## ABSTRACT

CRUZ, ANGEL ELISA. Understanding Soil Health Impacts to Food Security through Participatory Action Research with Smallholder Farmers in El Salvador (Under the direction of Dr. Michelle Schroeder-Moreno).

Smallholder farmers make up a significant portion of the world's population, with approximately 450-500 million smallholder farmers worldwide, representing 85% of the world's farms. Moreover, smallholder farmers are thought to represent half of the world's hungry. Thus, the fate of smallholder farmers is tied to reducing poverty and hunger worldwide and achieving global food security. Despite years of technological advances and millions invested in research and education, hunger and malnutrition are prevalent, food insecurity is increasing globally and environmental degradation on farmland continues. There is growing consensus that the industrial food system model has been destructive for rural communities and smallholder farmers in developing countries. The production methods advocated by conventional agriculture disrupt traditional livelihoods and accelerate indebtedness while increasing the risk of the small farmer. Moreover, agricultural outreach and education programs for smallholder farmers have been cut in many countries and research has shifted to focus on large-scale export crops and breeding programs, further

marginalizing smallholder farmers. Thus, much of the current agricultural research and extension programs are not benefiting the smallholder farmer in developing countries.

Sustained improvement to the livelihoods of poor farmers in developing countries, many located in tropical regions, requires a different type of approach and focus in agricultural research.

The overall objective of this dissertation research was to utilize a participatory action research process to evaluate strategies to improve food security and production for smallholder farmers in northeastern El Salvador through the following research objectives:

I. Determine the current household food security rates, production practices, and perceived agroecological barriers to improving production and food security in northeastern El Salvador

II. Evaluate the baseline soil health status for smallholder farms in northeastern El Salvador and assess three different soil health assessments as potential tools for use in smallholder farming communities

III. Evaluate the relationship between soil health on farms and household food security in smallholder farming communities of northeastern El Salvador

IV. Apply Participatory Action Research principles to agroecological field trials and utilize both farmer and researcher perspectives to evaluate organic fertility and soil conservation treatments on corn yield.

Overall, this research demonstrated that household food security is a significant struggle for many smallholder subsistence farmers in northeastern El Salvador. Both the months of inadequate household food provisioning (MIAHFP) and Escala Latinoamericana Y Caribeña de Seguridad Alimentaria (ELCSA) methods of assessing food security appear to be valid for assessing food security in smallholder farming communities of Central America. Total area land farmed, especially area planted in beans, and increased diversity of crops seem to positively impact food security. Access to improved seed and nitrogen fertilizers do not seem to impact household food security or yields, but farmers perceive lack of fertilizers to be a barrier to improving production. In addition, soil health is significantly correlated with increased food security. Our results demonstrate that a farm's soil health may directly impact the household food security. As for assessing soil health on smallholder farms, the three soil health assessments demonstrated clearly different overall soil health scores, especially the CATIE and CASH methods, in regards to both overall scores and individual indicators. Future research should examine how to better integrate the three different assessments and adapt them to specific situations.

Finally, in the participatory on farm field trials, results from both the farmer evaluations and researcher data demonstrate that the soil conservation treatment improved whole ear weight of corn. Furthermore, farmers chose the organic fertility and soil conservation techniques as their treatments and were part of the research process and evaluation, demonstrating new ways to evaluate farm trial from a farmer perspective. Our study demonstrates that agroecological field trials can be done with full farmer participation using a PAR methodology and provides a model for future PAR agricultural research.

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Sin Suelo Sin Comida: Utilizing participatory action research and farmer perspectives to evaluate the role of soil health in improving food security for smallholder farmers in northeastern El Salvador

by
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## DEDICATION

This thesis is dedicated to my family, my parents, Miguel and Lesia Cruz, who have supported me throughout my life, my brother Michael Cruz, and my partner Sean, who has been there to support me and celebrate with me throughout all the highs and lows of my doctoral career. I must also thank my second family, in El Salvador, where I have many brothers and sisters, mothers, fathers, sisters and grandmothers. They are the reason I decided to pursue further education in agroecology and inspired me to use it to benefit the poor and hungry. It was also these same families and farmers that made this dissertation possible. Had it not been for their time, willingness to share their stories and struggles, commitment, and enthusiasm for improving agriculture and soils, none of this research would have been possible. I hope that one day I will be able to re-pay them.

## BIOGRAPHY

Growing up in small town in western NC, surrounded by tobacco and Christmas tree farms, agriculture was a part of me from a young age. However, it wasn't until I was living in El Salvador, sweating under the tropical sun, dreaming about tractors and cold water, that I became passionate about sustainable agriculture. I saw firsthand the differences that improving agricultural production can have on the livelihoods of rural farmers and their families. Thus, I decided to move back to the US and pursue graduate school in the plant and soil sciences. I knew that in the US, we have access to some of the best resources and training in the world. I wanted to take advantage of those opportunities with the hope of eventually using my training to benefit the world's poorest and marginalized communities. After finishing my MS in Crop Science, also under the direction of Dr. Schroeder-Moreno, I knew it was time to go back to El Salvador. I finally had the opportunity to do research that combined all of my passions – soils, food security and smallholder farmers in Central America.

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# I. Introduction

## 1. The current challenge facing smallholder farmers in Central America

Despite a half century of agricultural intensification that has doubled global food production, hunger and malnutrition are still prevalent in many countries. The Food and Agriculture Organization of the United Nations estimates there are close to 1 billion people that go hungry worldwide (FAO, 2012). Of these, greater than 40% are small-scale producers who cultivate more than half of all farmland globally. Ironically, it is these farmers who struggle most to feed their families twelve months a year.

There are various ideas as to how to achieve food security for the more than 1 billion people worldwide experiencing some degree of food insecurity (Ejeta, 2009; Holt-Gimenez and Altieri, 2013). Some assert that improved agricultural practices will ensure food security, such as improved soil management (Lal, 2009), or agricultural intensification of small-scale farm operations and enhanced biotechnology (Pinstrup-Andersen and Pandya-Lorch, 1998). However, given that the number of hungry people has continued to rise despite the spread of Green Revolution technologies, it is clear that the solution to food insecurity is more complex than just increasing agricultural productivity at the national level. Food insecurity is not simply about the availability of food but also an issue of food access and distribution, and persistent poverty (Singh and Gilman, 1999).

Currently there is a large yield gap for small farmers in Central America growing cereal crops. Research shows the yield gap is likely due to a combination of water and nutrient limitations, pest, weed and disease pressure, lack of mechanization and lack of knowledge (Anthony and Ferroni, 2012). The Green Revolution (GR) technologies (synthetic fertilizers, pesticides, herbicides and improved seeds) have increased food production globally, yet most smallholder farmers have seen little benefit from these GR technologies. Large scale monocultures were responsible for much of the global yield increases because these technologies required too great an investment for small farmers to benefit (Otero and Pechlaner, 2008). In Central America, small farmers often do not have access to chemical inputs and costs can be prohibitive. Furthermore, in El Salvador, even when farmers do have access to fertilizers, their yields may remain low (Mendez et al., 2010a; Morris et al., 2013b). Despite lower yields, smallholder farmers still account for approximately 50% of the agricultural output for domestic consumption in most developing countries (ETC Group, 2009). Therefore, many argue that small farmer dominated agriculture and not large scale industrial agriculture is the backbone of food security in developing countries (Tscharntke et al., 2012a). Improving yields and food security status for smallholder farmers will also have national and global impacts.

Soil degradation affects approximately one-third of agricultural land globally (Blanco and Lal, 2010) and is one of the main factors stagnating food production (Bindraban et al., 2012). It impacts global food security through decreases in soil functions and, in turn, crop yields. In order to feed a growing population without destroying our natural resources, addressing declining soil health therefore must be made a global priority. Currently, however, the core role of soil in sustaining yields and combating global food security is often overlooked (Rojas et al., 2016). Agricultural productivity and food security in Latin America depend heavily on soil health. Decreases in soil health indicators often lead to declining household production (Stocking, 2003), a problem faced by 60% of rural communities in the tropics and sub-tropics.

Sustained improvement to the livelihoods of poor farmers in developing countries, many located in tropical regions, requires a different type of approach and focus in agricultural research. It should enhance the capacity of rural people to adapt to changing conditions, rather than delivering “finished technologies” (Sayer and Campbell 2001). Sayer and Campbell (2001) identify participatory approaches to research as crucial for increased adoption by farmers of improved agricultural practices. Participatory Action Research (PAR) is engaged research that aims to benefit all people involved, build collaborative relationships between researchers and participants, and facilitates reflection by all parties (McIntyre, 2008). It emerged as a response to the traditional top-down approach to rural development and agricultural research (Ellis, 2000). By involving community members or farmers in the research process, participatory methods have the potential to generate more appropriate and long-term solutions and adoption than top-down extractive research, since participants have ownership and investment in the project (Mayoux and Chambers, 2005).

## 2. El Salvador as a case study

El Salvador is one of the smallest and most densely populated countries in Latin America. With average population densities of over 200 inhabitants per $km^2$ and only 2% of its original forest cover, it is the most deforested country in the continental America’s (Mendez, 2004). Some of the primary impacts of deforestation are increased levels of soil erosion and maintenance and replenishment of potable water supplies. Like many Latin

American countries, El Salvador has a highly unequal distribution of wealth, displaying a Gini coefficient of 0.44, meaning that the richest 10% of the population receives incomes 44 times higher than the poorest 10% (Ministerio de Economia, 2009). Moreover, the increasing external debt of USD$12.95 billion (51.7% of GDP) makes it challenging for the government to sustain its budgetary commitments to social programs and assist the many families living in poverty. El Salvador was chosen as a case study because it represents a country with high levels of adoption of GR technology and still has a moderate percentage of its national GDP (12%) from agriculture. At the last estimate, 21% of total employment is in agriculture (World Bank, 2012). Although El Salvador is a small country with widespread bus access and paved roads, the villages and farms of most smallholder farmers are located between 1 and 15 kilometers from a town, with dirt roads only accessible in the dry season, intermittent access to running water and infrequent electricity. Most rural farms are located at elevations between 100 and 1200 meters above sea level (masl). The climate is humid with a rainy season between May and October.

Beginning in the mid-1980s, farmers began to manage their personal milpa (maize and bean) plots using synthetic fertilizers and pesticides to produce higher yields with lower labor investments. These technologies have been promoted by the national agricultural extension service (CENTA) and non-governmental organizations, which has contributed to the widespread use of GR technologies in the Salvadoran countryside. In one study with coffee cooperatives, farmers reported adopting the use of agrochemicals after seeing the rapid effects of herbicides and yield increases from synthetic fertilizers on neighbors' farms (Morris et al., 2013b). However, more recent work shows that despite farmers having difficulty affording the agrochemicals, many believe they have no choice but to spray for their land to produce maize and beans (Morris et al., 2013b).

Furthermore, large-scale, export-oriented agriculture was actively promoted throughout Latin America in the 1980's and El Salvador was no exception (Perez Martinez, 2008). The focus on high-value exports represented a shift in governmental support from subsistence agriculture, leaving many peasant households without access to credit or technical assistance (THRUPP, 1990). While these programs contributed to increased agricultural production and boosted GDP in many countries, such policies have also increased the vulnerability of smallholder farming households and undermined food security and sovereignty in much of the region (Altieri and Manuel Toledo, 2011). Today, one third of El Salvador's rural population lives in extreme poverty (de Ferranti et al., 2005). The declining support for rural agriculture has prompted many rural farmers to abandon agriculture in search of more profitable endeavors, often entailing migration to urban areas and other countries (Hecht and Saatchi, 2007). The influx of remittances from migration has had a remarkable impact on the Salvadoran economy, culture, and environment (Cuellar et al., 2002).

Furthermore, soil erosion and degradation is a major environmental threat in El Salvador that has required the country to take a nation-wide investment in decreasing erosion and improving sustainable agriculture production. Thus, understanding how to effectively and appropriately improve soil conservation and fertility techniques on smallholder farms is a critical need in El Salvador. In addition, the lead researcher had an established relationship and built a foundation of mutual trust with a local non-governmental organization, Fundacion

Hermano Mercedes Ruiz (FUNDAHMER) and farmers in the area, facilitating the development of the PAR process in this research.

## 3. Research Concepts

### 3.1. *Participatory Action Research*

Sustained improvement to the livelihoods of poor farmers in developing countries, many in tropical regions, requires a different type of agricultural research, that enhances the capacity of rural people to adapt to changing conditions, rather than delivering "finished technologies" (Sayer and Campbell 2001). Sayer and Campbell (2001) identify participatory approaches to research as crucial for increased adoption by farmers of technologies. Participatory Action Research (PAR; Figure 1.1) is engaged research that aims to benefit all people involved, build collaborative relationships between researchers and participants, and facilitates reflection by all parties (McIntyre, 2008). It emerged as a response to the traditional top-down approach to rural development and agricultural research (Ellis, 1998; Ellis, 2000). By involving community members in the research process, participatory methods have the potential to generate more appropriate and long-term solutions than top-down extractive research, since participants have ownership and investment in the project (Mayoux and Chambers, 2005).

In the last 20 years, PAR has gained support as a valid and important research approach in a variety of disciplines (Kindon et al., 2007). Although PAR is most commonly practiced in the social sciences, it is increasingly utilized in natural resources and agricultural fields (Castellanet and Jordan, 2002). Participatory action research is especially common in the field of agroecology research which promotes the blending of local knowledge and scientific knowledge (Altieri, 1999) and a growing number of agroecological researchers have begun utilizing PAR approaches and methodologies (Greenwood et al., 1993; Guzman et al., 2013a; Kindon et al., 2007). Truly participatory projects involve local people and organizations not only in the collection of information but also in project planning, design, and monitoring (Guijt, 1998). A key criterion in any PAR process is that participating community members make decisions and determine the direction a project takes, and projects are designed with participants based on their needs and priorities (Selener, 1997). However, PAR models (Figure 1.1) are still by no means mainstream methods of research (Probst 2002). Compared to traditional research methods and rural development, there has been relatively little research on PAR and its implementation in field and agricultural settings.

Participatory action research (PAR) results in stronger research results that are the product of involving farmers in the development of the study and interpretation of the data, and leads to the development of more sustainable and culturally appropriate strategies for strengthening food security (Putnam et al., 2014). In this dissertation, a PAR process was used to involve farmers in the entire research process and to carry out this research, I plan to work collaboratively with a local non-governmental organization, Fundacion Hermano

Mercedes Ruiz (FUNDAHMER). FUNDAHMER is a Salvadoran non- profit with over 20 years of experience in sustainable development in these rural communities.

### 3.2.*Food Security*

The ideas and concepts behind food security were first officially articulated in the early 1940's during World War II when forty-four government leaders met to discuss the "goal of freedom from want in relation to food and agriculture" (FAO, 2012). The right to food officially became a human right in 1948, and the term "food security" was first described at the World Food Summit in 1974. Since 1974, many definitions have become popular with different governments and organizations worldwide. The most widely used definition of food security is "a situation that exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences" (FAO, November, 2009). Food security is most commonly understood as being dependent on four conditions: availability, access, utilization and stability of the previous (Barrett, 2010). Likewise, food security can refer to global, national, community, household, and individual conditions, and can be either transitory or permanent (Pinstrup-Andersen, 2009).

Historically, policy and development programs related to food security have focused heavily on availability of food, however, availability does not guarantee access and access does not guarantee utilization (Barrett, 2010; Pinstrup-Andersen, 2009). The limitations of the notion of availability were first popularized by Sen in 1981. Through studies of large famines, Send found that people starved to death not because of a decrease in the availability of food, but because of a lack of access to available food due to limited power and entitlements of certain groups. Today, despite most professionals accepting the four conditions of food security, food policy globally tends to focus solely on food availability (Barrett, 2010). Food availability as an indicator of food security is limited because it is often an overall measurement of national food production and import numbers which does not demonstrate the nuances of household and individual food access. Incorporating food access and utilization provide a more holistic picture to address the complexity of food security and includes issues of power, distribution, and consumption behaviors (Morris et al., 2013a) .

Although the concept of food security is essential to understanding hunger issues, it is important to recognize there are several limitations. Food security addresses the physical and economic availability, access and utilization of food and encompasses important methods for measuring nutrition at individual levels (i.e. BMI, caloric intake, etc.). However, it does not make any judgment on where food comes from, who is producing it, how it is produced, or if it aligns with an individual or community's choice about the who, what, where, and how of food production and distribution.

#### 3.3.*1. Methods of assessing food security*

Food security measurements change whether you are looking at it on a national, community, household or individual level. Some common types of measurements used to understand the conditions of availability, access, and utilization include national food production and import numbers, coping strategies, months of inadequate household food provisioning (MIAHFP), food expenditures, dietary diversity, anthropometric measures, and caloric intake (Pinstrup-Andersen, 2009; Swindale and Bilinsky, 2006). How food security is measured is important because the results can change depending on the time and type of measurement and results are often used to guide policy-making and development interventions. When measurements focus solely on regional and national aggregate availability, food policy and development interventions address food aid and overall food production. However, these types of interventions do not address issues of waste, unequal access within the country or community, and how the food is used. In addition to these more quantitative measurements at different scales (national, regional, community, households and individual) it is also important to use more qualitative measurements to understand food security. Qualitative measurements are often guided by the target community's own definition of food security/insecurity and measure the subjects' perception of food security (Maxwell, 1996; Morris et al., 2013a). Qualitative data on food security are often collected using in-depth interviews, semi-structured interviews, and focus groups. This data can be complementary to quantitative data and provide a more holistic picture of food security when paired with more quantitative measurements. In this dissertation, I chose to focus on two common quantitative indicators for food security that would be appropriate for use in rural communities of Central America, including: months of inadequate household food provisioning (MIAHFP) and the FAO food security index.

a) Months of inadequate household food provisioning:

The months of inadequate household food provisioning (MIAHFP) indicator was developed by the U.S. Agency for International Development to measure how many months in a 12 month period a household lacks enough food to meet its basic needs. This measurement is relevant for smallholder farmers because food insecurity can be worse or only present at specific times of the year that overlap with shortages in income or shortages in subsistence food before the next harvest has started. These shortages can be related to low production levels, poor storage, and seasonally higher food prices (Morris et al., 2013a). Hence, undernutrition and hunger can be chronic issues in these communities experienced seasonally. The MIAHFP is one measurement that can provide a baseline understanding of the severity of a household's food security situation during the course of the past year. It is measured by asking the following two questions: 1) In the past 12 months, were there months in which you did not have enough food to meet your family's needs? 2) If yes, what months out of the past 12 did you not have enough food? However, it is important to note there are limitations to this approach. For example, participants may interpret the meaning of 'enough food' differently.

b) <u>FAO Food Insecurity Experience Scale</u>

Finally, the FAO Food Insecurity Experience Scale is another indicator for food security. It is an experience-based metric of severity of food insecurity that relies on people's direct responses. These responses are collected through the FIES Survey Module (FIES-SM; Appendix A) which consists of eight short questions that refer to the experiences of the individual respondent or of the respondent's household as a whole. Seven additional questions are asked if children are present in the household. The questions focus on self-reported food-related behaviors and experiences associated with increasing difficulties in accessing food due to resource constraints.

Based on the responses to the survey questions in the FIES, a scale of light, medium, or severe food insecurity is determined for the household. A household is deemed food secure if none of the food insecurity questions apply to them. Because a scale of food insecurity is created, the FIES results are comparable across countries and unique versions of the survey have already been adapted to various regions and countries. A specific version of the FIES scale, the "Escala Latinoamericana Y Caribeña de Soberanía Alimentaria," has been created and adapted to Latin America and the Caribbean (see Appendix A). The weakness with the FIES model and subsistence farmers is that there is the possibility of significant bias in responding to the questions and the time of the year the questions are asked could have a significant impact on the results.

### 3.4. *Soil Health*

Soil health is commonly defined as the "capacity of a living soil to function with natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain and enhance water and air quality, and promote plant and animal health" (Doran, 2002). Agricultural soil health incorporates not only chemical soil fertility, but also physical and biological soil functions and processes that are needed to support plant growth. Healthy soils support crop productivity, as well as environmental quality and animal health (Doran, 2002). Wide scale adoption of soil health promoting practices has the potential to make global impacts on farm resilience, productivity and economics. The quality of agricultural land and ability of that land to maintain high levels of production is threatened by the physical, chemical and biological degradation of these soils (Bindraban et al., 2012; Stott and Moebius-Clune, 2017). Examples of such threats include soil erosion, compaction, pollution, and decreased soil organic matter (Hurni et al., 2015; Rojas et al., 2016; Stott and Moebius-Clune, 2017).

Soil health cannot be directly measured but various individual soil indicators for the functioning of the soil can be used as a combined measure for soil health. A variety of soil health assessment tools exist, such as the Haney test (Haney et al., 2010; Haney et al., 2006), the Solvita® soil health test  and the CATIE in field agroecological soil health assessment [Centro Agronómico Tropical de Investigación y Enseñanza (Padilla and Suchini, 2001)]. In the U.S., the Natural Resources Conservation Service (NRCS) is a leader in developing methodologies for soil health assessments and standardization of soil health indicators for a variety of stakeholders, including producers. In 2001, (Friedman et al., 2001) NRCS published a guide for soil health assessment that combines in field measurements with some laboratory analyses. The NRCS soil health assessment has been widely used throughout the US, but has not been utilized in the Latin American tropics to our knowledge. Building on the work of the NRCS following a very similar methodology, Cornell developed the Comprehensive Assessment of Soil Health [CASH (Moebius-Clune et al., 2016)], which was designed for soil health assessment to aid in management decisions. The Cornell CASH methodology also integrates soil biological, physical and chemical indicators, (often interpreted based on soil texture) that change with management. In addition, the CASH method developed a soil health report that enables farmers to identify constraints (beyond just chemical) to the functioning of their agricultural soils and implement management strategies to target the constraints, as well as monitor changes in soil health over time. No comprehensive soil health assessment methodology designed specifically for the tropics exists to our knowledge, but the CASH method is the most comprehensive assessment as of yet.

## 4. Focus on agriculture as method to improve food security

Historically, rural development strategies for subsistence farmers focused on improving productivity and markets for agricultural products with little attention to off-farm activities. More recently, development activities' focus has shifted to almost all off farm activities. Studies have shown that farmers purposefully continue to participate in both market and subsistence agriculture because it spreads risk and provides a safety net should one succumb to market or natural disaster (Eakin et al., 2006). Additionally, subsistence food production may be the most readily available method of increasing access if you look at food security as being largely a problem of access to food. Because subsistence agricultural productivity is known to be low, improving productivity could have a significant impact on food security (Baiphethi and Jacobs, 2009).

Some researchers and practitioners argue that smallholder farmer dominated agriculture and not large scale industrial agriculture is the backbone of food security in developing countries (Tscharntke et al., 2012b). Moreover, it is well established that small and diversified farms can be more productive per unit area than large monocultures (De Schutter, 2011; Horlings and Marsden, 2011). Altieri (1999) proposd that sustainable agriculture practiced by smallholder farmers can improve food security and farmer livelihoods by:

- increasing agricultural productivity
- building stability and sustainability of farming systems
- contributing to pest and disease management
- diversifying products and income generation from the farm
- conserving soil and increasing soil health
- reducing risk to individuals and communities
- increasing efficiency of resource use
- reducing dependency on external inputs
- increasing nutritional status of individuals and communities

In recent years, a number of research and development projects have shown how improved production can improve rural livelihoods. In Salvadoran coffee farmers, maize and bean production were significantly correlated with a decrease in number of thin months. Farmers who produced their own maize and beans fared better in the seasonal hunger months than farmers who did not produce maize and beans (Morris et al., 2013a). Emerging research demonstrates that worldwide, smallholder agroecological production contributes substantially to food security, rural livelihoods, and local and national economies, yet there is still substantial opportunity for improvement in yields (Altieri et al., 2012). One caveat is that most of the research that has been done in Central America examining production strategies and food security challenges of smallholder farmers with a cash crop (such as coffee), but little work has been done understanding the livelihoods of subsistence smallholder farmers in

Central America. Work in Africa with subsistence farmers shows great potential, but more work specifically in Central America is needed.

## 5. Research Objectives

The overall objective of this doctoral resarch is to utilize a participatory action research process to evaluate strategies to improve food security and production for smallholder farmers in northeastern El Salvador.

The specific research objectives are outlined below:

i. Determine the current household food security rates, production practices, and perceived agroecological barriers to improving production and food security

ii. Evaluate the baseline soil health status for smallholder farms in El Salvador and assess three different soil health assessments as potential tools for use in smallholder farming communities

iii. Evaluate the relationship between soil health on farms and household food security in smallholder farming communities

iv. Apply PAR principles to agroecological field trials and utilize both farmer and researcher perspectives to evaluate organic fertility and soil conservation treatments on corn yield.

To understand how each research question is integrated into the overall PAR process see Figure 1.3.

## REFERENCES


Altieri, M. 1999. Applying agroecology to enhance the productivity of peasant farming systems in latin america. Environment, Development and Sustainability 1:197-217.

Altieri, M.A. 2009. Agroecology, small farms, and food sovereignty. Mon. Rev. -Indep. Social. Mag. 61:102-113.

Altieri, M.A. and V. Manuel Toledo. 2011. The agroecological revolution in latin america: Rescuing nature, ensuring food sovereignty and empowering peasants. J. Peasant Stud. 38:587-612.

Altieri, M.A., F.R. Funes-Monzote and P. Petersen. 2012. Agroecologically efficient agricultural systems for smallholder farmers: Contributions to food sovereignty. Agron. Sustain. Dev. 32:1-13.

Anthony, V.M. and M. Ferroni. 2012. Agricultural biotechnology and smallholder farmers in developing countries. Curr. Opin. Biotechnol. 23:278-285.

Baiphethi, M.N. and P.T. Jacobs. 2009. The contribution of subsistence farming to food security in south africa. Agrekon 48:459-482.

Barrett, C.B. 2010. Measuring food insecurity. Science 327:825-828.

Bharucha, Z. and J. Pretty. 2010. The roles and values of wild foods in agricultural systems. Philos. Trans. R. Soc. B-Biol. Sci. 365:2913-2926.

Bindraban, P.S., M. van der Velde, L. Ye, M. van den Berg, S. Materechera, D.I. Kiba, L. Tamene, K.V. Ragnarsdottir, R. Jongschaap, M. Hoogmoed, W. Hoogmoed, C. van

Beek and G. van Lynden. 2012. Assessing the impact of soil degradation on food production. Curr. Opin. Environ. Sustain. 4:478-488.

Castellanet, C. and C.F. Jordan. 2002. Participatory action reseach in natural resource management: A critique of the method based on five years' experience in the trasamazonica region of brazil. Taylor & Francis, New York.

Cuellar, N., I. Gomez, S. Kandel and H. Rosa. 2002. Rural poverty and the environment in el salvador: Lessons for sustainable livelihoods. PRISMA, San Salvador, El Salvador.

de Ferranti, D., G.E. Perry, W. Foster, D. Dederman and A. Valdes. 2005. Beyond the City: The rural contribution to development. The World Bank, Washington, DC.

