. Approximately 30% of the plants bore fruit, but most were damaged by the time they were ripe.

Figure 14: Phase 1; blight at TECOSO.

PHASE 2

Weather conditions during Phase 2 (July-October 2013) were mostly dry with only light rain during the first week of October. Thus, water potentially limited crop growth and it was possible to evaluate the effect of mulching and watering on tomato yields; there was also little evidence of insect, pests, blight or disease. Blight infestation was limited to the leaves on the lower half of the plants and did not appear to affect stems or fruit-bearing stalks. Browsing of leaves or fruit by insects was observed on only a few plants. Moles killed three experimental plants and two plants in the outer, non-experimental rows at TECOSO; a local “mole expert” was hired and removed the moles before they caused further damage.

The second experimental trials were successful: 97% of plants survived transplant and 96% produced fruits at the TECOSO site and 100% of plants survived transplant and produced fruits in both Evodi’s and Joseph’s fields. Tables 3-5 summarize treatment effects in each of the three research sites.

Treatment	Tomatoes Planted (#)	Tomatoes survived (#)	Tomato plants producing fruit (#)	Total tomatoes produced (#)	Total tomato yields (g)
no water, no mulch	47	45	44	300	6,107
no water, mulch	84	84	83	832	17,966
water, no mulch	84	81	79	811	21,051
water, mulch	97	94	94	1,248	34,604
TOTAL TECOSO	312	304	300	3,191	79,728

Table 3: Phase 2 yields by treatment at TECOSO

Treatment	Tomatoes Planted (#)	Alive (#)	Productive (#)	Total Fruit (#)	Total Fruit (g)
no water, no mulch	12	12	12	90	2,280
no water, mulch	12	12	12	178	4,925
water, no mulch	18	18	18	173	4,243
water, mulch	6	6	6	53	1,286
TOTAL EVODI	48	48	48	494	12,734

Table 4: Phase 2 yields by treatment at Evodi Tarimo's field

Treatment	Tomatoes Planted (#)	Alive (#)	Productive (#)	Total Fruit (#)	Total Fruit (g)
no water, no mulch	4	4	4	81	2,429
no water, mulch	2	2	2	55	2,091
water, no mulch	2	2	2	40	1,548
water, mulch	4	4	4	156	5,864
TOTAL JOSEPH	12	12	12	332	11,932

Table 5: Phase 2 yields by treatment at Joseph Tarimo's field

ANALYSIS OF TOMATO YIELDS AT TECOSO EXPERIMENTAL FIELD

Analysis of the tomatoes harvested at TECOSO was based on average weight of fruit harvested from each plant (g/plant), Table 6, the average weight of each fruit (g/fruit), Table 7, and the total number of fruit harvested from each plant (#fruit/plant), Table 8. The standard deviation is relatively high, but data are normally distributed with each treatment having only 1 or 2 x-µ outside of ±3 standard deviations.

Treatment	**mean g/plant**	***n***	**standard deviation (g)**	**range of mean g/plant (p=0.05)**
no water, no mulch	138.80[a]	44	122.41	102.63 - 174.97
no water, mulch	216.46[b]	83	149.41	184.31 - 248.60
water, no mulch	266.49[c]	79	154.03	232.50 - 300.43
water, mulch	368.13[d]	94	199.97	327.70 – 408.55

Table 6: Mean total grams/plant by treatment at TECOSO experimental field. Mean calculated as the sum of the total number of grams harvested from each plant per treatment divided by the number of productive individuals per treatment. *n*=number of productive individuals by treatment; Data in the same column bearing different superscripts are significantly different at p=0.05.

At p=0.05, mulch and water significantly affected tomato yield. Table 6 shows that watering once or twice a week and planting using mulch resulted in significant increases in average grams per plant when tomatoes are planted during the dry season of June – September. Mulching but not watering (b) produced on average 56% more grams per plant than not watering and applying no mulch (a). Watering but not mulching (c) produced on average 92% more grams per plant than (a) and an average 23% more grams as (b). Applying both water and mulch (d) produced on average 165% more grams per plant as (a), on average 70% g/plant more than (b) and on average 38% more g/per plant as (c). Interpreted differently, these numbers demonstrate that watering and mulching tomato plants during the dry season produced an average g/plant that is 38% greater than watering alone, an average g/plant that is 70% greater than mulching alone, and an average g/plant that is 165% greater than using neither water nor mulch.