De Schutter, O. 2011. The green rush: The global race for farmland and the rights of land users. Harv. Int. Law J. 52:503-559.

Deleon, A., D.M. Sangerman-Jarquin and J.A.C. Sanchez. 2009. Acceptance of maize platino, oro blanco and protemas cultivars of high proteinic quality in el salvador, central america. Agricultura Tecnica En Mexico 35:406-415.

Doran, J. 2002. Soil health and global sustainability: Translating science into practice. Agric. Ecosyst. Environ. 88:119-127.

Eakin, H., C. Tucker and E. Castellanos. 2006. Responding to the coffee crisis: A pilot study of farmers' adaptations in mexico, guatemala and honduras. Geogr. J. 172:156-171.

Ejeta, G. 2009. Revitalizing agricultural research for global food security. Food Secur. 1:391-401.

Ellis, F. 2000. Rural livelihoods and diversity in developing countries. Oxford University Press, New York.

Ellis, F. 1998. Household strategies and rural livelihood diversification. J. Dev. Stud. 35:1-38.

ETC Group. 2009. Who will feed us? questions for the food and climate crisis. Rep. #102. Action Group on Erosion, Technology and Concentration, .

FAO. November, 2009. Declaration of the world summit on food security. Food and Agriculture Organization of the United Nations, Rome.

FAO. May 2012. *Escala latinoamericana y caribena de seguridad alimentaria (ELCSA): Manual de uso y aplicaciones.*. Food and Agriculture Organization of the United Nations, Rome.

FAO. 2012. Committee on world food security: Thirty-ninth session. Food and Agriculture Organization of the United Nations, Rome.

Friedman, D., M. Hubbs, A. Tugel, C. Seybold and M. Sucik. 2001. Guidelines for soil quality assessment in conservation planning. United States Department of Agriculture, Natural Resources Conservation Service, Soil Quality Institute, .

Gliessman, S. 2012. A voice for sustainability from latin america. J. Sustainable Agric. 36:1-2.

Gliessman, S. 2009. Editorial: Community-based participatory action research with agroecology. J. Sustainable Agric. 33:799-800.

Graeub, B.E., M.J. Chappell, H. Wittman, S. Ledermann, R.B. Kerr and B. Gemmill-Herren. 2016. The state of family farms in the world. World Dev. 87:1-15.

Greenwood, D., W. Whyte and I. Harkavy. 1993. Participatory action research as a process and as a goal. Hum. Relat. 46:175-192.

Guijt, I. 1998. Participatory monitoring and impact assessment of sustainable agriculture initiatives: An introduction to key elements. IIED, London.

Guzman Casado, G., M. Gonzales de Molina and E. Sevilla Guzman. 2000. Introduccion a la agroecologia como desarrollo rural sostenible. Ediciones Mundi-Prensa, Madrid.

Guzman, G.I., D. Lopez, L. Roman and A.M. Alonso. 2013a. Participatory action research in agroecology: Building local organic food networks in spain. Agroecol. Sustain. Food Syst. 37:127-146.

Guzman, G.I., D. Lopez, L. Roman and A.M. Alonso. 2013b. Participatory action research in agroecology: Building local organic food networks in spain. Agroecol. Sustain. Food Syst. 37:127-146.

Haag, L.A., J.D. Holman, J. Ransom, T. Roberts, S. Maxwell, M.E. Zarnstorff and L. Murray. 2017. Compensation of corn yield components to late-season stand reductions in the central and northern great plains. Agron. J. 109:524-531.

Haney, R.L., E.B. Haney, L.R. Hossner and J.G. Arnold. 2010. Modifications to the new soil extractant H3A-1: A multinutrient extractant. Commun. Soil Sci. Plant Anal. 41:1513-1523.

Haney, R., E. Haney, L. Hossner and J. Arnold. 2006. Development of a new soil extractant for simultaneous phosphorus, ammonium, and nitrate analysis. Commun. Soil Sci. Plant Anal. 37:1511-1523.

Hecht, S.B. and S.S. Saatchi. 2007. Globalization and forest resurgence: Changes in forest cover in el salvador. Bioscience 57:663-672.

Holt-Gimenez, E. and M.A. Altieri. 2013. Agroecology, food sovereignty, and the new green revolution. Agroecol. Sustain. Food Syst. 37:90-102.

Horlings, L.G. and T.K. Marsden. 2011. Towards the real green revolution? exploring the conceptual dimensions of a new ecological modernisation of agriculture that could 'feed the world'. Glob. Environ. Change-Human Policy Dimens. 21:441-452.

Hurni, H., M. Giger, H. Liniger, R.M. Studer, P. Messerli, B. Portner, G. Schwilch, B. Wolfgramm and T. Breu. 2015. Soils, agriculture and food security: The interplay

between ecosystem functioning and human well-being. Curr. Opin. Environ. Sustain. 15:25-34.

Kindon, S., R. Pain and M. Kesby (eds.) 2007. Participatory action research appreaches and methods. Routledge, .

Lal, R. 2009. Challenges and opportunities in soil organic matter research. Eur. J. Soil Sci. 60:158-169.

Maxwell, D. 1996. Measuring food insecurity: The frequency and severity of "coping strategies". Food Policy 21:291-303.

Mayoux, L. and R. Chambers. 2005. Reversing the paradigm: Quantification, participatory methods and pro-poor impact assessment. Journal of International Development 17:271-298.

McIntyre, A. 2008. Participatory action research. Sage Publications, Los Angeles.

Mendez, V.E. 2004. Traditional shade, rural livelihoods, and conservation in small coffee farms and cooperative of western el salvador. Ph.D. Disseration. University of California: Santa Cruz, .

Mendez, V.E., C.M. Bacon, M. Olson, K.S. Morris and A. Shattuck. 2010a. Agrobiodiversity and shade coffee smallholder livelihoods: A review and synthesis of ten years of research in central america. Prof. Geogr. 62:357-376.

Ministerio de Economia. 2009. Encuesta de hogares de propositos multiples (EHPM). Gobierno de El Salvador, Direccion General de Estadistica y Censos, .

Moebius, B.N., H.M. van Es, R.R. Schindelbeck, O.J. Idowu, D.J. Clune and J.E. Thies. 2007. Evaluation of laboratory-measured soil properties as indicators of soil physical quality. Soil Sci. 172:895-912.

Moebius-Clune, B.N., H.M. van Es, O.J. Idowu, R.R. Schindelbeck, J.M. Kimetu, S. Ngoze, J. Lehmann and J.M. Kinyangi. 2011. Long-term soil quality degradation along a cultivation chronosequence in western kenya. Agric. Ecosyst. Environ. 141:86-99.

Moebius-Clune, B.N., D.J. Moebius-Clune, B.K. Gugino, O.J. Idowu, R.R. Schindelbeck, A.J. Ristow, H.M. van Es, J.E. Thies, H.A. Shayler, M.B. McBride, D.W. Wolfe and

G.S. Abawi. 2016. Comprehensive assessment of soil health – the cornell framework manual. Rep. Edition 3.1. Cornell University, Geneva, NY.

Morris, K.S., V.E. Mendez and M.B. Olson. 2013a. ''Los meses flacos': Seasonal food insecurity in a salvadoran organic coffee cooperative. J. Peasant Stud. 40:423-446.

Morris, K.S., V.E. Mendez, S.T. Lovell and M. Olson. 2013b. Conventional food plot management in an organic coffee cooperative: Explaining the paradox. Agroecol. Sustain. Food Syst. 37:762-787.

NRCS. 1999. Soil quality test kit guide. United States Department of Agriculture, Agriculture Research Service, Natural Resources Conservation Service: Soil Quality Institute, .

Otero, G. and G. Pechlaner. 2008. Conclusion: Food for the few? . *In* G. Otero (ed.) Food for the few. University of Texas Press, Austin, TX.

Padilla, C.D. and J.G. Suchini. 2001. Guía pare el sondeo agroecologico de suelos y cultivos. Rep. Manual Técnico; no. 112. Centro Agronómico Tropical de Investigación y Enseñanza (CATIE); Programa Agroambiental Mesoamericano, Turrialba, Costa Rica.

Perez Martinez, M.E. 2008. Adaptability of rural dwellers and settlements in conurbation areas: The case of bogota, colombia. Cuad. Desarro. Rural 5:61-86.

Pinstrup-Andersen, P. and R. Pandya-Lorch. 1998. Food security and sustainable use of natural resources: A 2020 vision. Ecol. Econ. 26:1-10.

Pinstrup-Andersen, P. 2009. Food security: Definition and measurement. Food Secur. 1:5-7.

Probst, K. 2002. Participatory monitoring and evaluation: A promising concept in participatory research? Lessons from two case studies in Honduras. Weikersheim: Margraf Publishers.

Putnam, H., W. Godek, S. Kissmann, J. Luckson Pierre, S.H. Alvarado Dzul, H. Calix De Dios and S.R. Gliessman. 2014. Coupling agroecology and PAR to identify appropriate food security and sovereignty strategies in indigenous communities. Agroecol. Sustain. Food Syst. 38:165-198..

Rojas, R.V., M. Achouri, J. Maroulis and L. Caon. 2016. Healthy soils: A prerequisite for sustainable food security. Environ. Earth Sci. 75:180.

Sayer, J. A. and B. Campbell. 2001. Research to integrate productivity enhancement, environmental protection, and human development. Conservation Ecology 5(2): 32.

Selener, D. 1997. Participatory action research and social change. Cornell, Ithaca.

Sen, A. 1981. Poverty and famines: An essay on entitlement and deprivation. Oxford University Press, Oxford.

Singh, N. and J. Gilman. 1999. Making livelihoods more sustainable. Int. Soc. Sci. J. 51:539-+.

Stocking, M. 2003. Tropical soils and food security: The next 50 years. Science 302:1356-1359.

Stott, D.E. and B.N. Moebius-Clune. 2017. Soil health: Challenges and opportunities. Global Soil Security109-121.

Swindale, A. and P. Bilinsky. 2006. Development of a universally applicable household food insecurity measurement tool: Process, current status, and outstanding issues. J. Nutr. 136:1449-1452.

THRUPP, L. 1990. Environmental initiatives in costa-rica - a political ecology perspective. Soc. Nat. Resour. 3:243-256.

Tscharntke, T., Y. Clough, T.C. Wanger, L. Jackson, I. Motzke, I. Perfecto, J. Vandermeer and A. Whitbread. 2012a. Global food security, biodiversity conservation and the future of agricultural intensification. Biol. Conserv. 151:53-59.

Tscharntke, T., Y. Clough, T.C. Wanger, L. Jackson, I. Motzke, I. Perfecto, J. Vandermeer and A. Whitbread. 2012b. Global food security, biodiversity conservation and the future of agricultural intensification. Biol. Conserv. 151:53-59.

WFP. February 2012. El salvador: Purchase for progress. World Food Programme, .

World Bank. 2012. World development indicators dataset 2012.

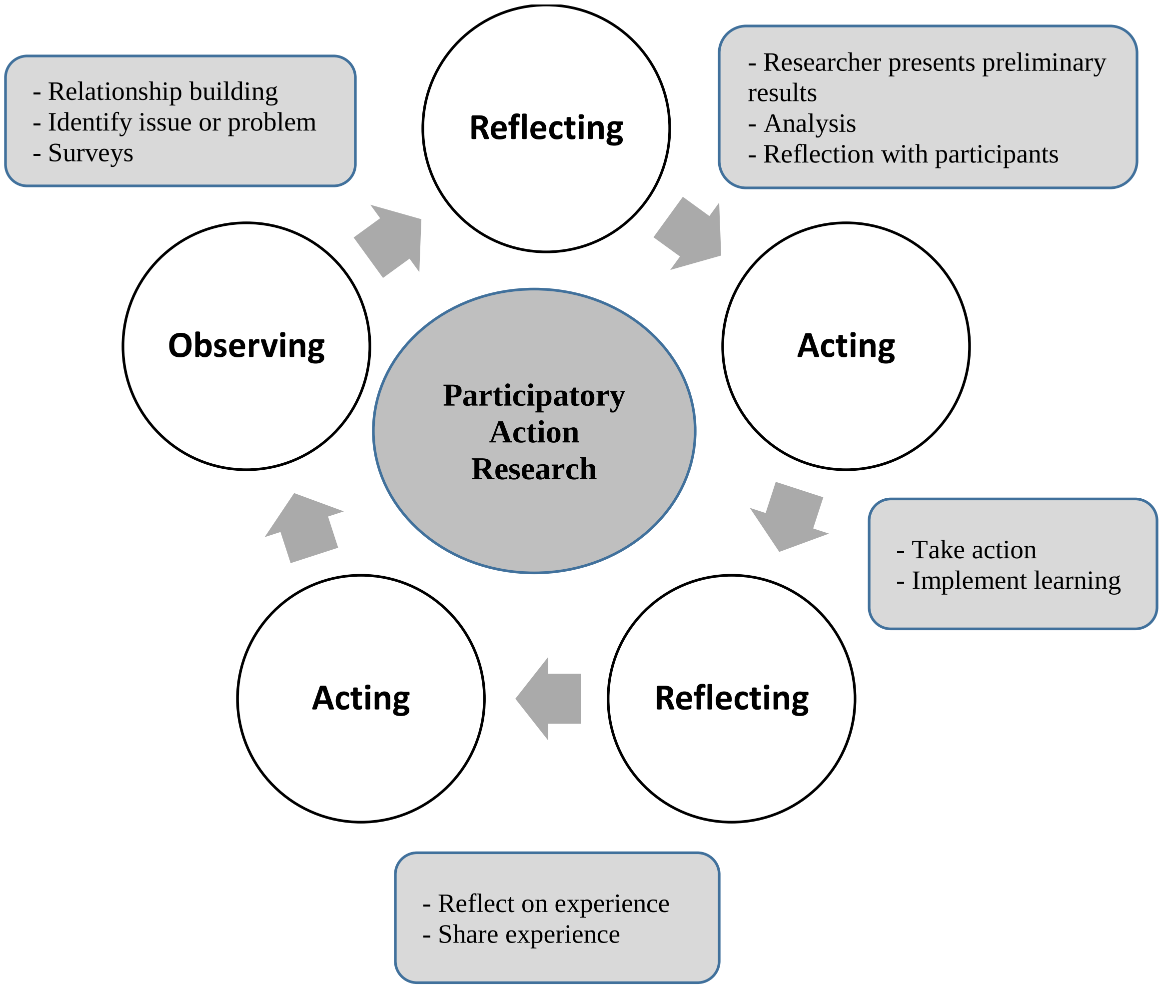


Figure 1.1. An example of the iterative process of Participatory Action Research (PAR) and potential steps within each phase. Once the process is started with an initial observation (or initial reflection) phase then it proceeds with reflection and action steps to interpret research and design action. Action and reflection phases can occur at the same time or intermittently through the process.

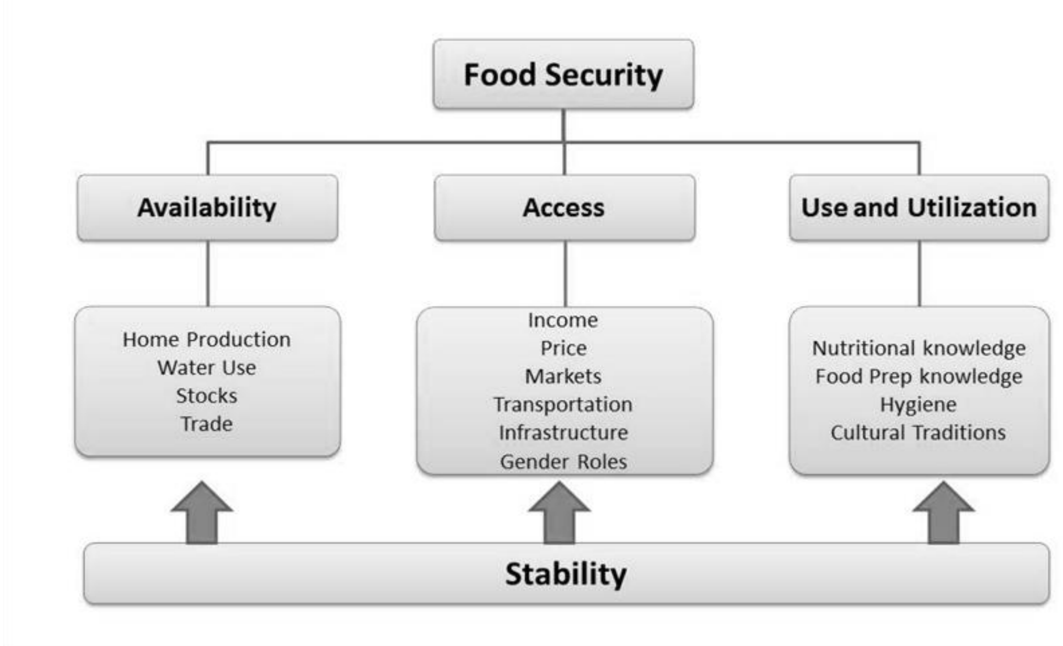


Figure 1.2. The pillars of food security and how they interact (Adapted from FAO 2012).

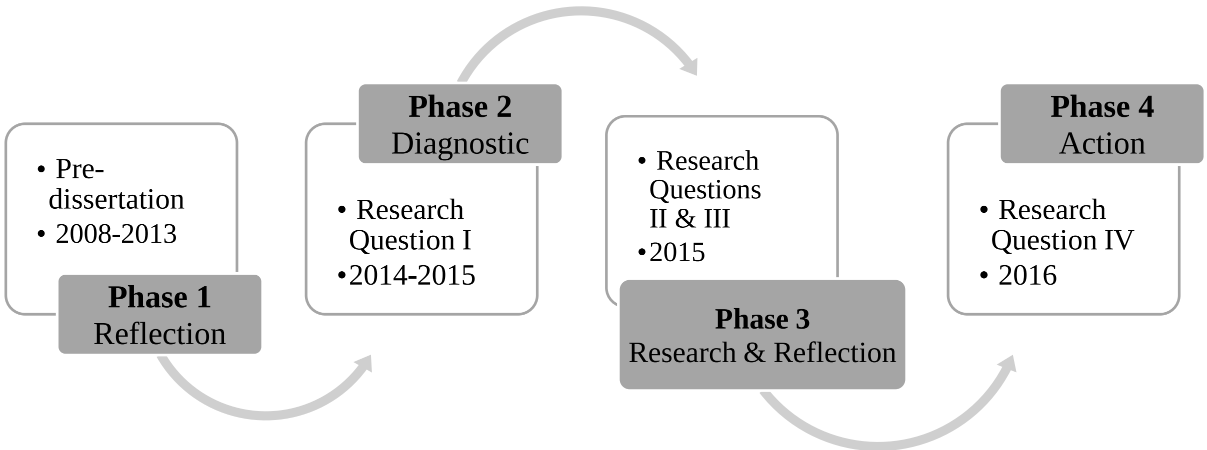


Figure 1.3. Summary of participatory action process (PAR) phases and how it integrates with the dissertation research objectives

# II. Examining food security and yield barriers for smallholder farmers in rural El Salvador

**Abstract**

A half century of agricultural intensification has doubled global food production, yet hunger and malnutrition are still prevalent in developing countries. In El Salvador, high population density and lack of arable land have contributed to high levels of food insecurity, especially in rural farming areas. Nonetheless, smallholder farmers account for approximately 50% of the agricultural output for domestic consumption in El Salvador. While synthetic fertilizers and pesticides have the potential to improve yields and food security, they are not always the most effective solution and yields can remain low for smallholder farmers. This study utilized a participatory research approach to carry out the following objectives: 1) determine household food security levels of smallholder farmers in two regions of El Salvador; 2) assess the relationship between production practices and yield for smallholder farmers in in two regions of El Salvador; and 3) identify what these farmers perceive to be the greatest agricultural production and household food security challenges they are currently facing. Data was collected in land reform communities in the eastern part of El Salvador in 2014 and 2015. Through focus groups, in-depth household surveys, and analysis of a variety of soil parameters, we characterize the relationship between agricultural production, soil health and food security. The majority of households interviewed had high levels of food insecurity. Our results demonstrated no relationship between fertilizer inputs and farm yields despite high usage of agrochemicals. Farmers were applying near double the amount of nitrogen necessary, but farmers perceived lack of fertilizer to be the main limiting factor to improving production. The results of this research demonstrate the potential for sustainable soil

management to improve food security and rural livelihoods for smallholder farmers in El Salvador.

## 1. Introduction

Despite a half century of agricultural intensification that has doubled global food production, hunger and malnutrition are still prevalent in many countries. The Food and Agriculture Organization of the United Nations estimates that nearly 1 billion people go hungry worldwide each year (FAO, 2012). Of these, more than 40% are small-scale farmers (IFAD-UNEP, 2013). Small-scale farmers, defined as those cultivating two hectares or less, cultivate more than half of all farmland globally. Ironically, it is these farmers who struggle most to feed their families throughout the entire year. There have been many different proposals for achieving greater food security (Ejeta 2009; Holt-Giménez et al. 2012). Some focus on improved agricultural practices as a means of improving food security, including soil management (Lal 2009), agricultural intensification of small-scale farms, and biotechnology (Pinstrup-Andersen and Pandya-Lorch 1998). Even though billions of dollars are spent annually on improving food security and researching potential solutions, there is still no consensus on best strategies and only small improvements have been made.

About 60% of rural communities in the tropics and subtropics are persistently affected by declining household food production, which also has an effect on household food security. Sub-Saharan Africa, parts of Latin America- especially Central America- and Central Asia are the regions that are suffering the most (World Health Report 1999). In Central America, small farmers growing cereal crops have very low yields (Anthony and Ferroni 2012). Green Revolution (GR) technologies (synthetic fertilizers, pesticides, herbicides and improved seeds) have increased food production globally, yet most smallholder farmers have seen little benefit from these technologies (Rosa et al. 2004; Gliessman 2007). Despite their lower yields, smallholder farmers still account for more than 50% of the agricultural output for domestic consumption in many developing countries (ETC Group 2009; Graeub et al. 2016). For example, in El Salvador, farms ranging from 0.5 ha to 3 ha produce 66% of the total grains for the country (Arias, 2014; p.115). The integral role of smallholder farmers in the national food system of El Salvador is not unique. Thus, many argue that small-scale farmer agriculture and not large-scale industrial agriculture is the backbone of food security in developing countries (Graeub et al., 2016; Tscharntke et al., 2012b).

Recent research on household food security for smallholder famers in Latin America has focused on farms with a cash crop, such as coffee (Mendez et al., 2010a). Studies find that the majority of small-scale coffee farmers struggle with periods of seasonal food insecurity, often lasting several months (Bacon et al., 2014; Mendez et al. 2010; Morris et al. 2013). In contrast, most of the research on subsistence farmers' experiences of food security has focused on Africa. Although some studies have analyzed rural household food security in Latin America (Bacon et al., 2014; Mendez et al., 2010a; Mendez et al., 2010b), few have specifically addressed the role of household food production for subsistence farmers in Latin America. Furthermore, few studies include the farmers' perspective. As opposed to only promoting best management practices from developed countries on smallholder farmers, it is important to identify which challenges, solutions, and opportunities farmers actually perceive, as only the perception of an impact will lead farmers to make changes in production

(Bacon et al., 2005). Thus, the first step to improving smallholder production must be to evaluate what challenges farmers perceive and what actions they are interested in taking.

We focused our study in El Salvador because food insecurity appears to be increasing despite high levels of adoption of conventional agriculture technologies. Like most countries, El Salvador has had significant grain production increases in recent decades, at least in commercial grains at the national level, with more than 160% growth since 1960 (FAOSTAT 2017). Interestingly, the increasing yields are not accompanied by an increase in income for the producers because the value of crop production per hectare has decreased by 3.9% from 1996 to 2011. Furthermore, despite significant increases in fertilizer use, yields and food supply, there has been an overall increase in the prevalence of undernourishment in El Salvador, a key indicator for food security, from 2000 onward (FAOSTAT 2016).

Beginning in the mid-1980s, farmers throughout El Salvador began to manage their personal *milpa* (corn and bean) plots using synthetic fertilizers, herbicides and pesticides to produce higher yields with lower labor investments. These technologies have been promoted by the national agricultural extension service (CENTA) and non-governmental organizations, which have contributed to the widespread use of green revolution technologies in the Salvadoran countryside. Within the country, research and extension is primarily directed towards raising productivity and encouraging international market integration (Deleon et al. 2009). Currently, 91% percent of the corn seed planted in El Salvador is *certificado* (certified); *certificado* is a legal designation under law in El Salvador and most other Central American countries and refers to commercialized hybrid or genetically engineered seeds (Ferrufino 2009; Olson et al., 2012). El Salvador has the highest percent usage of *certificado* seed in Central America. Furthermore, the ever-increasing fertilizer and pesticide consumption in El Salvador demonstrates the adoption of green revolution technology and increased industrialization of the country's agricultural system. Usage of total nitrogen and phosphorus fertilizers more than doubled from 2002 to 2012 (FAOSTAT 2016) and pesticide application follows a similar trend, more than quadrupling from 2006 to 2014 (FAOSTAT 2016). Despite the significant changes in agriculture production strategies and an overall national production increase, a recent study showed smallholder farmers to have low yields, less than half the national average and high costs that result in financial loses for many farmers (Morris et al. 2013).

A common response by governments and aid organizations to the lower yields of smallholder farmers has been to increase access to fertilizers and improved seeds, often providing them free of charge to poor farmers.  The past two leftist-leaning governments of El Salvador have taken this approach and created the Presidential Productivity Support Program, which gives free seeds and fertilizers to all farmers in the country (Ferrufino 2009). Only the study of Morris et al (2013) has examined the effectiveness of increased use of fertilizers and improved seed on yields or food security status for smallholder farmers in El Salvador and other Central American countries, where most farmers are farming marginal land with steep slopes. This study showed that even when farmers apply fertilizers, their yields remained low, as their costs increased, implying there might be another limiting factor to production besides fertilizer access, but it is unclear what this limiting factor may be.

In contrast to conventional agricultural technologies, agroecological approaches, such as cover crops and green manures, promote applying ecological principles to improve the management of agroecosystems (Altieri, 1999; Gliessman, 2014), emphasizing a reduction of synthetic external inputs (i.e. fertilizers and pesticides), especially for smallholder farmers. However, as this approach has not been widely tested or adopted in El Salvador including the regions where we conducted this study, it remains to be seen if they represent a viable options for these smallholder families. In other areas of Central America, agroecological production methods have been shown to be more resilient to climate change and climatic disturbances and disaster. A survey conducted in Nicaragua after Hurricane Mitch found that sustainable plots, which implemented soil and water conservation practices, had 20-40% more topsoil, greater soil moisture, and less erosion and had lowered economic losses compared to the conventional neighbor plots (Holt-Gimenez 2002). Sustainable land management strategies advocated in agroecological farm management have many benefits to farmers, including improving soil fertility and structure, conserving soil and water, improving soil biodiversity, and improving nutrient cycling. All of these benefits can lead to increased productivity (Branca et al. 2013), especially for the marginalized subsistence farmers in El Salvador.

In this light, the objectives of this study were to 1) determine household food security levels of smallholder farmers in two regions of El Salvador; 2) assess the relationship between production practices and yield for smallholder farmers in in two regions of El

Salvador; and 3) identify what these farmers perceive to be the greatest agricultural production and household food security challenges they are currently facing.

## 2. Methods

*Study Site*

Research was conducted between May and August 2014 within two farming communities in two distinct regions of El Salvador, one in the mountains of the northeast and one on the coast. These sites were chosen to provide a more diverse sampling that would represent smallholder farmers across the different agroecological zones of El Salvador. The climate in El Salvador can be described as semi-dry tropical, with a rainy season between May and October and a dry season from October through April. Average annual precipitation is approximately 2000 mm (MARN 2015). The natural vegetation of the region is classified as a humid, subtropical forest. The first farming community was in the municipality of Cacaopera in the Department of Morazan in the northeastern part of El Salvador. These farms (N=30) were located at elevations between 500 and 800 masl. The second farming community (N=13) was in the municipality of San Jose Villanueva in the Department of La Libertad in the central coastal part of El Salvador and were located at elevations of 100 to 200 masl. Both study locations were between 5 and 10 km from a town with dirt roads, intermittent access to electricity and no running water. Electricity was available to households that are closest to the main road, but the majority of households did not have electricity. Both farming communities had schools up to 6th grade levels.

These communities were chosen because of their history of more than 20 years working with a partner NGO, Fundación Hermano Mercedes Ruíz (FUNDAHMER). Choosing these communities, which have a long history of working with FUNDAHMER and built mutual trust over the years, ensured more candid responses during interviews and focus groups. While it can be difficult to obtain accurate data on personal information such as income, production practices, immigration, and concerns about food security, we believe that we received more honest responses as a result of the established relationship with FUNDAHMER. All initial communications were made with the communities and research participants through FUNDAHMER.

All households (N=43) in the study maintained subsistence plots of corn and beans (locally referred to as *milpas*), which were staples in their diet, and some plots contained a small amount of other vegetables for consumption or occasional sale. Some families sold excess corn and bean yields, while others only grew it for their own consumption. These corn and bean plots were commonly located on steep slopes with corn and beans intercropped and cultivated using only hand tools. Average farm size in El Salvador is 0.7 ha with an average of 6 people per household (Arias, 2014).

*Interviews and focus groups*

From June to August 2014, semi-structured interviews were conducted in Spanish with both male and female heads of household within the 43 families, generally lasting from one to two hours. All of the interviews were recorded and the open-ended questions were transcribed. All participants were chosen by researchers, making announcements at local meetings and asking for volunteers. The households that were willing to be interviewed and available during the timeframe of the research were chosen. Semi-structured interviews were conducted in the home of each family with the assistance of one person from the community, who was hired to help navigate and assist with either asking survey questions or recording responses. The initial survey and the follow-up focus group interview guide were developed based on previous livelihood surveys used in El Salvador from Mendez (2004). The 5-page survey instrument contained detailed questions on household demographics, migration, household infrastructure, farm management, production data, and food security. Questions also focused on participants' perceptions of challenges to production and feeding their family, as well as gauging participants' interest in learning and trying new agricultural production techniques. All data that was not deemed reliable by the interviewer were excluded from the analyses.

Household food security was measured during the interviews using the Latin American and Caribbean Food Insecurity Experience Scale [Escala Latinoamericana Y Caribeña de Seguridad Alimentaria (FAO 2012b) - ELCSA] and further validated by self-identification of food security. The ELCSA is an experience-based metric of severity of food insecurity that relies on people's direct responses. These responses were collected through ELCSA survey, which consisted of nine short questions (Appendix A) that refer to the experiences of the individual respondent or of the respondent's household as a whole. A household was defined as household heads, children living in the home, and anyone living in the home economically dependent on the heads of household. Seven additional questions asked if children were present in the household. All questions were asked in reference to the 3-months preceding the survey. The questions focused on self-reported food-related behaviors and experiences associated with increasing difficulties in accessing food due to resource constraints. Each question that was answered positively was assigned a score of one. A cumulative score for all responses was used to assess the severity of household food insecurity, by classifying each household as food secure (0 points), light food insecurity (1-5 points), medium food insecurity (6-10 points), or severe food insecurity (11-15 points) (Perez-Escamilla, 2009). Using this scale of food insecurity allowed for results that were comparable across countries, and unique versions of the survey have already been adapted and utilized in various regions and countries (Perez-Escamilla, 2011). In order to further validate the ELCSA results, respondents were asked to self-identify as food secure or not. In addition, all farming households were asked to classify their household as: a) growing more than enough food for their family, b) just enough food for their family, or c) not enough food for their family.

Three focus groups were held (one in San Jose Villanueva and two in Cacaopera) one year after the interviews, between August and October 2015, in the same communities where surveys were conducted. The purpose of the focus groups was to discuss results from the interviews and identify main perceived challenges to improving production and household food security. Focus groups were conducted with an interview guide of open-ended questions using methodology from Stewart, Shamdasani, and Rook (2006). Farmers had the opportunity to ask questions about their yield data and use of agrochemicals and to discuss the reactions as a group. Doing the focus groups a year after the interviews also helped understand if perceived challenges to production and household food security might change from year to year.

*Analyses*

To assess relationships among variables examined, we used Spearman correlations for non-parametric data on scale and livelihood data, and Pearson's correlations for normally distributed, continuous variables. Paired sample t-tests were used to compare the relationship between means of agricultural factors (yield, fertilizers applied, herbicide) and socio-economic factors (age, income, education, family size etc.). One-way analysis of variance (ANOVA) was also utilized to compare means between different factors. Responses to open-ended questions were coded based on common responses and themes, and relationships. Statistical analyses were conducted using the IBM Statistical Package for Social Sciences (SPSS) for Windows (v.24).

## 3. Results

*Household data*

The average age of the survey respondents was 49.5 years for males and 45.2 for females, with a range between 18 and 86 years (Table 2.1). The mean household size was 5 members, with a range from 2 to 10 members (Table 2.1). Age of respondents (both men and women) was negatively correlated with level of education ($P < 0.0001$; Spearman's $\rho = -0.704$), meaning that older respondents had less education. The level of education was positively correlated (*P* =0.001; Spearman's $\rho$ =0.0538) between male and female heads of households, meaning that men and women were likely to be married to someone with a similar level of education. In addition, the education level of males was negatively correlated (*P* =0.021; Spearman's $\rho$ = -0.388) with size of the household, meaning males who had a higher level education were more likely to have a smaller household. Lastly, 19% (N=8) of households were headed by single mothers, but this did not appear to be correlated with any other socio-economic data.

*Food Security*

Using the ELCSA scale, 24% (N=10) of the households were experiencing light food insecurity, 43% (N=18) were experiencing moderate food insecurity and 31% (N=13) were experiencing severe food insecurity. Only 2% (N=1) of the households were considered to be food secure. The level of food insecurity was also verified by comparing it to a household's self-identified level of food production (paired t-test; *P* =0.002). Families that said they produced less than enough food for their household were more likely to be food insecure. Food security levels were correlated with a variety of other agricultural and socio-economic data. Level of food insecurity was negatively correlated with total area of land owned (*P* =0.037; Spearman's $\rho$ = -0.319; Table 2.2), as well as total area of land farmed (*P* =0.023; Spearman's $\rho$ = -0.345; Table 2.2), meaning that households that had more land or farmed larger amounts of land were more likely to be less food insecure. There was a weak negative correlation between food insecurity and area of beans farmed (*P* = 0.05; Spearman's $\rho$ = -

0.299), meaning that households that farmed more beans were more likely to be less food insecure

The survey included an open-ended question in which participants were asked to name the biggest challenge to feeding the members of the household. The responses were grouped into three main categories (Figure 2.2), including: 1) lack of money (43.5% of households); 2) climate-related challenges, such as drought and heavy rains (15.2% of households); and 3) other harvest related challenges (8.6% of households). Information triangulated from focus groups further verified this finding, with participants in all three focus groups agreeing that lack of money or lack of income-generating work and climate concerns, such as drought or flooding, were the top challenges to food security. Participants in the focus groups also consistently agreed that owning land and farming more land were important to feeding their families. One participant simply said, “The more land we plant the more food security our families have and the more we eat.”

*Agricultural data*

The average household yield for corn was 1909 kg $ha^{-1}$(± 1020 std. dev), with a median yield of 1560 kg $ha^{-1}$ (Table 2.1). The average household bean yield was 862 kg $ha^{-1}$ (± 708 std. dev) with a median of 780 kg $ha^{-1}$ (Table 2.1) Mean yield may be a more accurate representation of the yield data because of the large variability within yields. During the same 2013 growing season, the average national corn yield in El Salvador was 2,941 kg $ha^{-1}$. When farmers were asked how they perceived harvests to be changing in the past ten years (with the options being improving, declining or staying the same), the majority (40% of households; N=14) said that harvests were declining and only 5.7% (N=2) said that harvests were improving. In addition, 45.7% (N=16) of all households refused to choose one of the three options and said harvests depended on the climate and that the climate was unpredictable. When asked how the harvests have changed in the past ten years, one participant said, "Yes, they are changing a lot…It has stopped raining and doesn't want to rain anymore…without rain we can't plant or harvest."

All farmers planted *criollo* seed, certified seed, or a combination of the two (without separating the yields). The majority of farmers, 40.5% (N=17), planted only certified corn seed, provided by the government through the Presidential Productivity Support Program earlier in that season. Thirty-one percent (N=13) of the farmers planted only *criollo* corn seeds from the region; 23.8% (N=10) of farmers planted a combination of *criollo* and certified corn seed without separating out the yields from the two seed varieties. More farmers reported having a preference for *criollo* beans, with 61.5% (N=24) of farmers planting only *criollo* bean seed. One participant said, "I always save my own bean seed even if we have to go without eating beans because the type of bean I have is good." Similarly, other farmers often said they liked the flavor of the local *criollo* beans instead of the certified bean seed they received in the subsidy packet. Twenty-one percent (N=8) of farmers planted only certified beans and 12.8% (N=5) of farmers planted a combination of *criollo* and certified beans. The source of seeds (*criollo* vs. certified) did not appear to impact the overall yield (Figure 2.3) for either corn or beans.

For the farmers in this study, access to fertilizers and herbicides did not appear to be a limiting factor, likely due to the existence of the Presidential Productivity Support Program.

Overall, 92% of farmers utilized synthetic fertilizers. The few farmers that were not doing so had chosen to only use organic fertility sources (such as compost, manure and legume based fertility). Synthetic fertilizers used included a 16N-20P-0K formula, given by the government as part of the subsidy program, and a 20N-20P-0K ammonium sulfate formula. The average amount of fertilizer applied was 93 kg N $ha^{-1}$ and 106 kg $P_2O_5$ $ha^{-1}$ (Table 2.1). The range of fertilizers applied for both N and $P_2O_5$ was quite large and went from 0 to 205 kg $ha^{-1}$. Herbicide use was not as widespread as fertilizer use, but was still prevalent with 88% (N=37) of farmers using Paraquat (a broad spectrum herbicide) as the main herbicide of choice. In addition, farmers applied very high levels of Paraquat, with the average application rate being 5L $ha^{-1}$, approximately double the recommended application rate of 1.5 to 3 L $ha^{-1}$. However, insecticide use was much less commonly used, with only 20% of farmers applying some form of insecticide, mainly Tamaron ® (a foliar insecticide for chewing/sucking pests with O,S-dimethyl phosphoramidothioate 600 g $L^{-1}$ active ingredient) or Volaton ® (a broad spectrum organophosphate insecticide with phoxim 2.5% active ingredient). Furthermore, we gathered no information on whether the farmers followed application rates recommended by manufacturers or extension-agents. Instead, during interviews, farmers often said when they noticed insect damage, they bought as much product as they could afford and then applied all of it at once.

Generally, there were no significant correlations between corn and bean yields with agricultural inputs. For example, corn grain yields were not correlated with either nitrogen or phosphorus fertilizer application rates (Figure 2.4; $P > 0.05$). There was also no relationship between herbicides use and yield ($P > 0.05$). In fact, total corn or bean yield does not appear to be correlated to any other agricultural or socio-economic indicator.

In summary, most farmers used high rates of fertilizers and herbicides, and there was no apparent relationship between application rates and yield. However, farmers perceived that lack of fertilizer and other agricultural inputs was a main limiter to crop productivity. When asked to name the main barrier to improving production (Figure 2.5), the majority of farmers (41%; N=17) said it was related to not having enough inputs (mainly fertilizers) or enough money to buy fertilizers and other agrochemicals. Climate change was the second most popular response to this open-ended question, with 29% (N =12) of farmers saying that the unpredictable climate was the main challenge to improving yields. Similarly, in focus groups, participants in all three of the focus groups agreed that a lack of fertilizers, and money for agricultural inputs, as well as climate change were the top challenges to improving their corn and bean production. Although the order of the top three challenges varied, all groups consistently had the same top three challenges.

Part of the focus group included presenting the survey results, where participants were given the opportunity to ask questions and discuss the results. One of the main discussion topics was the lack of a relationship between fertilizer and yield. Participants disagreed with the presented results of our surveys, saying that we made a "mistake" or "it had been a bad year." Other discussions centered on the need to take care of the soil, especially decreasing erosion. The older participants pointed out that younger farmers were not as interested in soil conservation.

In the communities in this study, few soil conservation methods were employed. Only 34% of all farmers said they were using one or more of the following practices: living erosion barriers, dead erosion barriers, ditches, or mulch. Therefore, 64% of farmers were not using soil and water conservation practices. In addition, only farmers over the age of 45 reported that they were using soil or water conservation practices. Despite low utilization of soil conservation practices, farmers expressed an interest in improving their soils and land. When asked what techniques they would like to learn or test on their agricultural land (Figure 2.5), the top answer was "learning about organic production" (34%; N=11), and more specifically about organic fertilizers to improve the soil. The second most common response was learning about soil erosion control practices.

## 4. Discussion

Approximately one-third of the households in our study had severe food insecurity, meaning that on a regular basis family members were skipping meals because food was unavailable. Our results concur with previous studies showing that food security is a major challenge faced by the majority of smallholder farmers in Central America (Morris et al., 2013a; Morris et al., 2013b). However, ours is one of the few studies that specifically investigated food security challenges faced by subsistence farmers. Furthermore, our results show that food insecurity in some parts of rural El Salvador may be much higher than previously thought. According to one government survey, only 12% of Salvadorans are undernourished (WFP 2015). Whereas our study showed 31% of surveyed households to have severe levels of food insecurity, implying that the prevalence of food insecurity may be higher in smallholder farming households compared to the rest of the population. Moreover, our results are similar to previous studies in Central America evaluating household food security using ELCSA, the same tool currently being used by the Food and Agricultural Organization within Latin America and the Caribbean. A study in a rural region of Guatemala in 2010, found that 18% of the households to have light food insecurity, 17% moderate, and 47% severe (Acker 2011) compared with our finding of 24%, 43%, and 31% of households having light, moderate, and severe food insecurity (Fig. 2.1). Another study conducted between 2010 and 2012 in Honduras found 89.3% of the households were food insecure, with 52.9% experiencing severe food insecurity (Chicoine et al. 2014). These previous studies incorporated all types of rural households instead of focusing uniquely on smallholder subsistence farmers as our study did. Our study was also unique in that it evaluated some of the potential factors contributing to food insecurity, as well as the farmers' own opinions in explaining their lack of food security.

Research participants perceived a lack of money and work as the main constraints to food security. Men often said there were no jobs to make money; women often said there is no money to buy additional (non-farm) food, such as rice, cooking oil and coffee. When asked what made it hard to feed his family, one male farmer said, "We don't lack land, but money is what we lack to be able to buy more inputs and grow more. And water, we don't have water." Another female farmer responded, "There is no money to buy extra food." Amount of land did positively impact a household's food security status; both a higher total area land owned and land farmed were significantly correlated with lower food insecurity. Our results concur with previous studies, showing that across the tropics, smallholder farmers typically depend on agriculture as both the primary source of food, as well as a main livelihood activity; thus any reductions in agricultural production can have significant impacts on food security, nutrition and overall wellbeing (Hertel and Rosch 2010; McDowell and Hess 2012; Rojas et al. 2016). To further elucidate the food security challenges faced by these households, we also analyzed agricultural production practices in the study communities.

Similar to a previous study (Morris et al. 2013), we found that farmers were applying greater than the recommended amounts of synthetic fertilizers yet corn yields remained very low. Fertilizer use did not correlate with increased corn yield. Still, farmers in this study reported consistently using > 50 kg $ha^{-1}$ of phosphorus and nitrogen fertilizers. Given an average nitrogen removal of 0.45 kg per 25 kg of corn grain (Logsdon et al., 2008) and a median yield of 1560 kg $ha^{-1}$ (from our study) the corn crop is only removing 25 kg $ha^{-1}$ of nitrogen. In general, a crop can only use approximately 50% of the nitrogen applied, thus it is appropriate to assume that a 50 kg $ha^{-1}$ of N is a sufficient application rate for given yields, which almost all farmers were achieving. With an average application rate of 93 kg of N $ha^{-1}$, the farmers in our study were applying approximately twice the required nitrogen, with some applying up to four times the required amount (Figure 2.4). Our results further confirm Gliessman's (2014) argument for the significance of  increasing the efficiency, rather than total inputs, of fertilizers for smallholder farmers. Gliessman proposes that a first step in working with smallholder farmers is to work towards more efficient use of inputs so that fewer inputs are needed and any negative impacts of their use will be reduced as well.

In the tropics, phosphorus availability to plants is often more limiting than nitrogen because of the high phosphorus fixing capacity of tropical oxisol and ultisol soils. In our study an average application of 106 kg $P_2O_5$ ha $^{-1}$ was reported, suggesting that farmers are applying sufficient phosphorus as well. However, it is possible that more phosphorus is being fixed than is available to the plants; thus, future studies should assess phosphorus fixation and availability in these soils. It may be that farmers are over applying nitrogen, but lack phosphorus. In addition, almost all farmers were applying fertilizers containing only nitrogen and phosphorus, i.e., the 16N-20P-0K fertilizer distributed by the government (Ministerio de Agricultura y Ganaderia 2011). In addition, micronutrient deficiency has often been found to be a limiting factor in improving yields (Havlin et al., 2014). Because of the possibility that micronutrients are limiting crop growth, future studies should include a holistic evaluation of crop production, yield, and sustainable livelihoods that incorporates soil testing. Results from our study suggest that increasing corn yields, and thus household food security, is not going to be achieved solely by adding more synthetic nitrogen fertilizer to the system.

Second, farmers in this study were using high levels of herbicides. For example, the recommended application rate of Paraquat is 1.5 to 3 L ha$^{-1}$, but the average rate applied by farmers was 5 L ha$^{-1}$, with some applying up to16 L ha$^{-1}$. In our study, 83% of all farmers applied herbicides, with all using paraquat as the herbicide of choice to both clear the fields for planting and weed control during the growing season. Furthermore, no relationship between yield and herbicide use was found in farms surveyed. Despite using large amounts of agricultural inputs, specifically fertilizers and herbicides, surveys and focus groups both demonstrated that farmers perceived lack of money for agricultural inputs as the biggest challenge to improve production. When asked what her biggest challenge to improving production was, one female farmer said, “The amendments are so expensive, fertilizer is even more expensive now and to spray the herbicide is also expensive.” Many farmers said their biggest costs in production were the inputs, specifically fertilizers and herbicides, with fertilizers being the most expensive. This study could not verify the economic impact of agricultural inputs because it lacked a detailed economic analysis. Future studies may incorporate in depth economic analysis, similar to that done by (Morris et al., 2013b).

Despite the likely over-application of fertilizers and herbicides and no apparent yield benefit from fertilizer or herbicide use (in this study), most farmers believed that agricultural inputs, mostly fertilizer, were the biggest factors limiting their production. The farmer dependence on fertilizer was not surprising given that the government promotes fertilizer so heavily through the Presidential Productivity Support Program. Moreover, the government’s agricultural extension agency that supports farmer educational programs has been increasingly reduced since the mid 90’s. Personnel cuts of up to 50% were implemented in most extension agencies throughout the country in the mid-nineties (PNUD 2001). The majority of the entire Ministry of Agriculture budget is spent on the fertilizer and certified seed subsidy program to improve yields for smallholder farmers. However, it appears that more funding could alternatively be spent on appropriate agricultural education, including proper use of fertilizers, herbicides, and soil fertility management.

This study also demonstrates that climate change, particularly changing rainfall patterns, is a primary concern of smallholder farmers, both as a threat to their families' food security as well as agricultural production. Central American smallholder communities have been identified as among the world's most vulnerable to climate change (Sanchez 2000; Davis & Mendez 2011). One farmer said, "The rain, that is the biggest [challenge]. From there, work and money, but we control that. We cannot control the rain…the weather has affected our harvests a lot." The concerns of these farmers about climate change were not surprising. Climate change adds an additional level of complexity to rural communities, as changing temperatures, changes in precipitation and extreme events will have unpredictable effects on production. In the last fifteen years, there have been more weather related disasters than in the last fifty years. In the summer of 2001, a severe drought destroyed 80% of the country's crops, causing famine across the country (GFDRR, ND) and in 2010, losses to agriculture from flooding exceeded USD100 million, while those resulting from drought were USD38 million (GFDRR, ND). In addition, the dependence of these communities on agrochemicals and single varieties of hybrid seeds increases their vulnerability to climate change (Davis and Mendez, 2011). For example, if poor, smallholder farmers increasingly depend on imported capital-intensive inputs, they are also dependent on market prices and volatility. Furthermore, the widespread introduction of a single variety of hybrid seed can pose environmental risks and reduces the genetic diversity of food crops, increasing risk and food insecurity for smallholder farmers. Future agricultural development programs in El

Salvador need to be inclusive of climate change adaptation and adopt soil and water conservation strategies suitable for a variety of climates to increase the resilience of these small farms (Branca et al. 2013).

These results imply that government programs and development projects, which largely promote fertilizer and improved seeds to increase household food security for smallholder farmers, have failed to achieve desired results. This situation may be attributed to lack of farmer education and misguidance. This study does not suggest that synthetic fertilizers or improved seeds are not appropriate solutions to the yield gap in smallholder farming systems, but that selective use, accompanied by soil testing to ensure accurate recommendation rates, instead of solely promoting improved seeds and chemical fertilizers may be more appropriate. Our results demonstrate that in some parts of El Salvador, farmers are not receiving any yield improvements from increased rates of fertilizer and improved seeds. Therefore, it is possible that more investments could be made in alternative forms of aid for smallholder farmers to increase food security. For example, selective use of improved seeds and more efficient fertilizers use should also be accompanied by other educational strategies, such as soil and water conservation, to improve both economic and agricultural sustainability for the household and farm in the long term (Morris et al., 2013). It is well established, that soil and water conservation practices can improve yield, soil moisture and increase resilience to climate change (Bunch 2000; Pretty et al. 2003; Uphoff 2002).

Helping farmers to limit their use of agrochemicals through agroecological practices can reduce reliance on external inputs, reduce costs, minimize vulnerability, and increase food security for farm households (Altieri, 2009; Altieri and Manuel Toledo, 2011; Altieri et al., 2012; Holt-Gimenez and Altieri, 2013). Governments and nongovernmental organizations that address food security from this more agroecological perspective can increase the long-term productivity of agricultural land through the building of human and natural capital, which supports both farmers, conserves the environment, helps to mitigate climate change, and builds the local food economy.

### *Conclusions*

This study involving a representative sample of subsistence farmers in El Salvador showed that the majority suffer relatively high food insecurity levels, and have low corn and bean yields, despite high application rates of chemical fertilizers. Although farmers perceived a lack of synthetic fertilizers as the biggest challenge for better yields, access to chemical fertilizers and improved seeds does not appear to be a limiting factor in improving the agricultural production. Findings of this study support the notion agricultural development programs should incorporate soil testing to optimize fertilizer inputs and include more agricultural education on agroecological management for farmers in order to achieve desired results. In addition, climate change is a primary concern of small farmers, both as a threat to their families' food security and agricultural production.

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## REFERENCES

Altieri, M. 1999. Applying agroecology to enhance the productivity of peasant farming systems in latin america. Environment, Development and Sustainability 1:197-217.

Altieri, M.A. y C.I. Nicholls. 2003 Native seeds: humankind patrimony essential for the cultural integrity od peasant agriculture. Policy Matters 11: 28-33

Altieri, M.A. 2009. Agroecology, small farms, and food sovereignty. Mon. Rev. -Indep. Social. Mag. 61:102-113.

Altieri, Miguel A., y Victor Manuel Toledo. 2011. The Agroecological Revolution in Latin America: Rescuing Nature, Ensuring Food Sovereignty and Empowering Peasants. Journal of Peasant Studies 38.3: 587-612.

Anthony, V. M., & Ferroni, M. 2012. Agricultural biotechnology and smallholder farmers in developing countries. *Current Opinion in Biotechnology, 23*(2), 278-285.

Arias Penate, J.S. 2014. Agricultura familiar e industrializacion sustentable: un Nuevo modelo de desarrollo agropecuario para El Salvador. 1ª ed. San Salvador, El Salv.: ADESES, 480 p.

Bacon, Chris; Mendez, Ernesto; & Brown, Martha. 2005. Participatory action research and support for community development and conservation: examples from shade coffee landscapes in Nicaragua and El Salvador. Center for Agroecology & Sustainable Food Systems. UC Santa Cruz: Center for Agroecology and Sustainable Food Systems. Retrieved from: http://escholarship.org/uc/item/1qv2r5d8

Bacon, C.M., W.A. Sundstrom, M.E.F. Gomez, V.E. Mendez, R. Santos, B. Goldoftas and I. Dougherty. 2014. Explaining the 'hungry farmer paradox': Smallholders and fair trade cooperatives navigate seasonality and change in Nicaragua's corn and coffee markets. Glob. Environ. Change-Human Policy Dimens. 25:133-149.

Branca, Giacomo, et al. 2013. "Food Security, Climate Change, and Sustainable Land Management. A Review." Agronomy for Sustainable Development 33.4: 635-50.

Davis, A. and V.E. Méndez. 2011. Prioritizing food security and livelihoods in climate change mitigation mechanisms: experiences and opportunities for smallholder coffee agroforestry, forest communities and REDD+. Policy Brief. Salvadoran Research Program on Development and Environment (PRISMA): San Salvador, El Salvador.

Ejeta, G. 2009. Revitalizing agricultural research for global food security. Food Security, 1(4), 391-401.

FAO. 2012. Committee on World Food Security. Thirty-ninth Session. FAO. Rome. Disponible de http://www.fao.org/docrep/meeting/026/MD776E.pdf

FAO. 2012b. *Escala Latinoamericana y Caribena de Seguridad Alimentaria (ELCSA): Manual de Uso y Aplicaciones.* Mayo de 2012. Disponible en: http://www.fao.org/3/a-i3065s.pdf

FAOSTAT Food and Agriculture Organization of the United Nations Statistical Yearbook. El Salvador. http://www.fao.org/faostat/en/#data/RF; accessed January 17, 2017.