The data were also analyzed to compare average grams per fruit by treatment (Table 7).

Treatment	**mean g/fruit**	***n***	**standard deviation (g)**	**range of mean g/fruit (p=0.05)**
no water, no mulch	22.96[a]	44	6.24	18.51-22.20
no water, mulch	21.59[a]	83	6.44	20.21 – 22.98
water, no mulch	25.96[b]	79	6.48	24.53 – 27.39
water, mulch	27.73[b]	94	6.79	26.36 - 29.10

Table 7: Average grams/fruit by treatment at TECOSO. Average calculated as the sum of total grams per treatment divided by the number of fruit harvested per treatment. *n*=number of individual tomato plants per treatment. Data in the same column bearing the same superscript are not significantly different at p=0.05.

At p=0.05, plants watered one or two times per week during the dry season (b) had on average 20% greater average grams per fruit than those not watered (a). Adding mulch in addition to watering yielded 7% greater mean g/fruit than watering alone, but this increase was not significant at p=0.05.

Treatment	**mean (#fruit/ plant)**	**N**	**standard deviation**	**range of mean #fruit/plant (p=0.05)**
no water, no mulch	6.81[a]	44	5.43	5.21 – 8.42
no water, mulch	10.02[b]	83	6.46	8.63 – 11.41
water, no mulch	10.27[b]	79	6.41	8.85 – 11.68
water, mulch	13.28[c]	94	6.76	11.91 – 14.64

Table 8: Average number of fruit/plant by treatment at TECOSO. Average calculated as the sum of the total number of fruit per treatment divided by the number of plants per treatment. *n*=number of productive plants per treatment. Data in the same column with the same superscript show no significant difference at p=0.05.

Planting with water or mulch (b) produced an average 49% greater mean number of fruits per plant (Table 8) (p=0.05) than planting with neither water nor mulch (a). Planting with both water and mulch (c) produced an average 31% greater fruit per plant than planting with either water alone or mulch alone(b) and an average 95% greater fruit per plant than planting with neither mulch nor water (a).

ANALYSIS OF ON-FARM EXPERIMENTS

Results from tomato cultivation on Evodi's field and Joseph's garden are not suited to statistical analysis, but suggest that planting at home sites is possible during the dry season. Only average yields from all of the experimental treatments can be analyzed from Evodi's field due to discrepancies in methodology; his 48 experimental plants produced an average 265 grams per plant – almost identical to TECOSO's average of 262 g/plant – despite his having trouble securing water for two weeks. Evodi planted each tomato plant with 1.5 scoops of manure from a 1L container and he and his wife tilled, weeded, and monitored the plants as many times weekly as their livelihood activities allowed. Evodi reported that his wife walks around their entire plot (3/4 acre) every day and checks on the status of their animals, plants, and the land in general, but that he made the decisions for maintaining the tomato plants. His family is young – his 3 children were 4, 6, and 9 years old in 2013 – and he was frequently gone each day to search for paid labor (personal observation). He often said, "My phone must always be on and I must always be speaking to someone so that people know I am ready at the first moment there is work." His tomatoes' yields suggest that planting with mulch during the cold, dry season is possible with minimal labor investment.

Results from Joseph's house suggest that smallholder plantings and improved care may result in even greater yields than that recorded on the TECOSO experiment field. Tomatoes from his field produced an average 275% greater grams per plant than TECOSO and an average 10 grams per fruit more than either TECOSO or Evodi's fields. Joseph, Evodi, and Peter Shayo attributed this disparity to Joseph's more generous fertilizer use; TECOSO's 300 tomatoes were planted using one scoop from a 1L container for each plant while Joseph used the same container and gave each of his 18 plants 3 full scoops.

Joseph's success may also be attributed to his love for working with plants and joy at experimenting with different planting methods. Each TECOSO member (and many Nanjara residents) has a business venture (e.g., knitting sweaters, harvesting for larger farms, brick-making, brewing mbege, etc.) and Joseph's is a seedling nursery (personal communication). He enjoyed our tomato experiment and, as "Plant Teacher" for TECOSO, he felt enormous responsibility to have the most successful harvest so he monitored the tomatoes twice daily (personal communication). Joseph and his wife are older with self-sufficient, young-adult children who contribute labor and some money (personal observation); this difference means Joseph had more time to contribute to managing the tomatoes.

ANECDOTAL ANALYSIS

PESTICIDE

The pesticide developed for this experiment was likely important in preventing pest infestations, but its effectiveness was not evaluated. Joseph Tarimo stated that the pesticide is a deterrent and “makes the bugs run away,” but does not kill insects; pests hide in the soil or on neighboring shrubs until its effects wore off (personal communication). A separate experiment was designed to measure its efficacy, but insufficient time and resources hampered its implementation. The consensus among members of TECOSO and other residents of Nanjara is that the pesticide was effective in deterring pests (personal communication). Nanjarans who came to visit the experimental fields and others who walked past asked how these tomatoes were planted and if pesticides and fertilizers were used. Local residents consider growing tomatoes during the dry season without chemical pesticides an achievement and evidence of the all-natural pesticide’s effectiveness (personal communication).

Red spider mites (*Tetranychus spp.*) were present throughout the experiment, but leaf discoloration was only occasionally observed. The pesticide was sprayed directly on mites to observe their reactions and the leadership trio (Joseph, Evodi, and Peter) stated: “they seem drunk.” Tomato farmers with larger ventures were very curious about the pesticide’s success given that, as Joseph described, “nobody can believe that we planted without chemical pesticides during the dry season. They think we are using magic.”

Joseph described each element of the pesticide and what he believes to be its contribution. *Uraro*, or cow urine, is believed to provide *mbollea* (fertilizer – in this case nitrogen) and is also believed to create a protective wax so that water is not able to enter into the plant. *Ndulele* (*Solanum incanum*) is also believed to create a protective wax to prevent water from accumulating; it was used as soap prior to the 1970’s and is also believed to be poisonous. Tobacco (*Nicotania spp.*), and *utupa* (*Tephrosia vogelii*) are also poisonous and both tobacco and *mbangi porini* (*Tagetes minuta*) have strong smells that “chase away” insects (Joseph Tarimo, personal communication). The efficacy of *Tephrosia vogelii* in combating invasive fish species is well documented throughout the world (Adaudi et al., 2008, Barnes and Freyre, 1966, Blommaert, 1949) and Joseph, Peter, and key elderly informants, recalled dropping *utupa* into the river so that “all of the fish would come up to the surface and [we] could just grab them.” Hot peppers (*Capsicum frutescens*) are believed to contribute a bad flavor and to create heat; temperatures can drop significantly overnight July-September and Joseph was concerned for the plants’ well-being. This experiment could not assess how each item contributed to the success of the pesticide, but insect damage was minimal (observed on less than 3% of plants).

This pesticide has the potential to benefit households in Nanjara and contribute to livelihood development for a few residents. It requires minimal start-up and investment costs, is water-soluble and appears harmless to human health when handled properly, and generated great local interest. To be developed as a business venture, it will need further research and testing to determine its efficacy, the optimal concentration for application, its shelf-life and how long it persists on plants (in the experiment we sprayed approximately once a week but also as needed if we saw insects on the plants). Creating a business will also require research into potential market demand, market opportunities, pricing, and assurance that there are no long-term negative effects to the environment or human health.

NATURAL, LOW-COST PLANTING METHODS

This experiment was designed to be repeatable by residents of Nanjara so it involved minimal investment in materials. The fertilizer used was manure-based as most local residents have stall-fed cattle, goats, pigs, and chickens. Manure availability is sometimes limited as most families have only one or two adult cattle, but it can be bartered (personal observation). Peter Shayo, TECOSO's chairman, and Joseph remarked at the end of the Phase 2 tomato harvest that manure may be a more complete fertilizer but its effects take longer to realize compared to store-bought NPK pellets; the time elapsed between planting, flowering, and harvesting fruit was longer than what is deemed average in Nanjara (personal communication). This lag may be a result of the season and colder temperatures, but Peter and Joseph suspect the all-natural farming methods may elongate maturation times. This difference is a potential deterrent to farmers looking to plant for commercial purposes because the increased maturation time represents delayed/ lost income.