Ferrufino, A. 2009. Mapeo del marcado de semillas de maiz blanco y frijol en Centroamerica Institute for Cooperation on Agriculture, Managua, Nicaragua.

GFDRR. ND. Global Facility for Disaster Reduction and Recovery. "Disaster Risk Management in Central America: El Salvador." Available at: http://www.gfdrr.org/sites/gfdrr.org/files/El_Salvador_DRM.pdf

Gliessman, S. R. 2007. Agroecology: The Ecology of Sustainable Food Systems. Second edition. CRC Press, Taylor & Francis Group, New York

Gliessman, S. R. 2014. Agroecology: The Ecology of Sustainable Food Systems. Third edition. CRC Press, Taylor & Francis Group, New York

Holt-Giménez, E. 2002. Measuring farmers' agroecological resistance after Hurricane Mitch in Nicaragua : a case study in participatory , sustainable land management impact monitoring. Agriculture, Ecosystems and Environment, 93, 87–105.

Holt-Gimenez, E. and M.A. Altieri. 2012. Agroecology, Food Sovereignty and the New Green Revolution. Journal of Sustainable Agriculture.

IFAD. 2013. International Fund for Agricultural Development. *Highlights Annual Report 2013.* Disponible de: https://www.ifad.org/documents/10180/de8dcd01-2d95-4d7e-bd0f-1dd2ea3a94c6

Lal, R. 2009. Challenges and opportunities in soil organic matter research. European Journal of Soil Science, 60(2), 158-169.

Logsdon, S., Clay, D., Moore, D., and Tsegaye T., editors. 2008. Soil Science: Step-by-Step Field Analysis. Measuring Nutrient Budgets, Calculating Nutrient Removal. Soil

Science Society of America, 677 S. Segoe Road, Madison, WI 53711, USA. Disponible de: https://www.soils.org/files/certifications/certified/education/self-study/exam-pdfs/147.pdf

Mendez, V.E. 2004. Traditional shade, rural livelihoods, and conservation in small coffee farms and cooperatives of western El Salvador. Ph.D. Dissertation, University of California: Santa Cruz.

Ministerio de Agricultura y Ganaderia (MAG) El Salvador. 2011. Plan de Agricultura Familiar y Emprendedurismo Rural para la Seguridad Alimentaria y Nutricional 2011-2014.

Ministerio de Medio Ambiente Y Recursos Naturales (MARN) El Salvador. 2015. Boletin Climatologico Anual.

Morris, K. S., Mendez, V. E., Lovell, S. T., & Olson, M. 2013. Conventional food plot management in an organic coffee cooperative: Explaining the paradox. Agroecology and Sustainable Food Systems, 37(7), 762-787. doi:10.1080/21683565.2013.774303

Perez-Escamilla, Rafael, et al. 2009. "Household Food Insecurity is Associated with Childhood Malaria in Rural Haiti." Journal of Nutrition 139.11: 2132-8

Perez-Escamilla, R., P. Paras, M. Julia Acosta, S. Peyrou, M. Nord and A. Hromi-Fiedler. 2011. Are the latin american and caribbean food security scale (ELCSA) items comparable across countries? Faseb j. 25

Pinstrup-Andersen, P. and R. Pandya-Lorch. 1998. Food security and sustainable use of natural resources: a 2020 Vision. Ecological Economics 26:1-10.

Rosa, H., S. Kandel, and L. Dimas. 2004. Compensation for Environmental Services and Rural Communities: Lessons from the Americas. International Forestry Review 6.2: 187-94.

Sanchez, P. 2000. Linking climate change research with food security and poverty reduction in the tropics. Agriculture Ecosystems & Environment, 82(1-3), 371-383.

Stewart, D.W., P.N. Shamdasani and D.W. Rook. 2006. Focus groups: theory and practice. Sage: Thousand Oaks/London/New Dehli.

Tscharntke, Teja, et al. 2012. Global Food Security, Biodiversity Conservation and the Future of Agricultural Intensification. Biological Conservation 151.1: 53-9.

Table 2.1. Summary of farm management and household characteristics of surveyed farmers (N=43)

| | Min | Maximum | Mean | Standard deviation |
|---|---|---|---|---|
| Household size | 2 | 10 | 4.8 | ±11.8 |
| Age of female head of household (yrs) | 18 | 76 | 45.2 | ±16.5 |
| Age of male head of household (yrs) | 20 | 86 | 49.5 | ±19.5 |
| Total land owned (ha) | 0 | 10.5 | 1.7 | ±2.4 |
| Total land farmed (ha) | 0.1 | 2.1 | 0.6 | ±0.5 |
| Total land rented (ha) | 0 | 1.4 | 0.2 | ±0.3 |
| Corn area planted (ha) | 0.05 | 1.4 | 0.5 | ±0.3 |
| Bean area planted (ha) | 0 | 0.7 | 0.3 | ±0.2 |
| Total nitrogen applied (kg $ha^{-1}$) | 0 | 205.7 | 93.4 | ±57.9 |
| Total phosphorus applied ($P_2O_5$ kg $ha^{-1}$) | 0 | 205.7 | 106.1 | ±61.6 |
| Corn yield (kg $ha^{-1}$) | 259 | 4415 | 1909 | ±1020 |
| Bean yield (kg $ha^{-1}$) | 85 | 2077 | 780 | ±708 |
| Herbicide applied (total L Paraquat $ha^{-1}$) | 0 | 16.7 | 5.4 | ±4.1 |

Table 2.2. Summary of significant correlations to level of food insecurity using Spearman's correlation (ρ).

| | Total area land owned (ha) | Total area land farmed (ha) | Total area of beans planted (ha) |
|---|---|---|---|
| Food Insecurity | $\rho = -0.319$<br>$P = 0.037$ | $\rho = -0.345$<br>$P = 0.023$ | $\rho = -0.299$<br>$P = 0.05$ |

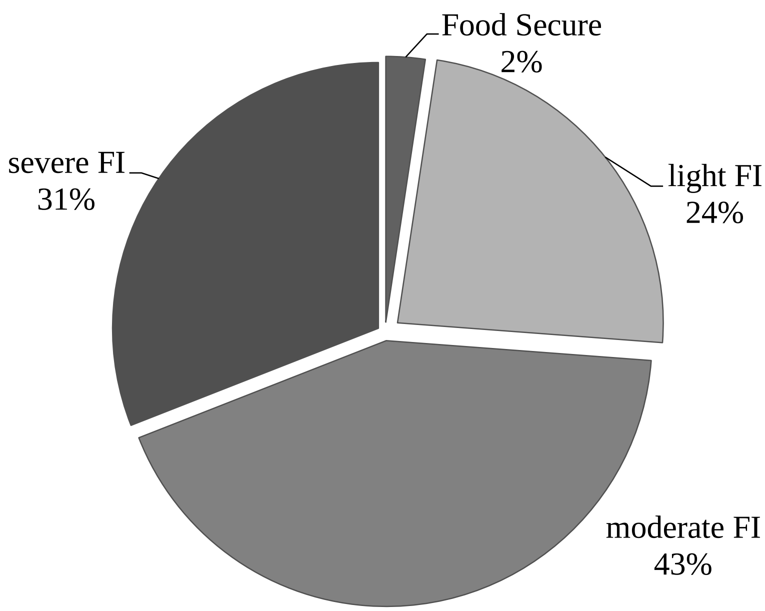


Figure 2.1. Results of the food insecurity (FI) surveys conducted in two regions of El Salvador with 43 subsistence farming households using the Latin American and Caribbean Food Insecurity Experience Scale [Escala Latinoamericana Y Caribeña de Seguridad Alimentaria (ELCSA)

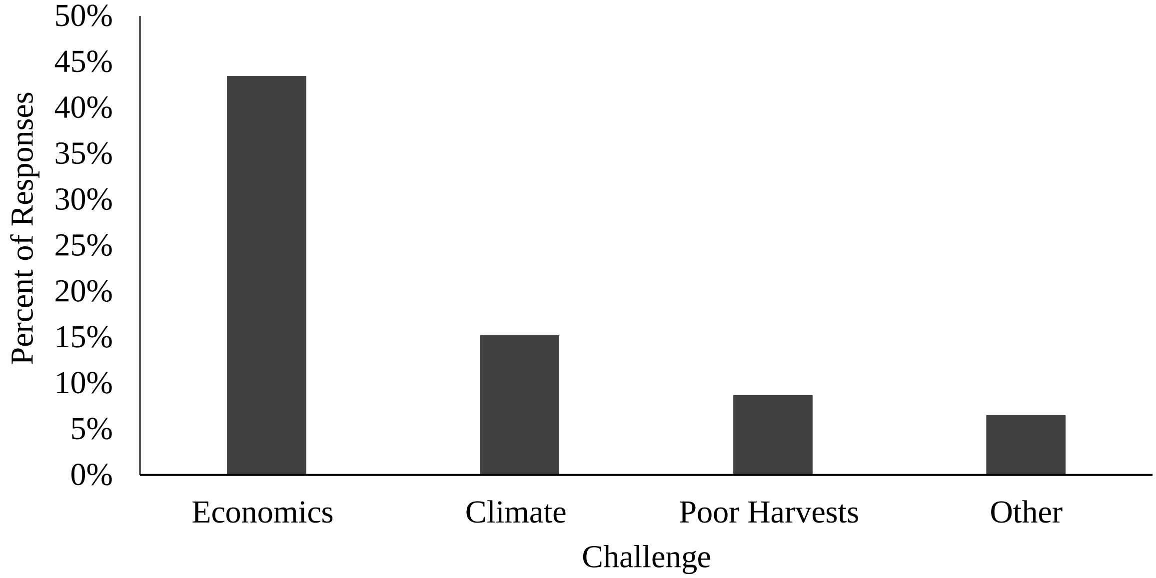


Figure 2.2. Summary of responses to perceived challenges to food security by interviewed households (N=43)

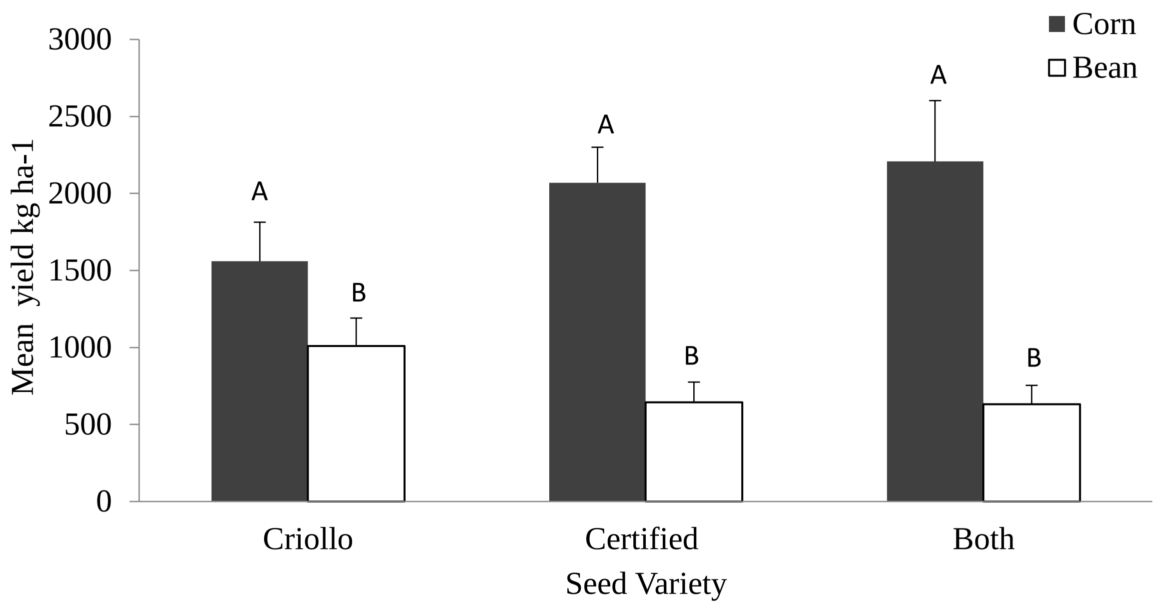


Figure 2.3. Mean yield of different corn and bean seed varieties. Error bars are standard error of the mean. Different letters are significantly different from one another. Mean corn and bean yields were not impacted by variety of seed used ($p > 0.05$)

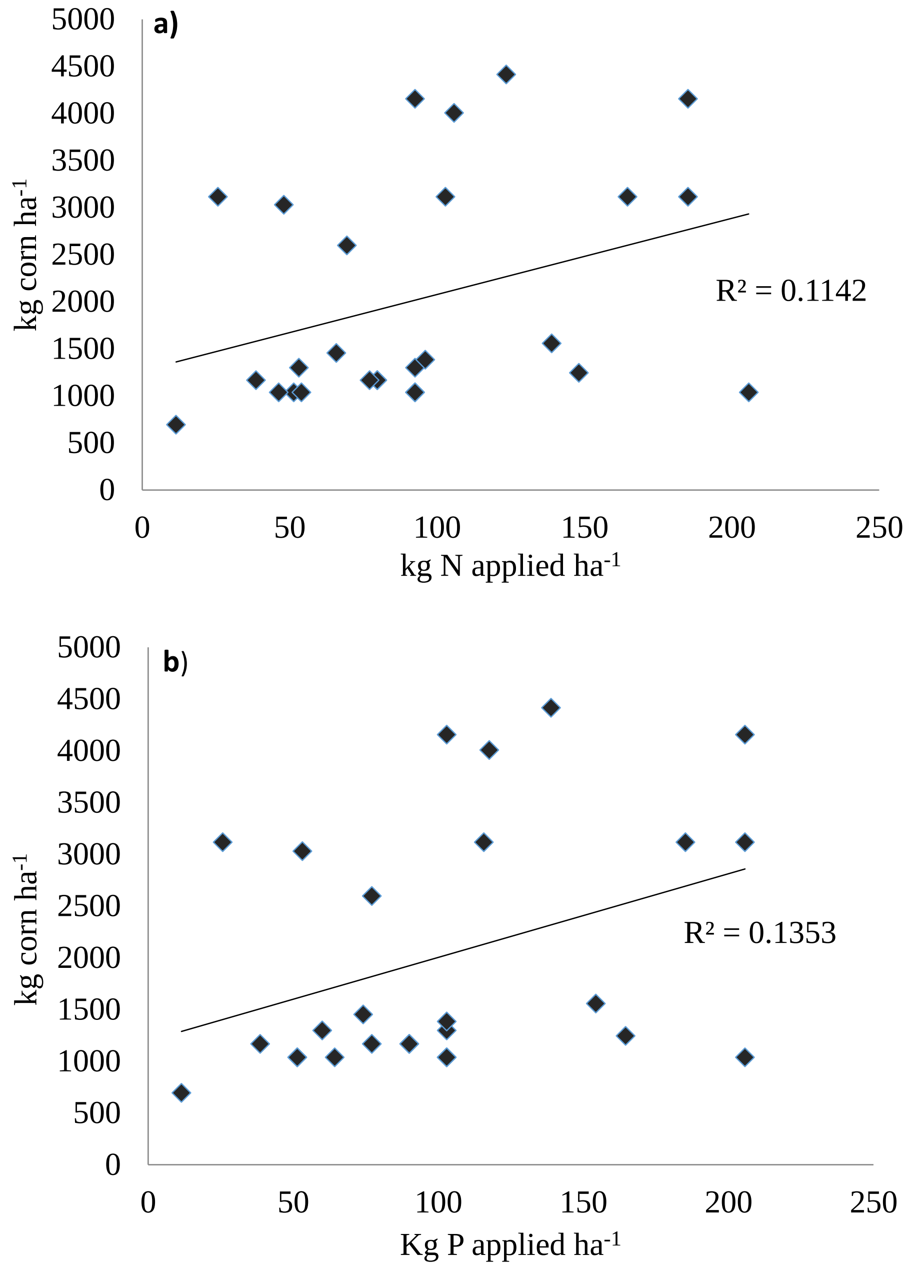


Figure 2.4. a) Corn yield compared to synthetic nitrogen inputs; b) Corn yield compared to synthetic P inputs. Application rates of N and P ($P_2O_5$) fertilizers were not correlated with total corn grain yield ($p > 0.05$).

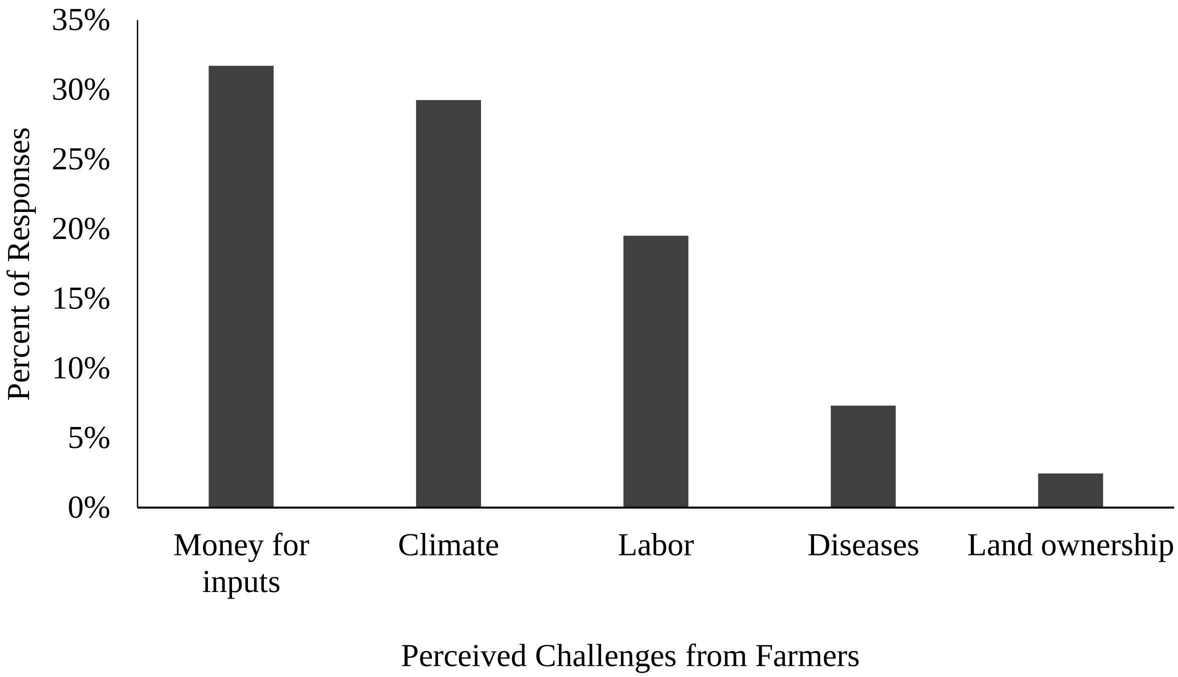


Figure 2.5. Summary of responses to perceived production challenges by farmers (N=43).

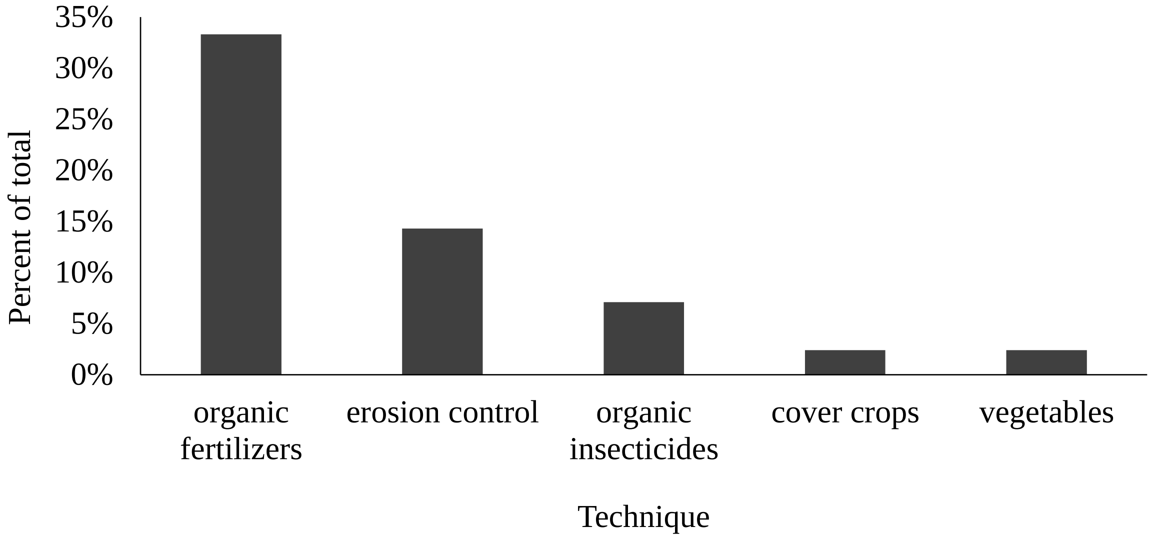


Figure 2.6. Summary of responses to farmer interest in learning new production techniques (N=43)

# III. Evaluating three different soil health assessments for use in tropical smallholder farming communities of El Salvador

**Abstract**

Metrics for cropland soil health comprise a number of soil biological, chemical, and physical parameters, and research has begun to emerge demonstrating that its impact on crop yield, yield stability, and food security can be significant. Throughout the tropics, agricultural productivity and food security for smallholder farmers is especially dependent on soil health. Unfortunately, there has been little research on soil health in tropical soils, especially in Latin America, and there is no readily agreed upon set of soil health indicators for the tropics. The goals of this study were to use a smallholder farming region in El Salvador as a location to 1) describe baseline soil health indicators on small farms in the northeastern region of El Salvador; 2) compare three different soil health assessments for applicability in the Latin American tropics and their implications for soil management recommendations. The three assessments utilized included the Cornell Comprehensive Soil Health Assessment (CASH), an NRCS guide for soil quality testing (NRCS), and a field soil health assessment tool developed by Centro Agronómico Tropical de Investigación y Enseñanza (CATIE). The chemical soil indicators were found to be the biggest constraints to production. The three soil health assessments demonstrated clearly different overall soil health scores, especially the CATIE and CASH methods in regards to both overall scores and individual indicators. All three methods have unique advantages and challenges. Future research should examine how to better integrate the three different assessments and adapt them to specific situations.

## 1. Introduction

Soil degradation affects approximately one-third of agricultural land globally (Blanco and Lal 2010). Soil degradation, or loss of soil health, is one of the main factors stagnating food production (Bindraban et al., 2012) and it impacts global food security through decreases in soil functions and, in turn, crop yields. In order to feed a growing population without destroying our natural resources, addressing declining soil health therefore must be made a global priority. Currently, however, the core role of soil ecosystems in sustaining yields and combating global food security is often overlooked (Rojas et al., 2016). Agricultural productivity and food security in Latin America depend heavily on soil health. Decreases in soil health indicators often lead to declining household production (Stocking, 2003), a problem faced by 60% of rural communities in the tropics and sub-tropics.

In their Hunger Task Force recommendations, (Sanchez and Swaminathan, 2005), conclude that restoring soil health, i.e., improving the state of the soil for crop productivity, should be the first step in increasing agricultural productivity on food-insecure farms. Such improvements in soil health via farm and soil management should be gauged by changes in soil properties. Therefore, the World Soils Agenda developed by the International Union of Soil Scientists lists the first two agenda items as 1) assessment of status and trends of soil degradation at the global scale and 2) definition of impact indicators and tools for monitoring and evaluating soil condition. Clearly, there is a need for more international standards for measuring and interpreting soil health that are accessible and appropriate for farmers, extension agents, and researchers.

Components of soil health are fundamental to not only food production stability, but also food nutrient quality and yield (Doran, 2002; FAO, 2008). Soil health is a concept encompassing various individual soil indicators for the functioning of the soil. Oftentimes, land managers and scientists combine the metrics into an overall measure of soil health. A commonly used definition of soil health is the “capacity of a living soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain and enhance water and air quality, and promote plant and animal health” (Doran, 2002). Agricultural soil health incorporates not only chemical soil fertility, but also physical and biological soil functions and processes that support plant growth. However, the quality of agricultural land and the ability of that land to continue high levels of production are threatened by the physical, chemical and biological degradation of the soil (Hurni et al., 2015). Examples of such threats include soil erosion, compaction, pollution, and decreased soil organic matter (Hurni et al., 2015; Panagos et al., 2014; Stocking, 2003; Stott and Moebius-Clune, 2017). Healthy soils thereby support not only crop productivity, but also environmental quality and plant and animal health (Doran 2002).Wide scale adoption of agricultural systems that support soil health has the potential to make global impacts on farm resilience, productivity economics, and the environment.

### *1.1. The need for soil health testing in Latin America*

There has been little research on soil health in tropical soils (Stocking, 2003), especially in Latin America, and no readily agreed upon set of soil health indicators for the tropics. Recently, there has been considerable research to define and standardize appropriate soil health indicators in the U.S. (Friedman et al., 2001; Moebius-Clune et al., 2016). In the tropics, African soils have been the subject of an effort to develop indicators for the region (Moebius-Clune et al., 2011), but Latin America has been almost ignored. Tropical soils differ from the temperate U.S. soils because their naturally highly weathered state often renders them highly degraded for agriculture, and nutrient depleted, especially total phosphorus (P).  Furthermore, analytical methods commonly used in the U.S. to assess soil health are often inaccessible in many Latin American countries due to lack of research facilities and economic resources and exchange of information. The needs of farmers, extension agents, and researchers in Latin America are unique and may require different soil tests and protocols than in the U.S. A clear need exists for soil health indicators, methodologies and standardizations that are applicable in the Latin American tropics to support monitoring of soil degradation, enable comparability across regions, and inform management decisions by farmers.

*1.2. A review of three current soil health assessment methodologies*

In the U.S., the Natural Resources Conservation Service (NRCS) is a leader in developing methodologies for soil health assessments and standardization of soil health indicators for various stakeholders, including agricultural producers. In 2001, the NRCS published a guide for soil quality assessment, which recommends chemical, physical and biological soil indicators and allows the farmer or researcher to choose the indicators best suited for the assessment (Friedman et al., 2001). The NRCS method combines in field measurements with laboratory analyses such as extractable phosphorus and total organic matter. Indicators are assigned a high, medium, or low score and then are combined for a total soil health score. The NRCS method has been widely used throughout the US, but has not been utilized in the Latin American tropics.

Building on the work of NRCS, Cornell developed the Comprehensive Assessment of Soil Health (CASH; Moebius-Clune et al., 2016), which was designed for soil health assessment to aid in management decisions. The Cornell CASH methodology differs from the NRCS method in a few ways. It integrates soil texture with specific biological, physical and chemical indicators that have been shown to change with management. Each indicator is interpreted based on a scoring function (0 to 100) and assessed to see if they constrain the soil processes they represent. The scoring functions have been adapted to soils mostly in the Northeastern U.S. (Moebius-Clune et al., 2016), but have been applied to tropical soils in

Kenya and Pakistan (Iqbal et al., 2014; Moebius-Clune et al., 2011). The total soil health score is a mean of the scores from each soil indicator measured. In addition, the CASH method includes a soil health report that enables farmers to identify constraints to the functioning of their agricultural soils. It also recommends management strategies to target those constraints and allows farmers to monitor changes in soil health over time.

The Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) in Costa Rica has also developed an in-field qualitative agroecological soil health assessment tool for Central America, (Padilla and Suchini, 2001). This assessment tool is aimed at agronomists working with smallholder farmers, as well as researchers, students, and field educators in the area. It was designed as an instrument for better understanding and documenting soil health in farmers' fields, with an agroecological focus. In order to increase accessibility for farmers and local agronomists, the CATIE assessment only incorporates physical and biological measurements that can be made in-field or by the farmer (Table 2.1), with no laboratory analyses included. In this tool, indicators are assigned a high, medium or low score that are then combined for a total soil health score. The primary weakness of this methodology is that it does not incorporate any chemical analyses to measure pH, phosphorus or micronutrients, which are commonly factors that limit productivity in tropical soils (Sanchez and Cochrane 1980). In addition, some of the indicators, such as percent soil cover, are subjective and may reflect user bias, making standardization across regions difficult. Moreover, there has been little, if any, published research documenting the use of the CATIE assessment in multiple countries.

### *1.3. El Salvador as a location to compare soil health assessments*

El Salvador is the most densely populated country in the Americas, as well as the most deforested country in the continental Americas. Because of this high population density and prevalent environmental degradation, minimizing erosion, reducing soil degradation, and improving soil health are national priorities (Ministerio de Agricultura y Ganareria (MAG), 2012). In addition, the majority of agricultural output in El Salvador is produced by smallholder farmers, whose livelihoods are often dependent on the productivity of their soils. The above-mentioned characteristics make El Salvador an ideal setting for evaluating and comparing various soil health indices for their applicability in the Latin American tropics.

The goals of this study were to use a smallholder farming region in El Salvador as a location to 1) Describe baseline soil health indicators on small farms; 2) Compare three different soil health assessments for applicability in the Latin American tropics and implications for soil management recommendations. We utilized the three soil health assessment methods described previously. A soil health score was calculated for each of the three soil health assessments and management implications and productivity constraints were evaluated for each assessment. The results of this research will aide in future work developing more comprehensive soil health assessments for the Latin American tropics that are accessible to diverse stakeholders, applicable for use in smallholder farming setting and can be easily standardized across regions.

## 2. Methods

### *2.1.Site description*

Research was conducted between September and November 2015 and all 18 farms in the study were located in the municipality of Cacaopera (13.7721° N, 88.0766° W) in the Department of Morazán in the northeastern part of El Salvador. The climate in El Salvador is a rainy season between May and October and a dry season with no rain from November through April. Average annual precipitation is approximately 1900mm. The natural vegetation of the region is classified as a humid, subtropical forest. The farms in Cacaopera were located at elevations between 500 and 800 meters above sea level (masl). All farms were between 5 and 10 km from a town with dirt roads, with intermittent access to electricity and no running water. Electricity is available to the households that are closest to the main road, but the majority of households did not have electricity. The farming communities have schools up to 6th grade.

This region was chosen because of the history of more than twenty years working with a partner non-governmental organization (NGO), Fundación Hermano Mercedes Ruíz (FUNDAHMER). Choosing this region, with the long history of working with FUNDAHMER and mutual trust built over the years, ensured more candid responses during interviews about production practices and ensured that farmers trusted researchers to take soil samples on their farms. All farms in the study maintain subsistence plots of corn and beans, referred to as *milpas*, which are staples in their diet, and some plots contain a small amount of other vegetables for consumption or occasional sale. Some families sell excess corn and bean yields, while others grow it for only their own consumption. These *milpa* plots were located on steep slopes with maize and beans intercropped or planted on adjoining plots. Average farm size in El Salvador is 0.7 hectares (ha) with an average of six people per household [Ministerio de Agricultura y Ganaderia (MAG), 2011], and the farms in our study ranged from 0.5 ha to 2 ha.

While collecting soil samples, brief interviews were conducted with the heads of households to ask about production practices. Surveys included detailed questions about fertilizer use, herbicide pesticide use, and other agricultural inputs, such as lime and manures. In addition, the total variety of crops planted and agroecological practices utilized on the farm were calculated from the surveys. The total number of agroecological practices was adapted from a survey by Caswell et al., (2016) and included the application of each practice in corn, beans and home vegetable garden. The agroecological practices included agroforestry (combination of trees planted with other crops), dead erosion barriers (usually rock), living fences, leaving organic matter on fields, erosion trenches, rotation of crops, and green manures. Number of crops was defined as the total number of different types of crops, including corn, beans, root crops, musaceas (bananas and plantains), vines, ornamentals, fruit trees, trees for firewood, trees for shade, and vegetables. The total number of vegetables crops was a different survey category. See Appendix B for detailed survey questions.

### *2.2.Soil health measurements in field*

All soil samples were collected between September and November of 2015. At each farm, three soil sampling locations were chosen to be representative of the farm as a whole. Each sampling location including sampling for each of the following indicators: primary macronutrients (extractable P, K), secondary macronutrients (Ca, Mg) and micronutrients (Zn, Cu, Mn, Fe), CEC, base saturation (%), surface hardness, texture, infiltration, aggregate stability, topsoil depth, organic matter content (%), worm counts, soil respiration, active carbon, and total numbers of organisms found (separated by orders). At each sampling location, a Garmin GPSMAP 64s handheld GPS was used to record location and elevation, and a Suunto PM-5 Clinometer (Vantaa, Finland) was used to measure slope at each sampling location. Each sampling consisted of taking ten 0 to 15 cm soil samples with a soil auger, compositing these samples, mixing thoroughly and sub-sampling a ~1 L volume of soil for analyses. Surface (0-15 cm) penetration resistance was assessed using a pocket penetrometer (ELE International). The mean penetration resistance of five sampling points was recorded. Earthworm populations were measured within a 25 cm x 25 cm square area to a depth of 25 cm. All of the soil in the area was removed and sieved to count and record the total number of earthworms present. Infiltration was measured using a single ring cylinder methodology adapted from the NRCS Soil Quality Test Kit Guide (NRCS, 1999) and Lowery et al. (1996). The sampling area was cleared of vegetation and a 30 cm diameter ring was driven into the ground to a depth of 7.5 cm. The time it took for 1L of water to infiltrate the surface inside the ring was recorded.

Due to the inability to conduct soil analyses at local laboratories in El Salvador and the cost of shipping soils internationally, a few of the recommended CASH indicators (including soil protein and available water capacity were not included in the analyses. The CASH indicators measured included soil texture, field penetrometer resistance, wet aggregate stability, organic matter content, respiration, active carbon, pH, and macro- (N, P, K. Mg) and micro-nutrient (Fe, Mn, Zn) content assessment. For each indicator, a score between 0 and 100 was assigned following the CASH scoring functions outlined. A lower score indicates a greater constraint on proper functioning of soil processes. After all indicators were scored, a soil health overall quality score was computed as the unweighted average of all individual indicator scores.

The NRCS Guideline (Friedman et al., 2001) recommends a wide variety of soil indicators that can be used to assess soil health. The following NRCS indicators were utilized to create a soil health score soil organic matter content, number of earthworms, infiltration time, pH, surface and sub-surface compaction, and extractable phosphorus and potassium. For each indicator a score of 1- poor, 2 - medium or 3- good was given. The scores were determined following the guidelines for each indicator outlined in (Friedman et al., 2001).

With a total of seven indicators, each farm could have a soil health score between seven and twenty-one.

The CATIE method recommends six total indicators: infiltration, topsoil depth, percent organic matter, percent soil cover, earthworm counts, and presence or absence of soil conservation practices. The scores were determined following the guidelines for each indicator outlined in the indicator table from the CATIE guide. With a total of six indicators, each farm could have a soil health score between six and eighteen.

### *2.3.Laboratory measurements*

All field soil samples were split in half, with half shipped to the Cornell Soil Health Testing Laboratory in Ithaca, NY and half taken to the Salvadoran National Center for Agricultural and Forestry Technology (Centro Nacional de Tecnologia Agropecuaria y Forestal – CENTA) located in San Salvador. The CENTA laboratories analyzed texture, pH in water, pH in KCl, extractable P and K, Ca, Mg, Na, CEC, BS, OM, Cu, Fe, Mn, and Zn. Soil OM content was determined by the Walkley Black method. Mehlich-1 extracts were analyzed for P, K, Zn, Mn, Fe, and Cu. The Cornell laboratories analyzed the soil samples for aggregate stability, active carbon, and soil respiration. Wet aggregate stability (AS) was measured using a rainfall simulation method adapted from Moebius et al. (2007). Active carbon (AC) was measured by the permanganate oxidation method described by Weil et al.

(2003). Soil respiration (SR) was measured by incubating air-dried soil and calculating the $CO_2$ released using the method outlined by Zibilske (1994).

### *2.4.Scoring functions*

Because of the lack of research and standardization of different soil health indicators in tropical soils, the same non-linear scoring functions were utilized that were developed for the Cornell Soil Health Test (Moebius-Clune et al., 2016). Scoring functions interpret the level to which represented soil functional processes from each indicator are constrained. The cumulative normal distribution function, CND with sample means (m) and sample standard deviation (s) from the CASH (Moebius-Clune et al. 2016) was used to calculate a score between 0 and 100 for each indicator, where erf is an error function.

$$CND(m, s) = 100 * \frac{1}{2} (1 + erf\ [(x-m)/ s \sqrt{2}])$$

The CND function with means and standard deviation from Moebius-Clune et al. (2016) was utilized for SH, AS, SR, and AC (see Table 3.4). The remaining soil properties were analyzed at CENTA and locally recommended critical values or ranges were defined for pH and contents for OM, P, K, Fe, Mg, Mn, and Zn. The micronutrient CASH score calculated for each farm is determined as the mean of the sub-scores for Mg, Fe, Mn, and Zn. The sub-scores can either be 0 for sub-optimal or 100 for optimal.

### *2.5.Statistical analyses*

For all soil health indicators measured, mean values of three sampling locations per farm were calculated and used for all statistical analyses. The farm was utilized as the experimental unit. Pearson's correlations were calculated between food security, production practices and soil health indicators in SPSS v. 24. Paired t-tests were used to evaluate the relationship with ordinal data. One-way ANOVA's were calculated using food insecurity level as the independent variable and production practices, and soil health indicators as the dependent variable to see if these indicators differed between food insecurity levels. All statistical analyses besides Pearson's correlations and paired t-tests were done in JMP (Version 12.2, SAS Institute; Cary, NC)

## 3. Results

### *3.1. NRCS soil health results*

The NRCS soil health assessment, which had a potential total score of 7 to 21 points, revealed an average of 12.8 (converted into a percentage of total possible points it equals 60%) points across farms, with a minimum score of 8 points and a high score of 16 points. With only seven total indicators, the NRCS assessment had infiltration and P levels as the lowest indicators (and thus the indicators most limiting production). Other farm and agricultural indicators that were significantly correlated with the total NRCS soil quality score included: number of total agroecological practices implemented on farm ($r$ = 0.518; P

=0.007), Zn (*r* =0.607; P = 0.01), total area of land planted (*r* = 0.675; P = 0.006), and total area of beans planted (*r* = 0.522; P = 0.038).

*3.2. Cornell CASH soil health results*

The CASH method revealed an overall soil health total score mean for all farms of 59.4 (±13.1 std. dev). The scores for each farm ranged from 42.6 to 81.6, with a range of 39.1 between the highest and lowest overall soil health scores for one farm. The mean scores for each soil health indicator across all farms were surface hardness: 79.5 (±20.9); aggregate stability: 80.7 (±23.5); active C 71.0 (±21.0) soil respiration 43.7 (±16.0), pH 35.8 (±39.6), P 27.6 (±30.6), K 100 (±0), % OM 91.7 (±14.1), and micronutrients: 44.5 (±24.5). Phosphorus and pH were deemed to be the indicators that were constraints or possible limitations to production on most farms (Table 3.2). Soil respiration and micronutrients were also possible constraints to production in many farms (Table 3.2). Other farm, soil and agricultural indicators that were significantly correlated with the total CASH soil health score included: CEC (Pearson's *r* = 0.636; *P* = 0.006), Mg (*r* = 0.627; *P* = 0.007), total area of land planted (*r* = 0.619; *P* = 0.014), total area of corn planted (*r* = 0.534; P = 0.033) and total variety of crops planted (R = 0.40; P = 0.016). In addition, presence of contour ditches in corn fields (locally referred to as *acequias*) was significantly related to a higher soil health score (ANOVA; P= 0.03).

*3.3. CATIE soil health results*

The CATIE soil health assessment, which had a potential total score between 6 and 18 points, resulted in an average farm score of 13.2 (converted into a percentage of the total points possible it equals 73%). The indicators with the lowest scores were the physical indicator (infiltration) and the biological indicator (earthworms). Other farm and agricultural indicators that were significantly correlated with the total CATIE soil health score included: total number of agroecological practices implemented on farm ($r$ = 0.645; P = 0.005), Zn ($r$ = 0.501; $P$ = 0.04), and total area of land owned ($r$ = 0.646; $P$ = 0.007).

The three soil health assessment methods differed in the calculated overall soil health scores, but some of the assessments were more related than others. The NRCS and CATIE methods had total soil health scores that were significantly positively correlated ($r$ = 0.699; $P$ = 0.002; Figure 3.1), as well as the NRCS and CASH ($r$ = 0.38; $P$ = 0.005; Figure 3.1). However , the CATIE and CASH test had no relationship between the two overall scores.

Other soil chemical indicators that were measured included CEC, % BS, Ca, Na, and Cu. The mean CEC was across all farms was 16.7 ($\pm$6.2 std. dev.). The mean % BS was 91.6% ($\pm$13.3). The means for the nutrients across all farms were: 11.3 ($\pm$5.5) meq $100g^{-1}$ Ca; 0.2 ($\pm$0.06) meq $100g^{-1}$ Na; and 1.1 ($\pm$0.8) mg $kg^{-1}$ Cu. Based on nutrient recommendations from the national laboratories of El Salvador, only two farms had low Ca and nine farms had low Cu.

## 4. Discussion

The first objective of this study was to determine baseline soil health indicators on small farms in the northeastern region of El Salvador. Chemical soil indicators, primarily pH, and P, were found to be the main constraints to production. This is to be expected of Andic Argiustolls with high levels of Al explaining the low P availability. Small farmers in the area rarely add liming agents, and in fact not a single farmer participating in the study had added lime to their soil. In an environment where pH limits production severely, liming can be a simple method to improve soil health and yields. The rarity of lime additions is likely a result of how little agricultural research and extension education is conducted for smallholder farmers in El Salvador. Since the late 1980's, research and extension has been primarily directed towards raising national productivity and encouraging international market integration (Deleon et al., 2009). In order to support smallholder farmers, the government began the Presidential Productivity Support Program in the early 2000's, which provides them with free seeds and fertilizers (Ferrufino, 2009). However, it does not offer lime additions or amendments other than N-P-K fertilizers. Thus the results of our study demonstrate that providing the means to mitigate soil acidity may help alleviate a major challenge to production and thus food security in El Salvador.

The micronutrients Mg, Fe, Mn, and Zn were assessed as part of the CASH assessment. All but one farm had very low Zn levels. A similar study examining soil health degradation in Kenya, found that Zn and Mg showed exponential decline over time under constant cultivation (Moebius-Clune et al., 2011). In contrast to Zn, the micronutrients Mn and Fe, were high on almost all farms in our study, another indication of degraded soils (Havlin et al., 2014). In addition to indicators recommended by the three soil health assessments, we also measured a variety of other chemical soil indicators that are considered important in tropical soils and are recommended measurements from the Salvadoran government agricultural organization, CENTA, including Ca, Na, CEC, % BS, and Cu. Of these, CEC was correlated with the overall CASH soil health scores on the studied farms' soils. Because several micronutrients were low (Zn and Cu) or too high (Fe and Mn) across farms and regardless of soil health, CEC may prove to be an important soil health indicator for future studies. This is because of not only its correlation with overall soil health but also its usefulness as an important piece of information about nutrient availability in the soils, which is especially important in lower nutrient soils.

In addition to chemical limitations, the low microbial activity that we observed (indicated by low earthworm counts and soil respiration) is another potentially limiting area for soils in this region. Soil microbes also play a central role in enhancing P and other micronutrients' availability to plants because they mediate the turnover of organic P sources like plant residues or manure inputs (Oberson et al., 2006). Improving microbial activity in these soils may prove valuable in increasing nutrient availability tropical soils with high P fixation.

Previous authors have stated that designing cropping systems for Central American hillside areas for productivity, reduced erosion and increase water holding capacity is the greatest agricultural challenge in the region (Altieri et al., 1998). To meet this challenge, soil health metrics are needed that guide farmers and researchers. The only soil health assessment of the three that incorporated erosion management and water holding capacity was the CATIE assessment. In contrast, neither the NRCS nor the CASH assessments calculate a score that is partly a function of any field management factors.

The second objective of this study was to compare three different soil health assessments for use in smallholder farming systems in the Latin American tropics. Although utilizing a single soil health score may ignore some facets of the component measurements, the benefit of using a single score is that it allows for rapid but more comprehensive comparisons of different practices' impact on soil functioning (Idowu et al., 2009). Examining these three soil health assessments together, the CASH and NRCS methods produce similar overall soil health scores, as well as the CATIE and NRCS methods. However, the overall CATIE and CASH scores are not, such that if a researcher or farmer were to test the same farm before and after implementation of some practice using the two of them, they would likely arrive at two different conclusions. For example, on farm 14 (Table 3.2), the CASH assessment created an overall score of 53.95, a "medium" soil health score according to Cornell's interpretation guide (Moebius-Clune et al., 2016). It also indicated that low pH and low P would be constraints to production. However, using the CATIE method, the overall score was 14 (78% of the total possible score) and indicates no limitations to soil health or production. The differences in results between the CATIE and CASH assessments are not surprising given the different indicators utilized in each assessment. The CATIE test only includes in-field measurements, and focuses on physical and biological soil indicators, with no chemical indicators in the overall assessment. The absence of chemical indicators included in the assessment is by design due to the lack of access to laboratory testing facilities and the high cost of analyses common throughout Latin America. On the other hand, the CASH assessment includes a large variety of chemical, physical and biological indicators, with the only in field measurement being surface compaction, measured with a penetrometer.

Each assessment has its own pros and cons (see Table 3.3 for a list) and future research should evaluate how to better integrate the assessments. However, the differences in results between the two types of soil health assessments are problematic for farmers, agronomists and researchers working to improve soil conditions. Farmers, local agronomists and researchers in Central America are likely to use the CATIE method because it was designed, adapted and distributed locally, but researchers in the US would likely to use the CASH or NRCS assessments. Using two different assessment methods may create discrepancies in future research and management recommendations for the region.

It is important to evaluate not only the overall soil health scores in each assessment but also the management implications for each. Each assessment has management implications developed from evaluating the results of each soil indicator used in the assessment. Based on the results of the CASH and NRCS assessments, the main management suggestions across all farms, would be for farmers to add lime and P fertilizers. Adding organic fertilizers such as manures high in P, would be optimal because these not only increase P availability over the long term and add micronutrients (Iqbal et al., 2014), but also increase soil microbial activity (Oberson et al., 2005; Iqbal et al., 2014). On the other hand, the results of the CATIE test state that the main limitations are soil physical structure (evidenced by slow infiltration) and low biological activity (apparent as low earthworm counts). The management recommendations to improve infiltration include deep tillage, adding cover crops and animal manures and organic residues. Because the participating smallholder farmers and nearly all similar producers lack access to machinery, deep tillage is not a viable option. Thus, adding cover crops, manures and organic residues are the best options for improving infiltration, which overlap with the recommendation from CASH and NRCS. Adding cover crops, organic residues, and animal manures is also known to improve soil biological activity (Oberson et al., 2005). Interestingly, both the CASH and CATIE assessments, with very different indicators tested and different total soil health scores led to similar overall management recommendations of adding animal manures. Our results imply that CEC may be a good indicator to include on future soil health studies in Central America because it is correlated with overall soil health and provides important information about nutrient availability in the soils, which is especially important in soils where there is high P fixation.

## 5. Conclusions

In conclusion, the three soil health assessments demonstrated clearly different overall soil health scores, especially the CATIE and CASH methods in regards to both overall scores and individual indicators. All three methods have unique advantages and challenges. Because soil constraints in the humid tropics are largely chemical (Sanchez and Salinas 1982), further demonstrated by our study, it is important to include at least some chemical indicators in future soil health assessments. Thus, a clear need exists for increased access to soil testing laboratories or increased access to accurate and affordable field-testing equipment in Central American research and extension settings. Our study also demonstrates that soil biological indicators, such as soil respiration or even earthworm counts, are important indicators to include in soil health assessments. In addition, many smallholder farms in Central America have unique production challenges characterized by steep slopes and shallow soils. The CATIE assessment is the only method that incorporates erosion control and soil management into the overall soil health score, which may be especially beneficial when working with farmers. Future research should examine how to better integrate the three different assessments and adapt them to specific situations in the tropics.

## REFERENCES

Altieri, M. 1998. An agroecological perspective to guide graduate educational programs in agricultural economics and rural development in latin america of the XXI century. Ecol. Econ. 27:227-236.

Bacon, C.M., W.A. Sundstrom, M.E.F. Gomez, V.E. Mendez, R. Santos, B. Goldoftas and I. Dougherty. 2014. Explaining the 'hungry farmer paradox': Smallholders and fair trade cooperatives navigate seasonality and change in Nicaragua's corn and coffee markets. Glob. Environ. Change-Human Policy Dimens. 25:133-149.

Bindraban, P.S., M. van der Velde, L. Ye, M. van den Berg, S. Materechera, D.I. Kiba, L. Tamene, K.V. Ragnarsdottir, R. Jongschaap, M. Hoogmoed, W. Hoogmoed, C. van Beek and G. van Lynden. 2012. Assessing the impact of soil degradation on food production. Curr. Opin. Environ. Sustain. 4:478-488.

Caswell, M., V.E. Méndez, J. Hayden, J. Anderzén, P. Merritt, A. Cruz, V. Izzo, S. Castro, J. Wiegel, A. Ospina and M. Fernandez. 2016. Assessing resilience in coffee-dependent communities of honduras, nicaragua and haiti . Rep. . RLG/LWR Research Brief #5.

Agroecology and Rural Livelihoods Group (ARLG), University of Vermont & Lutheran World Relief (LWR), Vermont.

Deleon, A., D.M. Sangerman-Jarquin and J.A.C. Sanchez. 2009. Acceptance of maize platino, oro blanco and protemas cultivars of high proteinic quality in el salvador, central america. Agricultura Tecnica En Mexico 35:406-415.

Doran, J. 2002. Soil health and global sustainability: Translating science into practice. Agric. Ecosyst. Environ. 88:119-127.

FAO. 2008. The right to food and access to natural resources. Food and Agriculture Organization of the United Nations, Rome.

Ferrufino, A. 2009. Mapeo del mercado de semillas de maiz blanco y frijol en centroamerica (map of the seed market for white maize and beans in central america). Interamerican Institute for Cooperation on Agriculture, Managua, Nicaragua.

Friedman, D., M. Hubbs, A. Tugel, C. Seybold and M. Sucik. 2001. Guidelines for soil quality assessment in conservation planning. United States Department of Agriculture, Natural Resources Conservation Service, Soil Quality Institute, .

Havlin, J.L., S.L. Tisdale, W.L. Nelson and J.D. Beaton. 2014. Soil fertility and fertilizers: An introduction to nutrient management, 8th edition. Pearson, .

Hurni, H., M. Giger, H. Liniger, R.M. Studer, P. Messerli, B. Portner, G. Schwilch, B. Wolfgramm and T. Breu. 2015. Soils, agriculture and food security: The interplay

between ecosystem functioning and human well-being. Curr. Opin. Environ. Sustain. 15:25-34.

Idowu, O.J., H.M. van Es, G.S. Abawi, D.W. Wolfe, R.R. Schindelbeck, B.N. Moebius-Clune and B.K. Gugino. 2009. Use of an integrative soil health test for evaluation of soil management impacts. Renew. Agr. Food Syst. 24:214-224.

Iqbal, M., H.M. van Es, Anwar-ul-Hassan, R.R. Schindelbeck and B.N. Moebius-Clune. 2014. Soil health indicators as affected by long-term application of farm manure and cropping patterns under semi-arid climates. Int. J. Agric. Biol. 16:242-250.

Lowery, B., W.J. Hickey, M.A. Arshad and R. Lal. 1996. Soil water parameters and soil quality. p. 143-155. *In* J. Doran and A. Jones (eds.) Methods for assessing soil quality.

Ministerio de Agricultura y Ganaderia (MAG). 2011. Plan de agricultura familiar y emprendedurismo rural para la seguridad alimentaria y nutricional 2011-2014. Gobierno de El Salvador, El Salvador.

Ministerio de Agricultura y Ganareria (MAG). 2012. Estrategia ambiental de adaptacion y mitigacion al cambio climatico del sector agropecuario, forestal y acuicola. Gobierno de El Salvador, El Salvador.

Moebius-Clune, B.N., H.M. van Es, O.J. Idowu, R.R. Schindelbeck, J.M. Kimetu, S. Ngoze, J. Lehmann and J.M. Kinyangi. 2011. Long-term soil quality degradation along a cultivation chronosequence in western kenya. Agric. Ecosyst. Environ. 141:86-99.

Moebius-Clune, B.N., D.J. Moebius-Clune, B.K. Gugino, O.J. Idowu, R.R. Schindelbeck, A.J. Ristow, H.M. van Es, J.E. Thies, H.A. Shayler, M.B. McBride, D.W. Wolfe and G.S. Abawi. 2016. Comprehensive assessment of soil health – the cornell framework manual. Rep. Edition 3.1. Cornell University, Geneva, NY.

NRCS. 1999. Soil quality test kit guide. United States Department of Agriculture, Agriculture Research Service, Natural Resources Conservation Service: Soil Quality Institute, .

Oberson, A., E.K. Bunemann, D.K. Friesen, M.R. Idupulapati, P.C. Smithson, B.L. Turner and E. Frossard. 2006. Chapter 37. improving phosphorus fertility in tropical soils through biological interventions. p. 531-546. *In* N. Uphoff (ed.) Biological approaches to sustainable soil systems. CRC Press, .

Padilla, C.D. and J.G. Suchini. 2001. Guía pare el sondeo agroecologico de suelos y cultivos. Rep. Manual Técnico; no. 112. Centro Agronómico Tropical de Investigación y Enseñanza (CATIE); Programa Agroambiental Mesoamericano, Turrialba, Costa Rica.

Panagos, P., K. Meusburger, M. Van Liedekerke, C. Alewell, R. Hiederer and L. Montanarella. 2014. Assessing soil erosion in europe based on data collected through a european network. Soil Sci. Plant Nutr. 60:15-29.

Rojas, R.V., M. Achouri, J. Maroulis and L. Caon. 2016. Healthy soils: A prerequisite for sustainable food security. Environ. Earth Sci. 75:180.

Sanchez, P. and M. Swaminathan. 2005. Hunger in africa: The link between unhealthy people and unhealthy soils. Lancet 365:442-444.