MARKETABILITY

The tomatoes harvested in Phase 2 were noted for their "sweet flavor" and residents commented that they appreciated being able to eat them without washing them extensively to remove chemical pesticides (personal observation). Members of TECOSO were aware that the pesticide used is water-soluble and were pleased that a simple rinse or wipe was sufficient. Joseph noted that he is usually unable to eat tomatoes because they give him heartburn but he said, "These tomatoes I can eat all day with no problems." Word spread quickly that tomatoes were available and Joseph's wife Ester sold some to women needing one or two for evening meals. But September is a financially difficult month for most families as the months of June and July typically generate little income, corn and potato stores are empty, and rice & wheat are considered expensive (personal communication, personal observation). Attempts to sell surplus were not successful despite seemingly high interest in and the praise received for the quality of the tomatoes. 2013 also marked an increase in tomatoes coming from Kenya where irrigation infrastructure is expanding.

Evodi's wife stated that she sold tomatoes approximately one dozen times to neighbors and friends seeking all-natural tomatoes. Neighbors stated that they appreciated knowing the tomatoes were planted without chemical pesticides even if they could not taste the difference (personal communication). Evodi's wife also stated that some of her customers were looking for last-minute additions to evening meals; produce is bought (sparingly, as refrigerators are rare) twice a week on market days so residents often run out of vegetables (personal observation, personal communication). Joseph's wife, Ester, also sold tomatoes and advertised aggressively by asking her friends and neighbors to let their communities know about her all-natural tomatoes. Most of her sales were around 5pm to children whose mothers needed a couple of tomatoes to add to the evening meal (personal observation, personal communication). Both Ester and Evodi's wife brought a bucket of tomatoes to sell at the market but the prices were low and tomatoes abundantly available so they did not earn much money (personal communication).

IV. DISCUSSION

This experiment demonstrated that mulching tomato plants and watering once or twice a week can increase tomato yields (mean grams per plant, average grams per fruit, and average number of fruit per plant) during the cold, dry season of June – September. Results were similar to experiments at SUA where mulch was correlated with increased yields (John et al., 2005, Lyimo et al., 2015). TECOSO members and other Nanjara residents stated that the labor required to mulch and water a small vegetable garden located in close proximity to the family home would be a worthwhile and feasible investment (personal communication).

These findings should be evaluated during the primary tomato-planting season of November-February to see if a similar increase in yield is possible. Mulch may become a vector for increasing fungal blight infestation rates during the "short rains" season of October & November or may also create suitable habitat for pests (John et al., 2005) such as red spider mites, although mulch was found reduce early and late blight infestation and fungal infestation during the rainy season in recent SUA experiments (Lyimo et al., 2015). Mulching tomato crops has the potential to increase yields during the rainy season (Lyimo et al., 2015), prevent soil runoff during extreme weather events and reduce soil temperature during hot days (Schonbeck and Evanylo, 1998).

These variable effects warrant additional, long-term experimentation in Nanjara. Future research should examine the effects of using different plant species for mulch material and applying at various thicknesses. Joseph Tarimo often warned that certain species could be toxic to the soil, including *Eucalyptus spp.* and *Cedrela odorata*, and that mulch material from *Pinus patula* would "change the soil so that nothing grows there" (personal communication); the toxicity or suitably of mulch material may not be evident after one growing season. Testing of soil nutrient and physical conditions is also necessary because TECOSO farmers and older residents of Nanjara reported that they are unable to replicate the same yields as previous generations (prior to ~1980) (personal communication). A last area of future research is applying mulch to other common homegarden plants to evaluate its effects on other crops. Tomatoes are considered amongst the most valuable crops, but residents of Nanjara also plant leafy greens, corn, potatoes, beans, and peppers for home consumption (personal observation); eggplants and peppers are also in the nightshade family and mulch could potentially have the same effect on their yields.

Elderly residents (>65 years) reported that vegetable varieties, including corn, have changed in the last 30 years and that currently available varieties are less productive and of lower quality (e.g., poor lower germination rates) (personal communication). Nanjara's altitude (>1700m) and its location on Mt. Kilimanjaro's northern (hotter, drier) slopes suggest that residents may benefit from crop varieties adapted to those specific conditions. If soils are not nutrient deficient, changes in available seeds may be responsible for the reported yield declines. As of 2013, most crops only have one brand of seed available in Tarakea (personal observation, personal communication), so perhaps a more competitive market would improve seed quality. A number of residents reported that a quarter acre of corn was sufficient to feed an average family for an entire year (>4 children) prior to the 1970's, but that a full acre is now inadequate (personal communication).

The changing farming conditions reported by elderly residents in Nanjara require adaptation and adjustment for community members to maintain their livelihoods. It is unreasonable to expect that the Tarakea River will increase its output or that the community can return to using their historical furrows. A more appropriate response is to explore resilient livelihoods and farming practices that have the capacity to adapt to changing conditions. Resilience is its ability to derive the same ecosystem services despite changes to ecosystem processes (Folke et al., 2002, Holling, 1973). Improving water use efficiency by mulching during the dry season is one such strategy and has the potential to buffer Nanjara's residents against unexpected challenges and help them to adapt to changing water access and availability. Folke et al. (2002) warned that true resilience requires cooperation from government agencies due to complexities in natural resource tenure and management, but planting with mulch could provide some relief.

Collaborating with public and private institutions also helps farmers gain greater understanding of the widespread impact of poor farming conditions, such as the impact of soil fertility on social cohesion (Mapfumo et al., 2013). The presence of diverse participants allows for more holistic and integrative education for farmers and this can translate into greater adoptive capacity of new technologies or farming methods (Mapfumo et al., 2013). Local leaders are present in Nanjara, but collaborative efforts with extension agents, researchers, and private sector professionals are lacking (personal communication). While TEOCOSO members participated in developing experimental methods and implementing project goals, they did not help to analyze data or discuss the widespread impact of the results (beyond improved yields). This type of consultative participatory research is less effective in building ownership and empowering communities to find solutions to their livelihood constraints (Chambers, 1994, Cornwall and Jewkes, 1995). Inviting local researchers, private sector representatives, and extension agents could help to develop TECOSO's perspectives on the relationships between farming practices and the community. Future research should consider a longer time investment with a larger, diverse research team that can present these perspectives to the residents of Nanjara and better address their needs, interests and capabilities.

V. OPPORTUNITIES AND CHALLENGES TO SMALL FARMER USE OF MULCH AND WATERING

COST OF WATER

In developing this project I considered water availability and costs (i.e., labor and capital) to small farmers in Nanjara. TECOSO members stated that the labor required to water crops would be worth the return. However, river levels during the study were very low and river water was unavailable to many farmers, piped water was rationed due to low availability and infrastructure problems, and many residents were preoccupied searching for day labor (personal observation). During the dry season motorcycles frequently delivered large drums of water throughout the village. Women from disadvantaged households walked up to 30 minutes each way to retrieve water from the river, often accompanied by children carrying a smaller bucket; older children (of either sex) were sometimes sent in their place (personal communication, personal observation).

TECOSO members insisted that watering crops once per week is a reasonable labor investment for local farmers, but restricted water availability and access suggests this is questionable. The cost (in either labor or money) of watering once a week appears to be too great for many households at present and future water availability is unpredictable.

HOME CONSUMPTION & MARKET INTEGRATION

TECOSO members repeatedly stated throughout this study that they would "eat more vegetables" and "sell a little at the market" if they were available during the dry season (personal communication). They consistently stated in late 2012 that vegetables were prohibitively expensive and that access to money was limited by the end of the dry season (personal communication). In fact, Kenyan tomatoes were abundant in the Tarakea vegetable market in September and October of 2013 and prices were extremely low. This discrepancy may be due to the smaller volumes brought in 2011 & 2012 (personal communication) compared to the huge volume brought in 2013 (personal observation) so the trend had not yet been established when this experiment was developed in late 2012. Tomatoes sold by the unit in late 2013 and 5 tomatoes were priced at 100 Tanzania Shilling (Tsh) ($0.074 in 2013). For context, a family's daily tea allotment is 50-100Tsh and considered an absolute necessity in Tanzanian life. 50Tsh is the smallest coin available and 30,000Tsh is an average monthly earning potential for unskilled workers (personal communication). At present, producing tomatoes at little cost with a reasonable labor investment will not result in huge profits at the local market.

Tomatoes are highly valued for their market potential, but small farmers have limited opportunities due to restricted market access and competition from Kenyan imports (personal observation). Vegetable purchasers come to Tarakea from as far as Dar Es Salaam (~600km), Moshi (~80km) and Arusha (~160km) to purchase large quantities of tomatoes and other vegetables in January and February; these harvests are considered crucial to the local economy and create important seasonal jobs for average residents. Joseph reported visiting Kenya in 2012 and seeing vast tomato fields with drip irrigation; he noted that this larger volume reduces production costs and makes it difficult for Tanzanian farmers to compete (Joseph Tarimo, personal communication).