Stocking, M. 2003. Tropical soils and food security: The next 50 years. Science 302:1356-1359.

Stott, D.E. and B.N. Moebius-Clune. 2017. Soil health: Challenges and opportunities. Global Soil Security109-121.

Table 3.1. Summary of all soil health indicators measured for the CATIE, NRCS, and CASH soil health assessments

| | NRCS[1] Low, medium, high | CASH[2] 0-100 score | CATIE[3] Low, medium, high |
|---|---|---|---|
| Chemical | Extractable P<br>pH | Extractable P<br>Extractable K<br>pH<br>Micronutrients (Mg, Fe, Mn, Zn) | |
| Physical | Infiltration<br>Surface hardness | Aggregate Stability<br>Surface hardness | Infiltration |
| Biological | # earthworms<br>Different soil organisms<br>% organic matter | Soil respiration<br>Active carbon<br>% organic matter | # earthworms |
| Other | | | % Cover<br># soil conservation practices<br>Topsoil depth |

[1] Natural Resources Conservation Service (NRCS; Friedman et al. 2001)
[2] Cornell Comprehensive Assessment of Soil Health (CASH; Moebius-Clune et al. 2016)
[3] Centro Agronómico Tropical de Investigación y Enseñanza (CATIE; Padilla and Suchini 2013).

Table 3.2. Summary of three different soil health assessments tested on the same 17 farms in smallholder farming communities of northeastern El Salvador.

| Farm | NRCS[1] (7-21) | CASH[2] (0-100) | CATIE[3] (6-18) |
|---|---|---|---|
| 1 | 15 | 64.51<br>High<br>Limitation: soil respiration | 15.3 |
| 2 | 13<br>Low indicators: infiltration | 84.41<br>Very High | 12.7<br>Low indicators: infiltration |
| 3 | 14<br>Low: P | 72.79<br>High<br>Limitations: low P, low micronutrients | 13.3 |
| 4 | 15.3 | 76.7<br>High | 13.7 |
| 5 | 15<br>Low indicators: infiltration | 76.79<br>High | 12.5<br>Low indicators: infiltration, % cover |
| 6 | 12.5<br>Low indicators: soil organisms, infiltration, P | 59.46<br>Medium<br>Constraint: low pH<br>Limitations: low P, low micronutrients | 12.5<br>Low indicators: infiltration |
| 7 | 14<br>Low indicators: pH; P | 60.01<br>Medium<br>Constraints: low pH, low P<br>Limitations: soil respiration | 14.3 |
| 8 | 13.7<br>Low indicators: pH, P | 62.13<br>High<br>Constraints: low pH; low P | 15 |
| 9 | 14<br>Low indicators: pH, P | 44.55<br>Medium<br>Constraint: low pH<br>Limitations: low P, low micronutrients | 15.7 |
| 10 | 11.3<br>Low indicators: infiltration; pH, P | 59.56<br>Medium<br>Constraints: low pH; low micronutrients<br>Limitations: soil respiration | 13<br>Low indicators: infiltration |
| 11 | 12.3<br>Low indicators: infiltration, pH, P | 63.31<br>High<br>Constraints: low pH; low P | 14.3<br>Low indicators: infiltration |
| 12 | 11.3<br>Low indicators: earthworms, pH, P | 56.41<br>Medium<br>Constraints: low pH; low P | 11.7<br>Low indicators: infiltration, earthworms |
| 13 | 12<br>Low indicators: earthworms, infiltration, P | 64.01<br>High<br>Constraint: low P<br>Limitations: low pH | 12<br>Low indicators: infiltration, earthworms |
| 14 | 12.5<br>Low indicators: Earthworms, soil organisms, pH, P | 53.95<br>Medium<br>Constraints: low pH; low P | 14 |
| 15 | 11.7<br>Low indicators: earthworms, soil organisms, | 46.38<br>Medium<br>Constraint: low micronutrients<br>Limitations: low pH; soil respiration | 13<br>Low indicators: earthworms |
| 16 | 9.3<br>Low indicators: earthworms, soil organisms, infiltration, pH, P | 44.92<br>Medium<br>Constraint: low pH<br>Limitations: surface hardness ; soil respiration; low P | 10<br>Low indicators: infiltration, % cover, earthworms |
| 17 | 10.7<br>Low indicators: soil organisms, infiltration, P | 42.55<br>Medium<br>Constraint: low pH<br>Limitations: soil respiration; low P | 12<br>Low indicators: infiltration |

[1] Natural Resources Conservation Service (NRCS; Friedman et al. 2001)
[2] Cornell Comprehensive Assessment of Soil Health (CASH; Moebius-Clune et al. 2016)
[3] Centro Agronómico Tropical de Investigación y Enseñanza (CATIE; Padilla and Suchini 2013).

Table 3.3. Summary of the opportunities and challenges during this study of utilizing the CATIE, NRCS, and CASH soil health assessments in the tropical soils of El Salvador in smallholder farming areas

| | NRCS[1] | CASH[2] | CATIE[3] |
|---|---|---|---|
| Opportunities | Adaptable to both researcher and farmer needs<br><br>Includes some physical, chemical and biological indicators | Comprehensive<br><br>Includes a large variety of chemical, physical and biological indicators<br><br>Larger scoring range for more precise comparisons | Designed locally<br><br>Farmer friendly<br><br>Incorporates management practices<br><br>Inexpensive |
| Challenges | Few scoring options - only low, medium and high scoring options | Lacking in-field indicators useful for farmers<br><br>Expensive<br><br>Methodologies for some biological indicators often inaccessible | Subjective<br><br>Few scoring options - only low, medium and high scoring options<br><br>No chemical indicators |

[1] Natural Resources Conservation Service (NRCS; Friedman et al. 2001)
[2] Cornell Comprehensive Assessment of Soil Health (CASH; Moebius-Clune et al. 2016)
[3] Centro Agronómico Tropical de Investigación y Enseñanza (CATIE; Padilla and Suchini 2013).

Table 3.4. Summary of the Cornell Comprehensive Assessment of Soil Health (CASH) measured indicators and the scoring functions used to evaluate soil health

| Indicator | Soil function evaluated | Type of scoring function | Scoring function (0-100)[1] | Sources for scoring function |
|---|---|---|---|---|
| PHYSICAL | | | | |
| Aggregate stability (%) | Structural stability, runoff, erosion, infiltration | More is better | CND(31,18)*100[2]<br>CND(35,19)*100 | Moebius-Clune et al. 2016 |
| Surface hardness (psi) | Surface rooting, water infiltration and transmission | Less is better | (1-CND(164,94)*100 | Moebius-Clune et al. 2016 |
| BIOLOGICAL | | | | |
| Total organic matter (%) | Water and nutrient retention | More is better | CND(3.07,0.86)*100<br>CND(3.99,0.99)*100 | CENTA[3] |
| Active carbon (ppm) | Soil biological activity; biological nutrient mineralization | More is better | CND (500,185)*100<br>CND(575, 200)*100 | Moebius-Clune et al. 2016 |
| Soil respiration (mg $CO_2$ g $soil^{-1}$) | Soil microbial community | More is better | CND(0.60,0.30)*100 | Moebius-Clune et al. 2016 |
| CHEMICAL | | | | |
| pH | Toxicity, chemical buffering, nutrient availability | Optimum | S = -63.1*$(pH)^2$ + 844.5*(pH) – 2716.5 | Gugino et al. 2009; Moebius Clune 2010 |
| Extractable P (ppm) | P availability | More is better | $\leq$1=0; 1-8 =25; 9-12 = 50; $\geq$13 = 100 | CENTA |
| Extractable K (ppm) | K availability | More is better | $\geq$74.5 = 100 | CENTA |
| Micronutrients:<br>Mg (meq $100g^{-1}$)<br>Mn (ppm)<br>Zn (ppm)<br>Fe (ppm) | Micronutrient availability | More is better | Mg $\leq$ 2.1= 0; $\geq$ 2.1= 100<br>Fe $\leq$ 11= 0; $\geq$ 11= 100<br>Mn $\leq$ 5.1= 0; $\geq$ 5.1= 100<br>Zn $\leq$ 3.1= 0; $\geq$ 3.1= 100 | CENTA |

[1] For indicators that were scored separately by soil textural category, the function for soils with clay<15% is listed first, followed by the function for soils with clay >15%.
[2] CND (m,s) = cumulative normal distribution, where m = mean, s = standard deviation.
[3] Centro Nacional de Tecnologia Agropecuaria y Forestal (CENTA) located in San Salvador, El Salvador

Table 3.5. Summary of results of the Cornell Comprehensive Assessment of Soil Health indicators

| Soil Indicator | Farm 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean SH[1] psi | 70.78 ±37.73 | 53.66 ±1.98 | 65.09 ±45.31 | 63.93 ±18.86 | 95.90 ±9.69 | 34.25 ±24.22 | 26.26 ±1.98 | 33.11 ±13.84 | 45.67 ±3.95 | 71.93 ±69.27 | 34.25 ±13.70 | 84.48 ±35.15 | 79.92 ±26.16 | 90.76 ±7.27 | 85.63 ±33.91 | 232.90 ±42.78 | 144.99 ±34.98 |
| Mean AS[2] (%) | 38.90 ±12.48 | 67.32 ±13.85 | 67.38 ±12.37 | 47.33 ±15.98 | 51.88 ±10.72 | 48.65 ±3.46 | 64.80 ±12.18 | 56.66 ±8.08 | 29.24 ±5.27 | 75.91 ±6.09 | 75.73 ±10.94 | 43.04 ±2.43 | 55.37 ±6.54 | 46.27 ±19.16 | 28.19 ±9.08 | 47.78 ±6.78 | 28.31 ±6.29 |
| Active C mg C/ kg | 574.16 ±81.83 | 693.88 ±53.35 | 718.39 ±55.61 | 733.94 ±94.24 | 680.11 ±28.70 | 521.63 ±78.10 | 535.74 ±62.13 | 529.33 ±134.54 | 475.39 ±28.61 | 673.77 ±134.54 | 697.07 ±47.70 | 723.28 ±59.54 | 740.91 ±145.34 | 568.04 ±57.41 | 539.52 ±64.52 | 582.86 ±107.44 | 460.36 ±83.59 |
| Mean SR[3] mg $CO_2$ /g soil | 0.47 ±0.02 | 0.70 ±0.12 | 0.64 ±0.09 | 0.63 ±0.21 | 0.58 ±0.08 | 0.78 ±0.02 | 0.51 ±0.12 | 0.52 ±0.17 | 0.54 ±0.09 | 0.51 ±0.11 | 0.54 ±0.12 | 0.59 ±0.01 | 0.69 ±0.07 | 0.56 ±0.09 | 0.40 ±0.03 | 0.40 ±0.05 | 0.39 ±0.09 |
| Mean pH | 6.00 ±0.10 | 6.32 ±0.06 | 6.54 ±0.03 | 6.58 ±0.09 | 6.54 ±0.04 | 5.52 ±0.01 | 5.35 ±0.22 | 5.31 ±0.37 | 4.96 ±0.44 | 5.18 ±0.33 | 4.76 ±0.11 | 5.52 ±0.31 | 5.54 ±0.65 | 5.50 ±0.02 | 5.68 ±0.11 | 5.42 ±0.09 | 5.55 ±0.01 |
| Mean P ppm | 26.13 ±34.24 | 8.47 ±7.42 | 2.67 ±2.89 | 5.67 ±7.23 | 39.00 ±52.33 | 1.90 ±1.00 | 0.76 ±0.49 | 2.13 ±2.07 | 3.56 ±1.00 | 6.06 ±1.23 | 0.40 ±0.00 | 0.40 ±0.00 | 0.97 ±0.87 | 0.40 ±0.00 | 9.00 ±4.36 | 7.00 ±3.00 | 2.00 ±1.73 |
| Mean % OM | 3.91 ±0.56 | 4.60 ±0.57 | 6.07 ±1.46 | 5.38 ±1.63 | 5.04 ±0.10 | 4.35 ±0.29 | 4.69 ±0.55 | 4.37 ±0.66 | 3.68 ±0.21 | 7.54 ±2.93 | 10.40 ±0.16 | 5.98 ±0.42 | 6.99 ±0.92 | 4.83 ±0.58 | 3.91 ±0.94 | 4.19 ±0.91 | 3.68 ±0.80 |
| Mean K meq/100g | 351.53 ±108.42 | 295.43 ±82.92 | 532.30 ±139.85 | 452.33 ±25.70 | 374.00 ±16.69 | 292.75 ±0.21 | 232.07 ±54.39 | 314.20 ±122.56 | 202.87 ±36.16 | 264.90 ±38.64 | 143.53 ±17.83 | 158.07 ±42.86 | 269.47 ±26.41 | 177.05 ±27.51 | 258.33 ±42.33 | 239.63 ±4.09 | 200.30 ±20.49 |
| Mean Mg meq/100g | 4.37 | 5.04 | 4.86 | 5.10 | 5.47 | 2.09 | 2.60 | 2.56 | 0.94 | 1.12 | 3.68 | 6.20 | 5.54 | 5.68 | 1.74 | 2.30 | 3.08 |
| Mean Fe ppm | 16.51 | 18.63 | 6.48 | 17.43 | 12.04 | 53.42 | 41.32 | 51.82 | 87.28 | 48.88 | 17.78 | 19.81 | 24.54 | 19.49 | 27.98 | 28.62 | 49.86 |
| Mean Mn ppm | 26.24 | 28.26 | 23.18 | 26.24 | 30.35 | 39.49 | 29.24 | 33.26 | 23.49 | 13.49 | 4.17 | 31.72 | 31.11 | 24.34 | 24.22 | 19.27 | 25.08 |
| Mean Zn ppm | 1.81 | 2.93 | 2.23 | 2.05 | 2.88 | 1.53 | 1.62 | 4.29 | 2.57 | 1.42 | 1.22 | 0.98 | 1.28 | 2.01 | 1.20 | 0.98 | 1.03 |

[1]Surface hardness
[2]Aggregate Stability

[3]Soil respiration

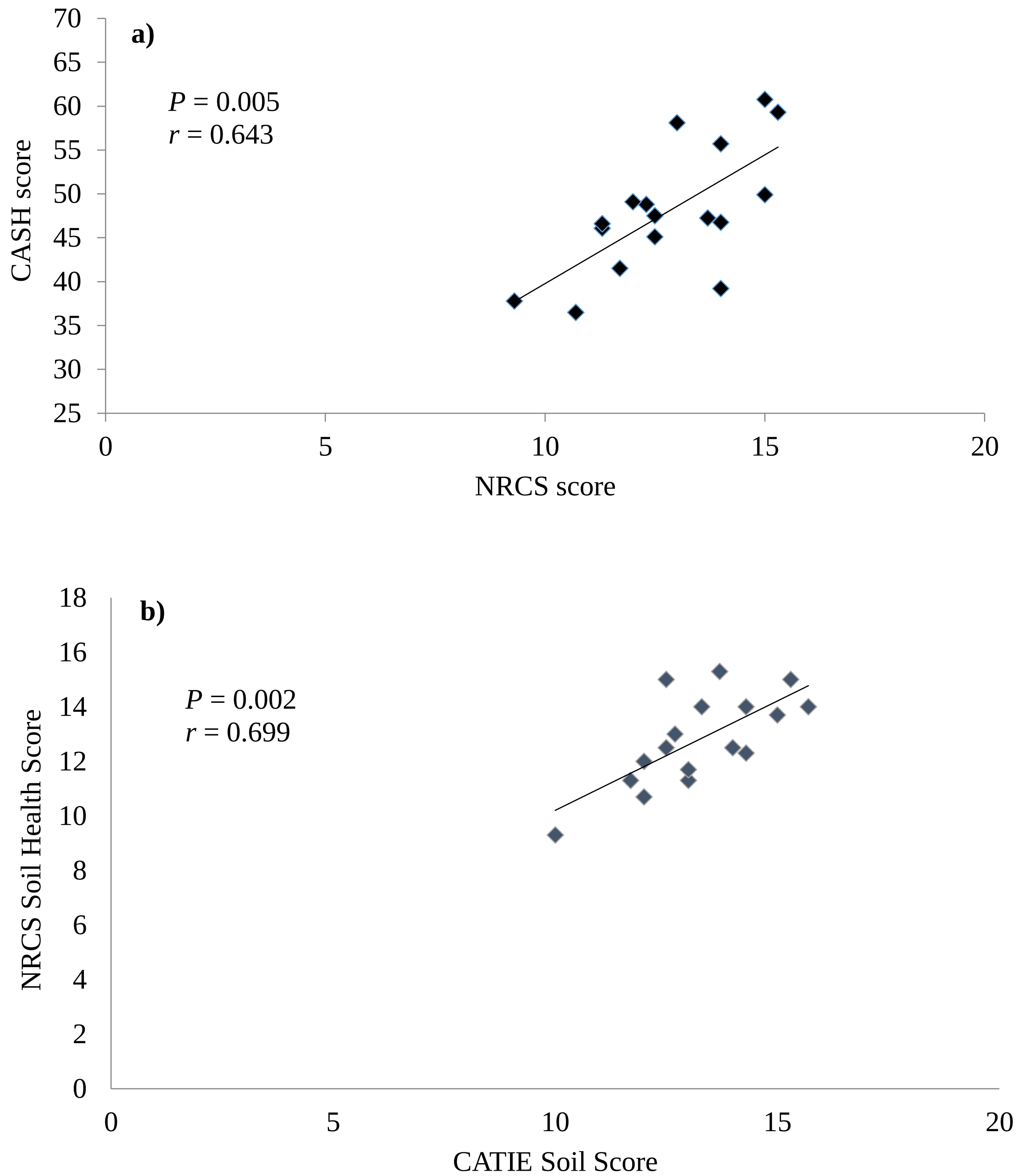


Fig 3.1. a) The NRCS and CATIE methods had total soil health scores that were significantly positively correlated (Pearson's $r = 0.699$; $P = 0.002$); b) The NRCS and CASH (Pearson's $r = 0.643$; $P = 0.005$).

# IV. Examining the Relationship between Soil Health and Food Security in a Smallholder Farming Community in El Salvador

## Abstract

One of the most important functions of soil is food production and it is becoming widely accepted that healthy soils are the basis for food security. Despite the obvious connections between soils and food security, there have been no empirical studies quantifying this relationship. The objective of this study was to determine if farms with increased soil health have improved household food security and livelihoods in rural El Salvador. A stratified simple random sampling method was utilized where three distinct household strata are identified based on level of food insecurity (low, middle, and high food insecurity). The goal was to have at least 6 farm households from each stratum, with a total of 18 farms. The total sample size was based on the total number of members in the cooperative. Soil samples were randomly taken at 3 fields within each farm composed of 10 composite soil cores per sampling point at each farm. Parameters for soil health were chosen based on the Cornell Comprehensive Soil Health Analysis. Spearman correlations (for non-parametric data) and chi squared were used to determine the relationship between overall soil health and food security, as well as other livelihood indicators. Analysis of variance (ANOVA) were utilized to compare means between different soil indicators and food security. The Cornell Soil Health Analysis Scores were significantly correlated with food security for the farming households. Micronutrients and CEC appeared to be the indicators most impacting food security. However, food security was also impacted by other factors, such as land area planted and total yield. Although the results demonstrate the complexity of the causes of food

insecurity indicating that not addressing one variable will solve the problem, they suggest that improving soil health could be part of the solution.

## 1. Introduction

Currently an estimated 1 billion people go hungry worldwide on a regular basis (FAO, 2012). Of these, approximately 80% live in rural areas and half are smallholder farmers, often farming marginal lands (FAO, 2012). In order to feed a growing population, small scale farming systems will need to undergo intensification with only moderate external inputs and mechanization. The greatest needs and potentials for improving agricultural production globally lie in small-scale farming (Hurni et al., 2015). Governments, non-governmental organizations, and researchers have advanced a number of technological strategies to improve food security for smallholder farmers, (Ejeta, 2009; Holt-Gimenez and Altieri, 2013), such as improved seeds, pesticides and fertilizers shown to deliver high yields (Beets, 1990; Christou and Twyman, 2004). However, increased inputs may not always be the most efficient use of smallholder farmers' limited resources, the most appropriate solutions for the landscape or their socio-economic conditions. Agricultural advances in technologies have improved the situation for some farmers, but food insecurity, low yields, and increasing environmental degradation persist for some of the world's poorest and most vulnerable farmers. Approximately 60% of rural communities in the tropics and sub-tropics experience consistently declining household food production, often attributable to declining soil health (Stocking, 2003).

Close to one-third of agricultural land globally is affected by soil degradation and is one of the main factors stagnating food production globally (Bindraban et al., 2012). The core role of soil ecosystems in sustaining yields and combating global food security is often overlooked (Rojas et al., 2016). Managing for soil health is a fundamental production factor determining food production stability, sustainable resource management, and food nutrient quality (FAO, 2008).

### *1.1.Soil health*

Soil health is commonly defined as the “capacity of a living soil to function with natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain and enhance water and air quality, and promote plant and animal health” (Doran, 2002). Agricultural soil health incorporates not only chemical soil fertility, but also physical and biological soil functions and processes that are needed to support plant growth. Healthy soils support crop productivity, as well as environmental quality and animal health (Doran, 2002). Wide scale adoption of soil health promoting practices has the potential to make global impacts on farm resilience, productivity and economics. The quality of agricultural land and ability of that land to maintain high levels of production is threatened by the physical, chemical and biological degradation of these soils (Bindraban et al., 2012; Stott and Moebius-Clune, 2017). Examples of such threats include soil erosion, compaction, pollution, and decreased soil organic matter (Hurni et al., 2015; Panagos et al., 2014; Rojas et al., 2016; Stott and Moebius-Clune, 2017).

Soil health cannot be directly measured but various individual soil indicators for the functioning of the soil can be used as a combined measure for soil health. A variety of soil health assessment tools exist, such as the Haney test[1] (Haney et al., 2010; Haney et al., 2006), the Solvita® soil health test[2] and the CATIE in field agroecological soil health assessment (Centro Agronómico Tropical de Investigación y Enseñanza;(Padilla and Suchini, 2001). In the U.S., the Natural Resources Conservation Service (NRCS) is a leader in developing methodologies for soil health assessments and standardization of soil health indicators for a variety of stakeholders, including producers (Friedman et al., 2001). The NRCS method combines in field measurements with some laboratory analyses. Building on the work of the NRCS following a very similar methodology, Cornell developed the Comprehensive Assessment of Soil Health (CASH; Moebius-Clune et al., 2016), which was designed for soil health assessment to aid in management decisions. The Cornell CASH methodology integrates soil biological, physical and chemical indicators, (often interpreted based on soil texture) that change with management. Each soil health indicator is interpreted based on a scoring function (0 to 100) and assessed to see if they constrain the soil processes they represent. In addition, the CASH method developed a soil health report that enables farmers to identify constraints (beyond just chemical) to the functioning of their agricultural soils and implement management strategies to target the constraints, as well as monitor changes in soil health over time. The CASH scoring functions have been adapted to soils mostly in the

[1] https://www.wardlab.com/haney-info.php
[2] https://solvita.com/soil/

Northeastern U.S. (Moebius-Clune et al., 2016) but it may be the most developed soil health testing framework to date. It will likely provide a good framework for standardized soil health assessment and monitoring beyond the US, but requires testing and adapting in order to serve a variety of regions and stakeholders in the tropics. No comprehensive soil health assessment methodology designed specifically for the tropics exists to our knowledge, but the CASH method is the most comprehensive assessment and has been utilized in the tropics successfully.

The CASH tool has been successfully utilized on a limited basis to assess soil various soil health indicators in the tropical soils of both Kenya and Pakistan (Moebius-Clune et al., 2011). In Kenya, the Cornell assessment tool was used to compare soil degradation over time with different management systems (Moebius-Clune et al., 2011). In Pakistan, it was shown to be an effective tool for evaluating differences in soil health after manure application on Pakistan soils (Iqbal et al., 2014). Understanding the soil health status of soils can be critical to improving food and nutritional security for smallholder farmers (Rojas et al., 2016) because soil health declines have been associated with significant declines in yield (Moebius-Clune et al., 2011).

### *1.2. Food Security*

The 2009 Declaration of the World Food Summit on Food Security, agreed that "food security exists when all people at all times, have physical, social and economic access to sufficient, safe and nutritious food, which meets their dietary needs, and food preferences for an active and healthy life" (FAO, November, 2009). Food security is most commonly understood as being dependent on four conditions: availability, access, utilization and stability of the previous three (Barrett, 2010). Food insecurity can result when there is a deficiency in availability, access, utilization or stability. Likewise, food security can refer to global, national, community, household, and individual conditions, and can be either transitory or permanent (Pinstrup-Andersen, 2009). Many questions about understanding food security, measuring food security and improving food security globally remain unanswered.

Previous researchers have argued that all of the four dimensions of food security are related to soils and agricultural production (Hurni et al., 2015; Rojas et al., 2016; Stocking, 2003). For example, food availability requires an adequate supply of food production, mostly produced on agricultural soils. A lack of access to land, with healthy/fertile soil, can hinder farmers from producing food and income for purchasing food (Hurni et al., 2015). In addition, nutrient impoverished soils are directly linked to crops with low concentrations of minerals (St Clair and Lynch, 2010), contributing to the more than 2 billion people suffer from micronutrient deficiencies (FAO, 2013). Pesticide use can also undermine the safety and nutritional quality of foods (Verger and Boobis, 2013), as well as microbial activity in the soil. Lastly, soil health contributes to the stability of a food system, the fourth component of food security. Soil health increases resilience to climate shocks and pest and disease outbreaks increasing the overall stability of access, availability and utilization of foods (Hurni et al., 2015).

Food security is a complex and highly subjective concept (Maxwell, 1996); because of this, it is difficult to capture all aspects of food security in a single—or even several—

quantitative indicators. Two main food security indicators were chosen for this study: Months of Inadequate Household Food Provisioning (MIAHFP) and the Latin American and Caribbean Food Insecurity Experience Scale (ELCSA). In addition, because of the complexity of and many factors that can impact household food security, it is important to gather livelihood data, such as income, education, household data and farm data.

Despite the intricate relationship between soil health and food security, there has been little research to quantify the relationship between soil health and food security at the household level, which is the unit where decisions are made determining soil management. Furthermore, quantitative evidence of this relationship is important to articulate the value of soil health to human livelihoods. Several scientists are currently developing methods to quantify soil services (Robinson et al., 2013) but no work has yet quantified the contribution of soils to food security. Moreover, little research is aimed at smallholder farming systems in the tropics, where a farmer's livelihood is more dependent on the productivity of the soils. The purpose of this study is to describe and compare the relationship between soil health and food security. An understanding of this relationship is critical for moving beyond productivity of staple crops as the sole indicator of food and livelihood security (Remans et al., 2011). Furthermore, quantitative evidence of this relationship is important in order to articulate the value of agrobiodiversity to human livelihoods (Ruel, 2003), particularly as we attempt to build food systems that balance the sometimes competing needs to adapt to climate change, provide environmental services, and provide enough food for a population increasingly demanding of animal protein (Smith and Gregory, 2013).

The complexity of both food security and soil health make quantifying the relationship difficult. Therefore, we chose a study site where the relationship between soil health and food security for smallholder farmers is likely to be strong and research was most needed – a smallholder farming community in El Salvador. El Salvador is the most densely populated country in the Americas, with the majority of agricultural output produced by smallholder farmers, thus demanding an efficient use of natural resources, especially soil. It provides an excellent location to examine soil health and the relationship between soil health and food security. Furthermore, soil erosion and degradation is a major environmental threat in El Salvador that has required the country to take a nation-wide investment in improving soil health. Thus, understanding how to effectively evaluate soil health in meaningful ways with limited resources is critical for the future of El Salvador.

The specific objectives of this research are to utilize a farming community in El Salvador as a case study for evaluating the relationship between soil health and food security through: 1) assessing current soil health indicators on each farm using standard soil health indicators, 2) determining current household food security and other livelihood indicators, and 3) examining the relationship between soil health, food security and other socio-economic indicators.

## 2. Methods

### *2.1 Study site*

Research was conducted between September and November 2015. All eighteen farms in the study were located in the municipality of Cacaopera (13.7721° N, 88.0766° W) in the Department of Morazán in the northeastern part of El Salvador. The climate in El Salvador is a rainy season between May and October and a dry season with no rain from November through April. Average annual precipitation is approximately 1900mm. The natural vegetation of the region is classified as a humid, subtropical forest. The farms in Cacaopera were located at elevations between 500 and 800 masl. All farms were between 5 and 10 km from a town with dirt roads, intermittent access to electricity and no running water. Electricity is available to the households that are closest to the main road, but the majority of households did not have electricity. The farming communities have schools up to 6th grade.

This region was chosen because of the history of more than 20 years working with a partner non-governmental organization (NGO), Fundación Hermano Mercedes Ruíz (FUNDAHMER). Choosing these communities in northeastern El Salvador, with their long history of working with FUNDAHMER and mutual trust built over the years, ensured more candid responses during interviews and focus groups. While it can be difficult to obtain accurate data on personal information such as income, production practices, immigration, and concerns about food security, we believe we received more honest responses as a result of the established relationship with FUNDAHMER and all initial communications were made with the communities and research participants through FUNDAHMER.

All households in the study maintain subsistence plots of corn and beans, referred to as *milpas,* which are staples in their diet, and some plots contain a small amount of other vegetables for consumption or occasional sale. Some families sell excess corn and bean yields, while others only grow it for their own consumption. These *milpa* plots are commonly located on steep slopes with maize and beans intercropped. Average farm size in El Salvador is 0.7 ha with an average of 6 people per household (Ministerio de Agricultura y Ganaderia (MAG), 2011) and the farms in our study ranged from 0.5 ha to 2 ha.

### *2.2. Food security analyses*

From September to November 2015, semi-structured interviews were conducted in Spanish with both male and female heads of household present for 18 families. When a household was headed by a single female, only the female was interviewed. Participants were chosen by researchers making announcements at local meetings and asking for volunteers. Interviews were conducted in the home of each family with the assistance of one person from the community hired to help navigate and assist with either asking survey questions or recording responses. Interviews generally lasted between one and two hours. The interview guide and survey (Appendix B) was modified from previous livelihood surveys from Mendez (2004). The 8-page survey instrument contained detailed questions on household demographics, migration, household infrastructure, farm characteristics, farm management, and food security. Questions also focused on participants' perceptions of challenges to production and feeding their family, as well as perceptions of soil health on their farms.

Interviews included detailed questions about the total variety of crops planted and agroecological practices utilized on the farm were calculated from the surveys. The total number of agroecological practices was adapted from a survey by (Caswell et al., 2016) and included the application of each practice in corn, beans and home vegetable garden. Agroecological practices included: agroforestry (combination of trees planted with other crops), dead erosion barriers (usually rock), living fences, leaving organic matter on fields, erosion trenches, rotation of crops, and green manures. Number of crops was defined as the total number of different types of crops, including corn, beans, root crops, musaceas (bananas and plantains), vines, ornamentals, fruit trees, trees for firewood, trees for shade, and vegetables. The total number of vegetable crops was a different survey category. See Appendix B for detailed survey questions.

Two main food security indicators were measured: Months of Inadequate Household Food Provisioning (MIAHFP) and the Latin American and Caribbean Food Insecurity Experience Scale (ELCSA). MIAHFP was developed by the U.S. Agency for International Development to measure how many months in a 12 month period a household lacks enough food to meet their basic needs. It is a subjective metric whereby the farmer judges how many months in the year their household feels they have enough to feed their families with the foods they want. This measurement has been frequently used in Central America, mostly in coffee farming communities (Bacon et al., 2014; Mendez et al., 2010a). In previous studies (Morris et al., 2013a), the months where the grains stores from the previous harvest start to run out are called *los meses flacos*, or the thin months. This indicator is measured by asking the following two questions: In the past 12 months, were there months in which you did not have enough food to meet your family's needs? If yes, which were the months (in the past 12 months) in which you did not have enough food to meet your family's needs? These questions were followed by a series of open ended questions (Appendix B) that captured farmers' perceptions of the definition of food insecurity including what foods were in low supply during the thin months and what factors contribute to or mitigate the thin months (Morris, 2013).

Household food security was also measured using the Latin American and Caribbean Food Insecurity Experience Scale [Escala Latinoamericana Y Caribeña de Seguridad Alimentaria (FAO, May 2012) - ELCSA]. It is an experience-based metric of severity of food insecurity that relies on people's direct responses. These responses are collected through the ELCSA survey (Appendix B) which consists of eight short questions that refer to the experiences of the individual respondent or of the respondent's household as a whole. A household was defined as household heads, children living in the home and anyone living in the home economically dependent on the heads of household. Seven additional questions are asked if children are present in the household, for a total of fifteen questions. All questions were asked in reference to the three-months preceding the survey. The questions focus on self-reported food-related behaviors and experiences associated with increasing difficulties in accessing food due to resource constraints. Each question that was answered positively was assigned a score of one. An additive score was used to assess the severity of household food insecurity. Based on the total responses, each household was classified as food secure (0 points), light food insecurity (1-5 points), medium food insecurity (6-10), or severe food insecurity (11-15) (Perez-Escamilla et al., 2009). Because a scale of food insecurity is created, the ELCSA results are comparable across countries and unique versions of the survey have already been adapted and utilized in various regions and countries (Chicoine et al., 2014; Perez-Escamilla et al., 2011).

In order to further understand farmers' perception of the their food security status, two additional questions were asked during the interviews. Respondents were asked whether their household was food secure or not. In addition, because all households depended primarily on agriculture as their main livelihood, respondents were asked to classify whether their household was: 1) growing more than enough food for their family, 2) growing just enough food for their family, or 3) not growing enough food for their family.

### *2.3 Soil sampling and soil health measurements*

All soil samples were collected between September and November of 2015. At each farm, three soil sampling locations were randomly chosen that were representative of the farm as a whole. Each sampling location consisted of taking ten 0 to 15 cm samples with a soil auger, compositing these samples, mixing thoroughly and sub-sampling a ~1L volume of soil for analyses. Each sampling location including sampling for each of the following indicators: macronutrients (extractable P, K), micronutrients (Ca, Mg, Na, Zn, Cu, Mn, Fe), CEC, % base saturation, surface hardness, texture, aggregate stability, % organic matter, soil respiration, and active carbon. For each sample, a Garmin GPSMAP 64s handheld GPS was used to record location and elevation. A Suunto PM-5 Clinometer (Vantaa, Finland) was used to measure slope at each sampling location. Surface (0-15 cm) penetration resistance was assessed using a pocket penetrometer (ELE International). The mean penetration resistance of five sampling points was recorded

This study utilized the CASH methodology for measuring soil health, using the Cornell Framework Manual as a guide (Moebius-Clune et al., 2016). Due to the inability to conduct soil analyses at local laboratories in El Salvador and the cost of shipping soils internationally, two of the recommended Basic CASH indicators were not included in the analyses (soil protein and available water capacity). The CASH indicators measured included soil texture, field surface hardness (SH), wet aggregate stability (AS), organic matter content (% OM), soil respiration (SR), active carbon (AC), pH, and macro- (N, P, K) and micro-nutrient (Fe, Mg, Mn, Zn) content assessment. For each indicator, a score between 0 and 100 was calculated following the CASH scoring functions outlined in the manual. The lower the score the greater the constraint placed on proper functioning of soil processes. After all indicators were scored, a soil health overall quality score was computed as the unweighted average of all individual indicator scores.

### *2.4. Laboratory measurements*

All field soil samples were split in half, with half shipped to the Cornell Soil Health Testing Laboratory in Ithaca, NY and half taken to the Salvadoran National Center for Agricultural and Forestry Technology (Centro Nacional de Tecnologia Agropecuaria y Forestal – CENTA) located in San Salvador. The CENTA laboratories analyzed texture, pH in water, pH in KCl, extractable P and K, Ca, Mg, Na, CEC, % BS, % OM, Cu, Fe, Mn, and

Zn. OM was determined by the Walkley Black method. Mehlich-1 extracts were analyzed for P and K, Zn, Mn, Fe, and Cu. The Cornell laboratories analyzed the soil samples for AS, AC, and SR. Wet aggregate stability (AS) was measured using a rainfall simulation method adapted from (Moebius et al., 2007). Active carbon (AC) was measured by the permanganate oxidation method described by (Weil et al., 2003). Soil respiration was measured by incubating air-dried soil and calculating the CO2 released using the method outlined by (Zibilske, 1994).

### *2.5.Cornell CASH scoring function*

Because of the lack of research and standardization of different soil health indicators in tropical soils, the same non-linear scoring functions were utilized that were developed for the CASH (Moebius-Clune et al., 2016). Scoring functions interpret the level to which represented soil functional processes from each indicator are constrained. The cumulative normal distribution function (CND) with sample means (m) and sample standard deviation (s) from the Cornell Soil Health Test (Moebius-Clune et al., 2016) was used to calculate a score between 0 and 100 for each indicator.

$$CND(m,s) = 100* \frac{1}{2} (1 + erf [(x-m)/s\sqrt{2}])$$

The CND function with means and standard deviation from Moebius-Clune et al. (2016) was utilized for SH, AS, SR, and AC. The remaining soil properties were analyzed at CENTA and recommended critical values or ranges were defined by CENTA for % OM, pH, P, K, Fe, Mg, Mn, and Zn (see Table 4.1). The total soil health score is a mean of the scores from each soil indicator measured.

*2.6.Statistical analyses*

For all soil health indicators measured, mean values of the three representative sampling locations per farm were calculated and used for all statistical analyses. Pearson's correlations were calculated between food security, livelihood indicators, production practices and soil health indicators in SPSS v. 24. Paired t-tests were used to evaluate the relationship with ordinal and nominal data (level of education, presence or absence of soil conservation practices, pesticide and herbicide use). One-way ANOVA's were calculated using food insecurity level (light, moderate, or severe) as the independent variable and livelihood indicators, production practices, and soil health indicators as the dependent variable to see if these indicators differed between food insecurity levels. All statistical analyses besides Pearson's correlations and paired t-tests were done in JMP (Version 12.2, SAS Institute; Cary, NC)

A discriminate analysis was conducted in order to determine with what accuracy soil health indicators of a farm could predict the food security grouping of that farm household. The following soil health indicators were included in the analysis as the independent variables (or predictor variables): aggregate stability, active carbon, soil respiration, pH, P, K, Ca, Mg, Na, CEC, % BS, % OM, Cu, Fe, Mn, Mg, Zn. The groupings were determined based on the results of the ELCSA surveys with group 1 being light food insecurity; group 2 moderate food insecurity; and group 3 severe food insecurity. The Wide Linear discriminant method was utilized.

## 3. Results

### *3.1. Food security*

Food insecurity was a significant problem for the farmers in this study with 100% of households reporting some level of food insecurity according to the ELCSA food insecurity assessment (Table 4.2). 41% of households experienced a light level of food insecurity, 35% experienced moderate food insecurity, and 24% experienced severe food insecurity (Figure 4.1). 71% of the families reported that they did not produce sufficient corn and beans to feed their families for the full twelve months of the year (MIAHFP; Table 4.2). Farmers reported a distinct "lean" season, generally June, July, and August, during which 50% of the households reported lacking food. The mean number of hungry months across households was 2.4. A household's self-assessment of food security status was significantly related to the scale of food insecurity (paired t-test; $P$=0.008).

Agriculture was the primary livelihood activity (or source of income) for all households. 89% of the households depended on agriculture as their main source of income, either they sold grain or other farm products or worked in agriculture to generate income. In addition, 100% of households planted corn, beans, or both to supply the majority of their diet. On average, households had 3.9 income generating activities; the primary source of income outside of agricultural work was artisan work, such as making hammocks.

Several agricultural factors were significantly correlated (using Pearson's correlation) with household food insecurity. These included total area of land planted ($r$ = -0.715; $P$ = 0.002), total area of corn planted ($r$ = -0.652; $P$ = 0.005) and yield of corn per ha ($r$ = -0.555; $P$ = 0.032). In addition, number of total different crops planted (one-way ANOVA; $P$ = 0.023; Figure 4.1) and total area of land planted (one-way ANOVA; P = 0.048; Figure 4.2) differed between food security categories. The households in the severe food insecurity category had the lowest averages for both. Soil health indicators that were significantly correlated with food security included Mg ($r$ = -0.660; $P$ = 0.005), Na ($r$ = -0.704; $P$ = 0.002), CEC ($r$ = -0.363; $P$ = 0.014), Fe ($r$ = 0.522; $P$ = 0.034), and CASH score ($r$ = -0.553; $P$ = 0.026; Figure 4.3 ).

*3.2. Soil health indicators*

The CASH method of calculating a soil health score revealed a mean total score for all farms was 59.37 (±13.1 std. dev). The average scores for each farm ranged from 42.55 to 81.62, with a range of 39.06 between the highest and lowest overall soil health scores. The mean scores for each soil health indicator across all farms (Table 4.2) were surface hardness: 79.53 (±20.9); aggregate stability: 80.7 (±23.5); active C 70.96 (±21.0) soil respiration 43.72 (±16.0), pH 35.82 (±39.6), P 27.6 (±30.6), K 100 (±0), % OM 91.7 (±14.1), and micronutrients: 44.5 (±24.5). Phosphorus and pH were deemed to be the biggest constraints to production on most farms (Table 4.2). Soil respiration and micronutrients were also potential limitations to production in many farms (Table 4.2).

Other soil chemical indicators that were measured included CEC, % BS, Ca, Na, and Cu. The mean CEC was across all farms was 16.7 ($\pm$6.2 std. dev.). The mean % BS was 91.6% ($\pm$13.3). The means for the nutrients across all farms were: 11.3 ($\pm$5.5) meq $100g^{-1}$ Ca; 0.2 ($\pm$0.06) meq $100g^{-1}$ Na; and 1.1 ($\pm$0.8) mg $kg^{-1}$ Cu. Based on nutrient recommendations from the national laboratories of El Salvador, only two farms had low Ca and nine farms had low Cu.

### *3.3. Soil health and food security*

There was a significant negative correlation between household food insecurity and total farm level soil health score ($r$ = -0.566 ; $P$ = 0.022). In order to better understand the relationship between the various soil health indicators and the food insecurity levels, a discriminate analysis was conducted. Based on the soil health indicators (% aggregate stability, active carbon, soil respiration, pH, P, K, Ca, Mg, Na, CEC, % BS, % OM, Cu, Fe, Mn, Mg, Zn) a farm could be classified into one of the three food insecurity categories (light, moderate, severe) with 95% accuracy (Figure 4.5). Not a single farm was misclassified (0% misclassification) into the wrong group based on the soil health indicators (Figure 4.5).

Other farm and household indicators that were significantly correlated with the total Cornell soil health score included: cation exchange capacity ($r$ = 0.636; P = 0.006), total area of land planted ($r$ = 0.619; $P$ = 0.014), total area of corn planted ($r$ = 0.534; $P$ = 0.033) and total variety of crops planted ($r$ = 0.668; $P$ = 0.009). In addition, presence of contour ditches in corn fields (local referred to as acequias) was significantly related to a higher soil health score (*P*= 0.03).

## 4. Discussion

Food insecurity was a serious problem in this rural agricultural area of El Salvador, with a quarter of all households experiencing severe food insecurity, meaning that these households skipped meals on a regular basis. 100% of households were experiencing some level of food insecurity. Our food insecurity results may be much higher than government estimates, but are similar to previous studies in Central America evaluating household food security using ELCSA, the same tool currently being used by the Food and Agricultural Organization within Latin America and the Caribbean. According to one government survey, only 12% of Salvadorans are undernourished (WFP, February 2012), but our study showed 31% of surveyed households to have severe levels of food insecurity. A study in a rural region of Guatemala using ELCSA in 2010, found 18% of the households to have light food insecurity, 17% moderate, and 47% severe (Acker, 2011). A similar study conducted between 2010 and 2012 in Honduras found 89.3% of the households to be food insecure, with 52.9% experiencing severe food insecurity (Chicoine et al., 2014). These previous studies incorporated all types of rural households instead of focusing on smallholder subsistence farmers. This study adds to the literature on food security and smallholder subsistence farmers without a cash crop, which has mostly been focused in Africa up to this point.

Previous research has examined experiences of food insecurity in coffee farming communities; these studies find that coffee farmers frequently experience “hungry months” (Bacon et al., 2014; Morris et al., 2013a). This is one of the few studies that specifically examines food security challenges faced by subsistence farmers without a cash crop. Our study documents that subsistence farmers without a cash crop also struggle with a lean season, which tends to be in June, July and August – the same period for coffee farmers (Bacon et al., 2014; Morris et al., 2013a). One explanation for this lean season is that it occurs at the beginning of the rainy season before the first corn harvest (see Table 4.5), when grain reserves from the previous year are beginning to run out and farmers are buying fertilizers and herbicides for the current crops (Bacon et al., 2014; Morris et al., 2013a; Morris et al., 2013b). Another potential explanation is that the seasonal hunger coincides with the mid-season dry period throughout Mesoamerica (see Table 4.5 for explanation), as suggested by Bacon et al. (2014). The year our study took place there was a significant dry period in July[3]. However, it is difficult to ascertain the specific reasons for the “hungry months” of June, July and August because households achieve food security through a complex portfolio of livelihood strategies, including growing crops for food, selling crops with which to purchase food, earning income through off-farm employment or small businesses, and making use of wild food species (Bharucha and Pretty, 2010). We

[3] http://www.laprensagrafica.com/tag/canicula-el-salvador-2015_149182

recommend additional research to examine potential food security resources or solutions during these months.

This study used two measures of food insecurity. The ELCSA and MIAHFP methods of assessing food security were significantly correlated. Few studies have been done using both of these methods to assess food security in Central America and compared the results. A household's self-assessment of food security (where households deemed themselves as food secure or not) was also significantly related to both the ELCSA and MIAHFP food security assessments. Our results add validity to both methods as appropriate ways of measuring food security in smallholder farming communities in Central America.

Despite the strengths of both MIAHFP and ELCSA as tools for assessing household food security, both methods lacks the ability to incorporate the complexity of food security. Our study was unique in that it not only evaluated household food security, but also incorporated some of the environmental factors contributing to food insecurity, focusing especially on soil health, because of the household's dependence on soil for their livelihood and the potential to improve soil health in the future.

Interestingly, land and farming area did positively impact a household's food security status. A higher total area of beans planted, more so than corn, was also correlated with lower levels of food insecurity. Agriculture was the main source of income for all households corroborating previous studies (Bacon et al., 2014) and further demonstrating that a smallholder farmer's household food security status is directly related to the soil they farm. Our results concur with previous studies, showing that across the tropics, smallholder farmers typically depend on agriculture both as the primary source of food, as well as a main livelihood activity, thus any reductions in agricultural production can have significant impacts on food security, nutrition and overall well-being (Hertel and Rosch, 2010; Rojas et al., 2016). Results from our study demonstrate that yield, and factors impacting yield, such as soil health (Hurni et al., 2015; Rojas et al., 2016), are likely to directly impact food security for the farming families in our study.

A significant correlation between a farm's CASH soil health score and the household food security status (Figure 4.4) demonstrates the important relationship between soil health and food security for smallholder farming households. Moreover, to our knowledge, this is the first time the relationship between soil health and food security has been quantified. Due to the complexity of assessing both food security and soil health, and the many factors that can impact both, it is not surprising that the correlation is relatively weak (but still significant). Thus, it is important to analyze this relationship in depth because correlation does not imply causation. We conducted a discriminate analysis to see if it was possible to accurately predict a household's food security status (light, moderate, severe) based on the farm's overall soil characteristics. All farms were accurately grouped into the correct food security group from the CASH soil health indicators with a 95% accuracy level. Thus, a significant difference in overall soil health indicators implies a difference in the farm household's food security status.

Although it is difficult to elucidate the specific details of the relationship between soil health and food security, it is not surprising that a relationship can be quantified given that smallholder farmers are highly dependent on agriculture for their livelihoods. In degraded tropical soils, similar to those in this study, soil health declines have been associated with declines in grain yield (Moebius-Clune et al., 2011) even when full fertilizer rates are applied. A study in Kenya showed significant declines in pH, CEC, Zn, Mg, and Ca under continuous cultivation, which is similar to our study where a number of farms had very low Mg, Zn, and Ca levels. While it is impossible to say that micronutrient deficiencies and factors affecting nutrient availability (CEC and pH) on farms resulted in higher food insecurity for the household, it is likely they were contributing factors. Nutrient impoverished soils are known to contribute to systemic food and nutritional security issues (Rojas et al., 2016). Therefore, it is important to note that agricultural soil degradation can be reduced by improving soil management. Thus, improving soil health should be examined as a potential strategy for improving food security for smallholder farming households. This research contributes to the growing literature on soil health and food security, particularly as to how soil health contributes to food security at the farm and household level. While the relationship between soil health and food security is likely more clear in subsistence farming households, this study was admittedly designed to examine the relationship at the household scale, not the community scale, and was limited by a small sample size. Future research on soil health and food security in the tropics should consider using a larger scale as the unit of analysis, such as the community.

In conclusion, household food security is a significant struggle for many smallholder subsistence farmers and both, the MIAHFP and ELCSA methods of assessing food security appear to be valid for assessing food security in smallholder farming communities of Central America. The uniqueness of this study is that it incorporated both food security and soil health at the farm level, where decisions regarding soil management are made. Our results suggest that improving soil health may directly improve food security for smallholder farmers. Acknowledging our results are a preliminary case study, we recommend future work expand upon our results in a larger region and larger time frame as our results are only a snapshot in time. This study may serve as a model for future work examining soil health and food security for smallholder farmers in degraded areas of the tropics.

## REFERENCES

Bacon, C.M., W.A. Sundstrom, M.E.F. Gomez, V.E. Mendez, R. Santos, B. Goldoftas and I. Dougherty. 2014. Explaining the 'hungry farmer paradox': Smallholders and fair trade cooperatives navigate seasonality and change in nicaragua's corn and coffee markets. Glob. Environ. Change-Human Policy Dimens. 25:133-149.

Barrett, C.B. 2010. Measuring food insecurity. Science 327:825-828.

Beets, W.C. 1990. Raising and sustaining productivity of smallholder farming systems in the tropics : A handbook of sustainable agricultural development. AgBé Pub, Alkmaar, Holland.

Bharucha, Z. and J. Pretty. 2010. The roles and values of wild foods in agricultural systems. Philos. Trans. R. Soc. B-Biol. Sci. 365:2913-2926.

Bindraban, P.S., M. van der Velde, L. Ye, M. van den Berg, S. Materechera, D.I. Kiba, L. Tamene, K.V. Ragnarsdottir, R. Jongschaap, M. Hoogmoed, W. Hoogmoed, C. van Beek and G. van Lynden. 2012. Assessing the impact of soil degradation on food production. Curr. Opin. Environ. Sustain. 4:478-488.

Caswell, M., V.E. Méndez, J. Hayden, J. Anderzén, P. Merritt, A. Cruz, V. Izzo, S. Castro, J. Wiegel, A. Ospina and M. Fernandez. 2016. Assessing resilience in coffee-dependent communities of honduras, nicaragua and haiti . Rep. . RLG/LWR Research Brief #5.

Agroecology and Rural Livelihoods Group (ARLG), University of Vermont & Lutheran World Relief (LWR), Vermont.

Chicoine, A.L., T.M. Kemmer, M. Coello, R.M.M. Sevilla, S.V.P. Sepulveda and R.V. Arriaga. 2014. ELCSA, a survey for measuring household food security, reveals an extremely high prevalence of food insecurity in the montana de la flor and santa maria regions of honduras. Top. Clin. Nutr. 29:239-249.

Christou, P. and R. Twyman. 2004. The potential of genetically enhanced plants to address food insecurity. Nutr. Res. Rev. 17:23-42.

Doran, J. 2002. Soil health and global sustainability: Translating science into practice. Agric. Ecosyst. Environ. 88:119-127.

Ejeta, G. 2009. Revitalizing agricultural research for global food security. Food Secur. 1:391-401.

FAO. November, 2009. Declaration of the world summit on food security. Food and Agriculture Organization of the United Nations, Rome.

FAO. May 2012. *Escala latinoamericana y caribena de seguridad alimentaria (ELCSA): Manual de uso y aplicaciones.*. Food and Agriculture Organization of the United Nations, Rome.

FAO. 2013. The state of food and agriculture. FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO), Rome.

FAO. 2012. Committee on world food security: Thirty-ninth session. Food and Agriculture Organization of the United Nations, Rome.

FAO. 2008. The right to food and access to natural resources. Food and Agriculture Organization of the United Nations, Rome.

Friedman, D., M. Hubbs, A. Tugel, C. Seybold and M. Sucik. 2001. Guidelines for soil quality assessment in conservation planning. United States Department of Agriculture, Natural Resources Conservation Service, Soil Quality Institute.

Haney, R.L., E.B. Haney, L.R. Hossner and J.G. Arnold. 2010. Modifications to the new soil extractant H3A-1: A multinutrient extractant. Commun. Soil Sci. Plant Anal. 41:1513-1523.

Haney, R., E. Haney, L. Hossner and J. Arnold. 2006. Development of a new soil extractant for simultaneous phosphorus, ammonium, and nitrate analysis. Commun. Soil Sci. Plant Anal. 37:1511-1523.

Hertel, T.W. and S.D. Rosch. 2010. Climate change, agriculture, and poverty. Appl. Econ. Perspect. Policy 32:355-385.

Holt-Gimenez, E. and M.A. Altieri. 2013. Agroecology, food sovereignty, and the new green revolution. Agroecol. Sustain. Food Syst. 37:90-102.

Hurni, H., M. Giger, H. Liniger, R.M. Studer, P. Messerli, B. Portner, G. Schwilch, B. Wolfgramm and T. Breu. 2015. Soils, agriculture and food security: The interplay

between ecosystem functioning and human well-being. Curr. Opin. Environ. Sustain. 15:25-34.

Iqbal, M., H.M. van Es, Anwar-ul-Hassan, R.R. Schindelbeck and B.N. Moebius-Clune. 2014. Soil health indicators as affected by long-term application of farm manure and cropping patterns under semi-arid climates. Int. J. Agric. Biol. 16:242-250.