Tomato imports from Kenya constrain market opportunities for small farmers (avg.= 0.5-1 acre plot) in Nanjara by driving down market prices (personal observation, personal communication). Traders serving large urban centers are similarly uninterested in smallholders' tomatoes because their yields are too small to warrant traveling to Nanjara and purchasing from multiple households is difficult (personal communication). Tomato market options are now only available to wealthier residents who are not limited by water availability and who can produce larger quantities. This situation is widespread across sub-Saharan Africa with small household producers unable to compete with large farms (Jayne et al., 2010). Farmers' groups can help households develop market opportunities (Jayne et al., 2010) which suggests that TECOSO members have the potential to benefit from their organization.

Nanjara's experience is typical throughout Tanzania: large farms have driven agricultural growth in the last 15 years and smallholder market opportunities are very limited (Pauw and Thurlow, 2011). Agricultural growth has contributed 2/3 of the annual national GDP increase of 6.6%, but this is due to mass production of rice, wheat, and export crops and not the vegetable crops of small farmers (Pauw and Thurlow, 2011). The rate of poverty reduction is slower than the agricultural growth rate and poorer families remain undernourished (Pauw and Thurlow, 2011, Asfaw et al., 2012). Increasing crop yields on current agricultural land is an important goal throughout Sub-Saharan Africa to meet the needs of its growing population without further impingement on natural resources (Asfaw et al., 2012).

Planting tomatoes with mulch and watering once a week during the dry season in Nanjara can augment yield by as much as 165%, but there are barriers to widespread adoption. The best use of mulching tomatoes appears to be in gardens close to homes using minimal additional labor (including water collection) and providing vegetables for home consumption. Higher volume tomato production intended for sale to larger markets requires additional time, labor and resource investments that are likely to exceed what many residents of Nanjara are able or willing to invest. Expanding market opportunities should be a focus of future research in Rombo District to promote economic and livelihood development for small farmers. Collaboration between private, public, research, and non-governmental institutions is thought to be necessary for market development (Best, 2003, Sanginga et al., 2004, Bindlish and Evenson, 1997, Jayne et al., 2010), but Tanzania's low GDP means that economic returns would need to be significant to justify the investment. Improved tomato yields in Nanjara are unlikely to be sufficiently lucrative to create incentives for government or private sector entities to build infrastructure.

It seems equally unlikely that smallholders in Nanjara would be willing to risk investing in a process with little assurance of return. Market development targeted towards smallholders is often constrained by smallholders' inconsistent crop productivity and generally low surplus (Jayne et al., 2010) and involves greater risk as farmers must choose to allocate resources even if market prices are not fixed (Best, 2003). Limited market opportunities then constrain smallholders' ability to increase their productive capacity and further restricts market development (Jayne et al., 2010). For example, Evodi once planted 2 acres of corn in his forest plot and a thief stole the entire harvest; he now says he will never plant corn again and prefers beans and potatoes because they carry less value and so are less risky (personal communication). His corn was planted for subsistence and risking investment towards in even more uncertain market conditions seems even less likely.

Nevertheless, greater participation in market development may be essential to improving opportunities for smallholders in Nanjara. Tanzania's reliance on rain-fed irrigation leaves farmers vulnerable to climate change and what appears to be increasingly erratic, extreme and unpredictable precipitation patterns (Trenberth et al., 2007). Elderly residents (> 65 years) report that current rainfall patterns are characterized by inconsistent start dates and more extreme events[7] – causing erosion, less water absorption in the soil, and increased damage to crops -- and an overall decrease in crop production in comparison to thirty years ago (personal communication). Perceptions of unpredictable and unreliable rainfall patterns are documented throughout Kilimanjaro Region (Mbonile et al., 2003), but climate and precipitation data are very limited for Rombo District. Elderly residents, all members of TECOSO, and other residents of Nanjara report feeling frustrated that they do not now know when to plant their fields (e.g., seedlings are either planted too long before the rains start or they may be unable to plant with the start of the rains) (personal communication); in late 2012 the rains started for one week and were then followed by a 3-week drought in contrast to historical rainfall patterns (personal observation, personal communication). Some residents planted with the start of the rains and their crops were harmed by the ensuing drought.

Climate models suggest that export products – particularly grain – are especially vulnerable to erratic rains and shortages would create serious economic problems throughout Tanzania (Ahmed et al., 2011, Arndt et al., 2012). A reduction in grain

[7] "extreme events" defined as having larger volumes of water in one day or rain event.

exports is expected to reduce economic growth that will lead to reduced import capacity and increased food insecurity for the country's most vulnerable populations (Arndt et al., 2012). Other models predict climate-based grain shortages leading to rising prices and an increase in the number of people in poverty (Ahmed et al., 2011). Nanjara is especially vulnerable to climate-induced poverty and food insecurity given its remote location and what TECOSO members and other residents identify as lack of economic alternatives.

Creating a framework for improving smallholder participation in market development involves coordinating public and private entities to bring farmers to regional and urban markets so they learn the needs of their target buyers (Sanginga et al., 2004). But in 2013 most members of TECOSO and many residents of Nanjara had never or only rarely traveled further than 30 minutes from their village and were apprehensive of visiting larger urban centers (personal communication); a group market visit would require a great deal of preparation and coordination that does not seem likely without help from an outside institution.

EXTENSION & ADOPTION

An initial analysis of the results of this study was presented at a seminar in late October 2013 and open to all residents of Nanjara; average grams per plant, grams per fruit, and number of fruits per plant were presented for each site, and their significance discussed. Attendees asked questions about the differences in site productivity and the ecological effects of mulch were discussed at length. TECOSO members collectively decided to plant tomatoes at the nursery site during the following planting season and to invest any profits into infrastructure development. A nursery was planted in November and transplanted in December. By February 2014 only a few crates of tomatoes had been harvested and TECOSO members chose to divide the profits equally instead of re-investing. Joseph said in a phone conversation:

> "you know, Emmy, it's difficult to get a lot of people to do one thing. Some people do the work and some don't, so it's hard. And they didn't understand. Most of the people, they didn't understand why it's important to take care of your land. But I understood. And Peter and Evodi, they did understand. So we're going to work. We're going to work very hard to educate them."

Training & Visitation programs in Kenya and Burkina Faso found that other farmers are often the first line of contact for learning about new agricultural practices (Bindlish and Evenson, 1997) and receiving advice from trusted close relations (friends, neighbors, family members) is significant in increasing adoption rates of new agricultural practices in Tanzania (Elly and Silayo, 2013, Lwoga et al., 2011). Joseph's approach and TECOSO's leadership may be well-suited to serving as educational agents for their peers.

I also presented two outreach seminars to share proper pesticide production and application procedures with TECOSO members and other Nanjara residents. Joseph and Evodi described the ingredients used and how they contributed to deterring pests and then demonstrated how to make and apply the pesticide. The participants were excited that it requires very few materials and that the plants are locally available; the conversation eventually turned towards developing the pesticide as a business venture. Peter Shayo asked me to design an experiment to test its efficacy at different concentrations so that farmers wouldn't "accuse him of selling a product that kills plants" or "a useless product that doesn't do its job." TECOSO created a "pesticide nursery" so the plants will be available as needed; tobacco, utupa, hot peppers, and mbangi porini seeds were planted in an aboveground nursery and transplanted several weeks later. Since then very few TECOSO members use the pesticide despite its efficacy. Joseph believes that the labor investment for producing it is too great even if the chemical pesticides are expensive (Joseph Tarimo, personal communication).

Livelihood constraints may prevent TECOSO farmers from experimenting with changes in their agricultural practices. A large study throughout East Africa found a negative correlation between food security and farmers experimenting with changes in their agricultural practices, although the study was unable to discern causal relationships (Kristjanson et al., 2012). However, limited education and limited experience outside of one's community have been found to inhibit farmer decisions to experiment with new technologies (Kebede et al., 1990). A study of adoption rates for improved cassava varieties in Nigeria found that subsistence farmers need greater extension services than those with surplus (Polson and Spencer, 1991). Use of these examples is not meant to suggest that adopting this experiment's dry season tomato cultivation and pesticide are the only appropriate response for Nanjara's farmers, but rather to demonstrate that adoption may be a slow and challenging process.

Increasing outreach seminars and extension services may benefit farmers in Nanjara by providing education and support when implementing new technologies. Increased time spent with an extension agent was correlated with increased rates of adoption of new agricultural methods (Bindlish and Evenson, 1997). TECOSO members expressed hesitation to change their planting methods or to use an improved tomato variety despite the potential to increase yields (personal communication); the tomato variety acquired at the AVRDC was perceived as "less sweet" and less valuable due to its rounder shape and softer, juicier constitution that is less well-suited for transporting (personal communication). Variable adoption rates were observed in a 2012 study of an improved pigeonpea variety in western Tanzania; adoption rates were highest amongst farmers with the highest levels of education (Asfaw et al., 2012). This suggests that outreach and educational seminars may help provide farmers in Nanjara with a nuanced understanding of market opportunities and the potential of improved varieties. Future outreach and extension for TECOSO members and other Nanjara farmers should begin by asking what kinds of topics they deem most beneficial for their development, if any.

CONCLUSION

Lack of access to water, lack of access to capital, and the limited size of land holdings are the most important constraints to on-farm activities among small farmers of Nanjara and are challenges faced by small farmers throughout much of sub-Saharan Africa. External forces, particularly climate change and increasing integration into the cash economy, are exacerbating the need for household and communities to respond, but adapting to these changes is difficult. Increasing water use efficiency by planting with mulch could potentially allow year-round planting by farmers which elderly residents remember from their youth. Planting tomatoes with mulch and watering once a week was found to significantly increase yields during the dry season in this study. However, not all Nanjara residents have access to water, the labor cost to access water is high for households far from the river and piped water is only available to wealthy residents. Improving access to water and increasing water use efficiency build upon historic agricultural practices and are adaptive responses that have the potential to enhance household and community resilience to changing climatic and economic conditions. However, improving water access and water use efficiency for all village farmers will likely require external support and assistance.

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APPENDIX A: WOMEN

Only anecdotal evidence is available but this paper would be remiss not to discuss the severity of the problems women face in their everyday lives. At *mbege* parties or in the late afternoon, women often asked me to sit and tell “women’s stories” to compare livelihoods in Tanzania and in the States/developed world. There are endearing similarities in the rhetoric exchanged, such as “when a man enters the kitchen, you can just enter behind him and fix all of his mistakes” and “men would not last one day if they had our cycles. They would run home to their mothers and just die.” But women mostly recounted facing significant obstacles, which are listed below.

- Extremely high prevalence of physical and sexual violence against women. >50% are reportedly assaulted by their husbands, sometimes precipitated by the consumption of massive amounts of alcohol. Women can only complain to the local councils, but these processes are geared towards finding a resolution and do not encourage separation.
    - Many women complain that their husbands drink all of the money, and often before the children are able to eat.
    - Women who leave their husbands must also usually leave their children behind.
- Mama J., Mama S., Mama R., and Mama B. independently report that >90% of men engage in extramarital affairs; HIV is prevalent in the village and Mama J. says “of course we are afraid. I am so afraid that he will bring it to me. But Emmy, what can I do? There’s nothing I can do. So I just pray.”
- Reproductive care is increasingly available but is still lacking. A significant percentage (20-40%?) of women have either lost a child shortly after birth, during childbirth, birthed a stillborn child, or died during childbirth. During this project’s one-year period, no fewer than 6 different women lost a baby either during or shortly after birth (within one month).
    - Women are chastised if they are unable to work during their menstrual cycles due to pain and discomfort. NSAID medicines, such as ibuprofen, are not available to them and they also lack materials to keep themselves clean and comfortable. Maria remarked one day “Emmy, we’ve all noticed that you never have drops running down your leg. Do you have a menstrual cycle? What do you use? Every woman here has drops” She further explained that men chastise women who have noticeable spots and will publicly humiliate them. Young girls often miss 2-3 days of school every month and their educations suffer greatly.
- Male teachers routinely sexually assault girls as young as 12; the girls are offered 5,000Tsh ($3.5) and better grades if they participate.
- Some women are able to leave their husbands and remain with their children on their father’s land, but they are not permitted a voice in local councils; local councils are voluntary groups where members pay a small monthly fee as a form of life insurance. The council can mitigate effects of certain events such as crop failure, theft, and other unexpected expenses. These councils are crucial to the community-centric lifestyle in Nanjara, but single women are often excluded. Some are allowed cursory membership but they are not afforded a vote.