Maxwell, D. 1996. Measuring food insecurity: The frequency and severity of "coping strategies". Food Policy 21:291-303.

Mendez, V.E., C.M. Bacon, M. Olson, K.S. Morris and A. Shattuck. 2010. Agrobiodiversity and shade coffee smallholder livelihoods: A review and synthesis of ten years of research in central america. Prof. Geogr. 62:357-376.

Ministerio de Agricultura y Ganaderia (MAG). 2011. Plan de agricultura familiar y emprendedurismo rural para la seguridad alimentaria y nutricional 2011-2014. Gobierno de El Salvador, El Salvador.

Moebius, B.N., H.M. van Es, R.R. Schindelbeck, O.J. Idowu, D.J. Clune and J.E. Thies. 2007. Evaluation of laboratory-measured soil properties as indicators of soil physical quality. Soil Sci. 172:895-912.

Moebius-Clune, B.N., H.M. van Es, O.J. Idowu, R.R. Schindelbeck, J.M. Kimetu, S. Ngoze, J. Lehmann and J.M. Kinyangi. 2011. Long-term soil quality degradation along a cultivation chronosequence in western kenya. Agric. Ecosyst. Environ. 141:86-99.

Moebius-Clune, B.N., D.J. Moebius-Clune, B.K. Gugino, O.J. Idowu, R.R. Schindelbeck, A.J. Ristow, H.M. van Es, J.E. Thies, H.A. Shayler, M.B. McBride, D.W. Wolfe and

G.S. Abawi. 2016. Comprehensive assessment of soil health – the cornell framework manual. Rep. Edition 3.1. Cornell University, Geneva, NY.

Morris, K.S., V.E. Mendez and M.B. Olson. 2013a. "Los meses flacos': Seasonal food insecurity in a salvadoran organic coffee cooperative. J. Peasant Stud. 40:423-446.

Morris, K.S., V.E. Mendez, S.T. Lovell and M. Olson. 2013b. Conventional food plot management in an organic coffee cooperative: Explaining the paradox. Agroecol. Sustain. Food Syst. 37:762-787.

Padilla, C.D. and J.G. Suchini. 2001. Guía pare el sondeo agroecologico de suelos y cultivos. Rep. Manual Técnico; no. 112. Centro Agronómico Tropical de Investigación y Enseñanza (CATIE); Programa Agroambiental Mesoamericano, Turrialba, Costa Rica.

Panagos, P., K. Meusburger, M. Van Liedekerke, C. Alewell, R. Hiederer and L. Montanarella. 2014. Assessing soil erosion in europe based on data collected through a european network. Soil Sci. Plant Nutr. 60:15-29.

Perez-Escamilla, R., P. Paras, M. Julia Acosta, S. Peyrou, M. Nord and A. Hromi-Fiedler. 2011. Are the latin american and caribbean food security scale (ELCSA) items comparable across countries? Faseb J. 25.

Perez-Escamilla, R., M. Dessalines, M. Finnigan, H. Pachon, A. Hromi-Fiedler and N. Gupta. 2009. Household food insecurity is associated with childhood malaria in rural haiti. J. Nutr. 139:2132-2138.

Pinstrup-Andersen, P. 2009. Food security: Definition and measurement. Food Secur. 1:5-7.

Remans, R., D.F.B. Flynn, F. DeClerck, W. Diru, J. Fanzo, K. Gaynor, I. Lambrecht, J. Mudiope, P.K. Mutuo, P. Nkhoma, D. Siriri, C. Sullivan and C.A. Palm. 2011. Assessing nutritional diversity of cropping systems in african villages. PLoS One 6:e21235.

Robinson, D.A., N. Hockley, D.M. Cooper, B.A. Emmett, A.M. Keith, I. Lebron, B. Reynolds, E. Tipping, A.M. Tye, C.W. Watts, W.R. Whalley, H.I.J. Black, G.P. Warren and J.S. Robinson. 2013. Natural capital and ecosystem services, developing an appropriate soils framework as a basis for valuation. Soil Biol. Biochem. 57:1023-1033.

Rojas, R.V., M. Achouri, J. Maroulis and L. Caon. 2016. Healthy soils: A prerequisite for sustainable food security. Environ. Earth Sci. 75:180.

Ruel, M. 2003. Operationalizing dietary diversity: A review of measurement issues and research priorities. J. Nutr. 133:3911S-3926S.

Smith, P. and P.J. Gregory. 2013. Climate change and sustainable food production. Proc. Nutr. Soc. 72:21-28.

St Clair, S.B. and J.P. Lynch. 2010. The opening of pandora's box: Climate change impacts on soil fertility and crop nutrition in developing countries. Plant Soil 335:101-115.

Stocking, M. 2003. Tropical soils and food security: The next 50 years. Science 302:1356-1359.

Stott, D.E. and B.N. Moebius-Clune. 2017. Soil health: Challenges and opportunities. Global Soil Security109-121.

Verger, P.J.P. and A.R. Boobis. 2013. Reevaluate pesticides for food security and safety. Science 341:717-718.

Weil, R., K. R. Islam, M. A. Stine, J. B. Gruver and S.E. Samson-Liebig. 2003. Estimating active carbon for soil quality assessment: A simple method for laboratory and field use. American Journal of Alternative Agriculture 18:3-17.

WFP. February 2012. El salvador: Purchase for progress. World Food Programme, .

Zibilske, L. 1994. Carbon mineralization. methods of soil analysis: Part 2—Microbiological and biochemical properties. Soil Science Society of America Journal835-863.

Table 4.1. Summary of the Cornell Comprehensive Assessment of Soil Health (CASH) measured indicators used to evaluate soil health

| Indicator | Soil function evaluated | Type of scoring function | Scoring function (0-100)[1] | Sources for scoring function |
|---|---|---|---|---|
| PHYSICAL | | | | |
| Aggregate stability | Structural stability, runoff, erosion, infiltration | More is better | CND(31,18)*100[2]<br>CND(35,19)*100 | Moebius-Clune et al. 2016 |
| Surface hardness | Surface rooting, water infiltration and transmission | Less is better | (1-CND(164,94)*100 | Moebius-Clune et al. 2016 |
| BIOLOGICAL | | | | |
| Total organic matter | Water and nutrient retention | More is better | CND(3.07,0.86)*100<br>CND(3.99,0.99)*100 | CENTA[3] |
| Active carbon | Soil biological activity and biological nutrient mineralization | More is better | CND (500,185)*100<br>CND(575, 200)*100 | Moebius-Clune et al. 2016 |
| Soil respiration | Soil microbial community | More is better | CND(0.60,0.30)*100 | Moebius-Clune et al. 2016 |
| CHEMICAL | | | | |
| pH | Toxicity, chemical buffering, nutrient availability | Optimum | S= -63.1*(pH)2 + 844.5*(pH) – 2716.5 | Gugino et al. 2009; Moebius Clune 2010 |
| Extractable phosphorus | P availability | More is better | <1=0; 1-8 =25; 9-12 = 50; > 13 = 100 | CENTA |
| Extractable potassium | K availability | More is better | >74.5 = 100 | CENTA |
| Micronutrients:<br>Mg (meq 100g-1)<br>Mn (ppm)<br>Zn (ppm)<br>Fe (ppm) | Micronutrient availability | More is better | Mg < 2.1= 0; > 2.1= 100<br>Fe < 11= 0; > 11= 100<br>Mn < 5.1= 0; > 5.1= 100<br>Zn < 3.1= 0; > 3.1= 100 | CENTA |

[1] For indicators that were scored separately by soil textural category, the function for soils with clay<15% is listed first, followed by the function for soils with clay >15%.
[2] CND (m,s) = cumulative normal distribution, where m = mean, s = standard deviation.

[3] Centro Nacional de Tecnologia Agropecuaria y Forestal (CENTA) located in San Salvador, El Salvador

Table 4.2. Summary of soil health indicator results

| Soil Indicator | Farm 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 70.78 | 53.66 | 65.09 | 63.93 | 95.90 | 34.25 | 26.26 | 33.11 | 45.67 | 71.93 | 34.25 | 84.48 | 79.92 | 90.76 | 85.63 | 232.90 | 144.99 |
| SH[1] psi | ±37.73 | ±1.98 | ±45.31 | ±18.86 | ±9.69 | ±24.22 | ±1.98 | ±13.84 | ±3.95 | ±69.27 | ±13.70 | ±35.15 | ±26.16 | ±7.27 | ±33.91 | ±42.78 | ±34.98 |
| Mean | 38.90 | 67.32 | 67.38 | 47.33 | 51.88 | 48.65 | 64.80 | 56.66 | 29.24 | 75.91 | 75.73 | 43.04 | 55.37 | 46.27 | 28.19 | 47.78 | 28.31 |
| AS[2] (%) | ±12.48 | ±13.85 | ±12.37 | ±15.98 | ±10.72 | ±3.46 | ±12.18 | ±8.08 | ±5.27 | ±6.09 | ±10.94 | ±2.43 | ±6.54 | ±19.16 | ±9.08 | ±6.78 | ±6.29 |
| Active C | 574.16 | 693.88 | 718.39 | 733.94 | 680.11 | 521.63 | 535.74 | 529.33 | 475.39 | 673.77 | 697.07 | 723.28 | 740.91 | 568.04 | 539.52 | 582.86 | 460.36 |
| mg C/ kg | ±81.83 | ±53.35 | ±55.61 | ±94.24 | ±28.70 | ±78.10 | ±62.13 | ±134.54 | ±28.61 | ±134.54 | ±47.70 | ±59.54 | ±145.34 | ±57.41 | ±64.52 | ±107.44 | ±83.59 |
| Mean SR[3] mg $CO_2$ | 0.47 | 0.70 | 0.64 | 0.63 | 0.58 | 0.78 | 0.51 | 0.52 | 0.54 | 0.51 | 0.54 | 0.59 | 0.69 | 0.56 | 0.40 | 0.40 | 0.39 |
| /g soil | ±0.02 | ±0.12 | ±0.09 | ±0.21 | ±0.08 | ±0.02 | ±0.12 | ±0.17 | ±0.09 | ±0.11 | ±0.12 | ±0.01 | ±0.07 | ±0.09 | ±0.03 | ±0.05 | ±0.09 |
| | 6.00 | 6.32 | 6.54 | 6.58 | 6.54 | 5.52 | 5.35 | 5.31 | 4.96 | 5.18 | 4.76 | 5.52 | 5.54 | 5.50 | 5.68 | 5.42 | 5.55 |
| Mean pH | ±0.10 | ±0.06 | ±0.03 | ±0.09 | ±0.04 | ±0.01 | ±0.22 | ±0.37 | ±0.44 | ±0.33 | ±0.11 | ±0.31 | ±0.65 | ±0.02 | ±0.11 | ±0.09 | ±0.01 |
| Mean P | 26.13 | 8.47 | 2.67 | 5.67 | 39.00 | 1.90 | 0.76 | 2.13 | 3.56 | 6.06 | 0.40 | 0.40 | 0.97 | 0.40 | 9.00 | 7.00 | 2.00 |
| ppm | ±34.24 | ±7.42 | ±2.89 | ±7.23 | ±52.33 | ±1.00 | ±0.49 | ±2.07 | ±1.00 | ±1.23 | ±0.00 | ±0.00 | ±0.87 | ±0.00 | ±4.36 | ±3.00 | ±1.73 |
| Mean % | 3.91 | 4.60 | 6.07 | 5.38 | 5.04 | 4.35 | 4.69 | 4.37 | 3.68 | 7.54 | 10.40 | 5.98 | 6.99 | 4.83 | 3.91 | 4.19 | 3.68 |
| OM | ±0.56 | ±0.57 | ±1.46 | ±1.63 | ±0.10 | ±0.29 | ±0.55 | ±0.66 | ±0.21 | ±2.93 | ±0.16 | ±0.42 | ±0.92 | ±0.58 | ±0.94 | ±0.91 | ±0.80 |
| Mean K | 351.53 | 295.43 | 532.30 | 452.33 | 374.00 | 292.75 | 232.07 | 314.20 | 202.87 | 264.90 | 143.53 | 158.07 | 269.47 | 177.05 | 258.33 | 239.63 | 200.30 |
| meq/100g | ±108.42 | ±82.92 | ±139.85 | ±25.70 | ±16.69 | ±0.21 | ±54.39 | ±122.56 | ±36.16 | ±38.64 | ±17.83 | ±42.86 | ±26.41 | ±27.51 | ±42.33 | ±4.09 | ±20.49 |
| Mean Mg meq/100g | 4.37 | 5.04 | 4.86 | 5.10 | 5.47 | 2.09 | 2.60 | 2.56 | 0.94 | 1.12 | 3.68 | 6.20 | 5.54 | 5.68 | 1.74 | 2.30 | 3.08 |
| Mean Fe ppm | 16.51 | 18.63 | 6.48 | 17.43 | 12.04 | 53.42 | 41.32 | 51.82 | 87.28 | 48.88 | 17.78 | 19.81 | 24.54 | 19.49 | 27.98 | 28.62 | 49.86 |
| Mean Mn ppm | 26.24 | 28.26 | 23.18 | 26.24 | 30.35 | 39.49 | 29.24 | 33.26 | 23.49 | 13.49 | 4.17 | 31.72 | 31.11 | 24.34 | 24.22 | 19.27 | 25.08 |
| Mean Zn ppm | 1.81 | 2.93 | 2.23 | 2.05 | 2.88 | 1.53 | 1.62 | 4.29 | 2.57 | 1.42 | 1.22 | 0.98 | 1.28 | 2.01 | 1.20 | 0.98 | 1.03 |

[1]SH = Surface hardness

[2]AS = Aggregate stability

[3]SR = Soil respiration

Table 4.3. Summary of household food insecurity assessment and farm level soil health scores across 17 farms in northeastern El Salvador

| Farm | Food Insecurity Scale[1] | # Hungry Months[2] | Cornell Soil Health Score[3] (0-100) |
|---|---|---|---|
| 1 | Light | 0 | 64.51<br>High<br>Possible limitation: soil respiration |
| 2 | Moderate | 3 | 84.41<br>Very High |
| 3 | Light | 1 | 72.79<br>High<br>Possible limitations: low P, low micronutrients |
| 4 | Moderate | 2 | 76.7<br>High |
| 5 | Moderate | 2 | 76.79<br>High |
| 6 | Light | 1 | 59.46<br>Medium<br>Constraint: low pH<br>Possible limitations: low P, low micronutrients |
| 7 | Severe | 3 | 60.01<br>Medium<br>Constraints: low pH, low P<br>Possible limitations: soil respiration |
| 8 | Moderate | 2 | 62.13<br>High<br>Constraints: low pH; low P |
| 9 | Severe | 3 | 44.55<br>Medium<br>Constraint: low pH<br>Possible limitations: low P, low micronutrients |
| 10 | Moderate | 2 | 59.56<br>Medium<br>Constraints: low pH; low micronutrients<br>Possible limitations: soil respiration |
| 11 | Light | 1 | 63.31<br>High<br>Constraints: low pH; low P |
| 12 | Moderate | 2 | 56.41<br>Medium<br>Constraints: low pH; low P |
| 13 | Light | 1 | 64.01<br>High<br>Constraint: low P<br>Possible limitations: low pH |
| 14 | Light | 1 | 53.95<br>Medium<br>Constraints: low pH; low P |
| 15 | Severe | 3 | 46.38<br>Medium<br>Constraint: low micronutrients<br>Possible limitations: low pH; soil respiration |
| 16 | Severe | 3 | 44.92<br>Medium<br>Constraint: low pH<br>Possible limitations: surface hardness soil respiration; low P |
| 17 | Moderate | 4 | 42.55<br>Medium<br>Constraint: low pH<br>Possible limitations: soil respiration, low P |

[1] Latin American and Caribbean Food Insecurity Experience Scale (ELCSA)
[2] Months of Inadequate Household Food Provisioning (MIAHFP
[3] Cornell Comprehensive Assessment of Soil Health (CASH; Moebius-Clune et al. 2016)

Table 4.4. Summary of group means from soil health indicators utilized as predictor variables in the discriminate analysis to verify if the different food insecurity (FI) groups can be accurately predicted by a variety of soil health indicators.

| Count | FI Scale | AS[1] % | AC[2] mg C/kg | SR[3] Total mg $CO_2$ /g soil | pH | P ppm | K ppm | Ca meq/100g | Mg meq /100g | Na meq/100g | CEC | %BS | %OM | Cu ppm | Fe ppm | Mn ppm | Zn ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 1 | 55.38 | 636.70 | 0.62 | 5.63 | 5.42 | 294.45 | 11.88 | 4.38 | 0.23 | 18.12 | 92.13 | 6.08 | 0.88 | 23.03 | 24.75 | 1.67 |
| 7 | 2 | 52.91 | 642.10 | 0.56 | 5.86 | 9.11 | 294.17 | 12.10 | 4.09 | 0.20 | 17.80 | 93.74 | 5.23 | 1.41 | 31.20 | 26.91 | 2.21 |
| 4 | 3 | 42.50 | 533.38 | 0.45 | 5.35 | 5.10 | 233.23 | 9.03 | 1.88 | 0.15 | 12.78 | 87.25 | 4.13 | 0.90 | 46.30 | 24.05 | 1.60 |

[1]AS = Aggregate stability
[2]AC = Active carbon
[3]SR = Soil respiration

Table 4.5. Summary of Salvadoran smallholder subsistence farmers’ seasonal calendar. The shaded months represent the “hungry months” or lean season. Figure was adapted and modified from Bacon et al. (2014) and Morris, Mendez, Olson (2013).

| Farm/Household Activities | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Corn planting (2 cycles) | | | | | X | X | | X | X | | | |
| Corn weeding & fertilizing (buying herbicides and fertilizers) | | | | | | X | X | X | X | | | |
| Corn harvesting | | | | | | | | | X | X | X | |
| Bean planting (2 cycles) | | | | | | X | | | X | | | |
| Bean weeding (buying herbicides) | | | | | | X | X | X | X | X | | |
| Bean harvesting | | | | | | | | | | X | X | X |
| Canicula (mid season dry period) | | | | | | X | X | | | | | |

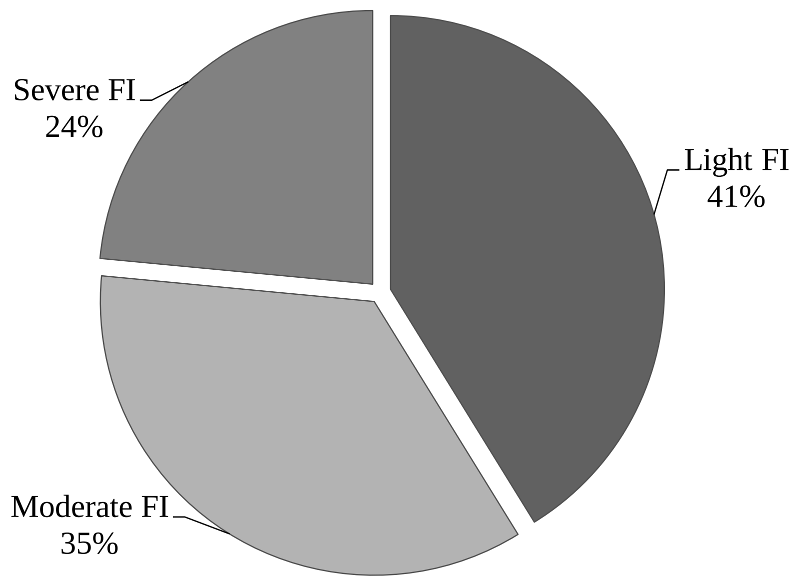


Figure 4.1. Results of food insecurity (FI) surveys conducted in northeastern El Salvador with 17 subsistence farming households using the Latin American and Caribbean Food Insecurity Experience Scale [Escala Latinoamericana Y Caribeña de Seguridad Alimentaria (ELCSA)

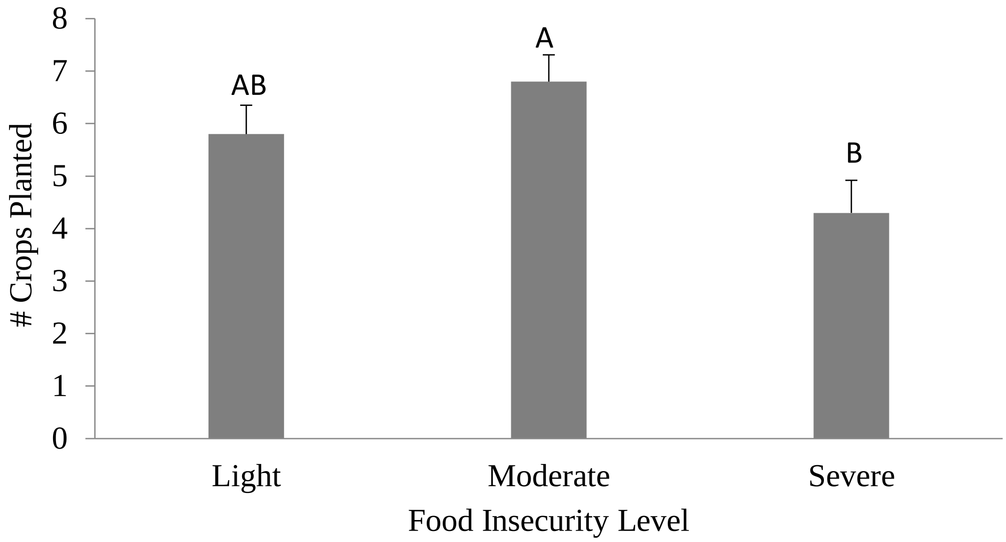


Figure 4.2. Number of total different types of crops planted per household as compared to household food insecurity levels for 17 subsistence farming households in northeastern El Salvador (*P*= 0.023)

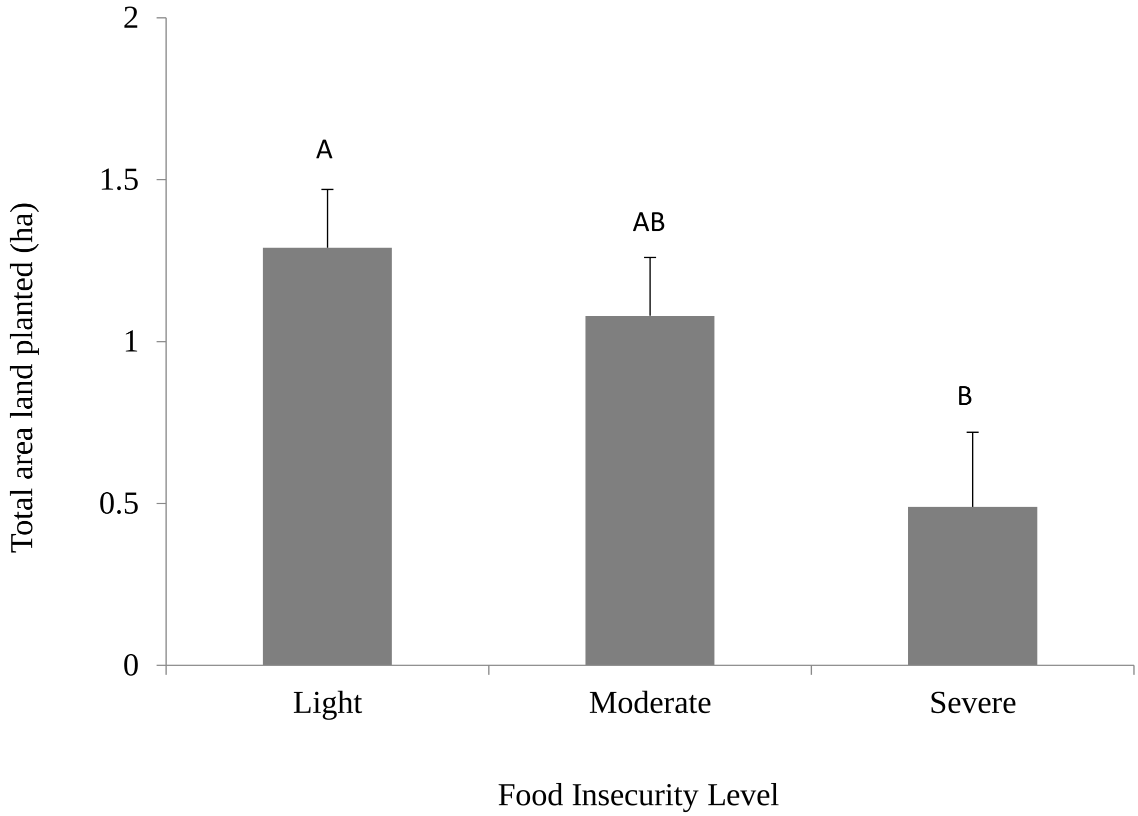


Figure 4.3. Total area land planted with corn and beans per household as compared to household food insecurity levels for 17 subsistence farming households in northeastern El Salvador (*P*= 0.048)

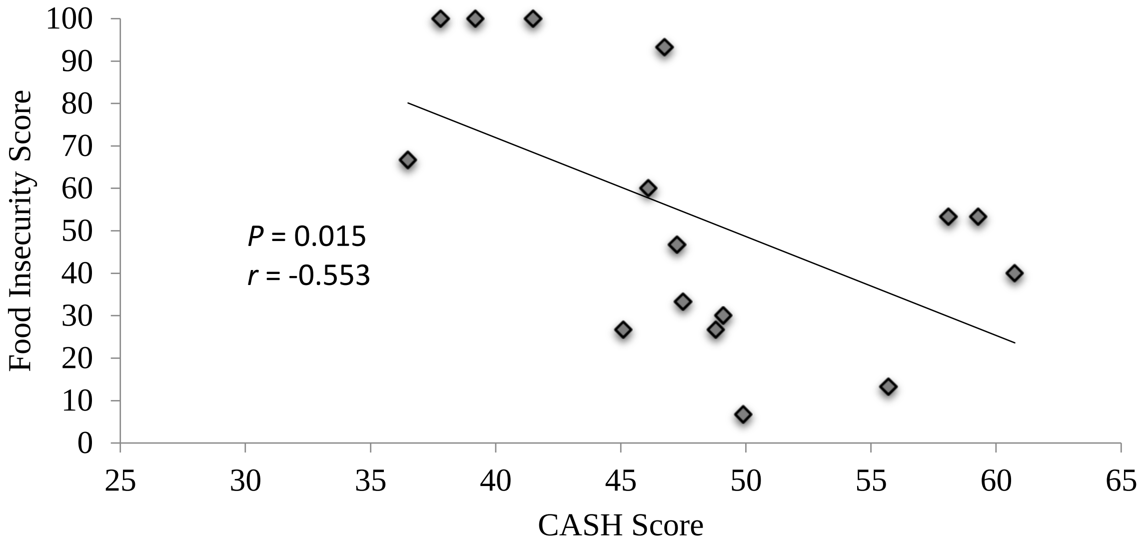


Figure 4.4. Household food insecurity score compared to the overall farm Cornell CASH soil health score for 17 subsistence farming households in northeastern El Salvador. Correlation was calculated using Pearson's correlation.

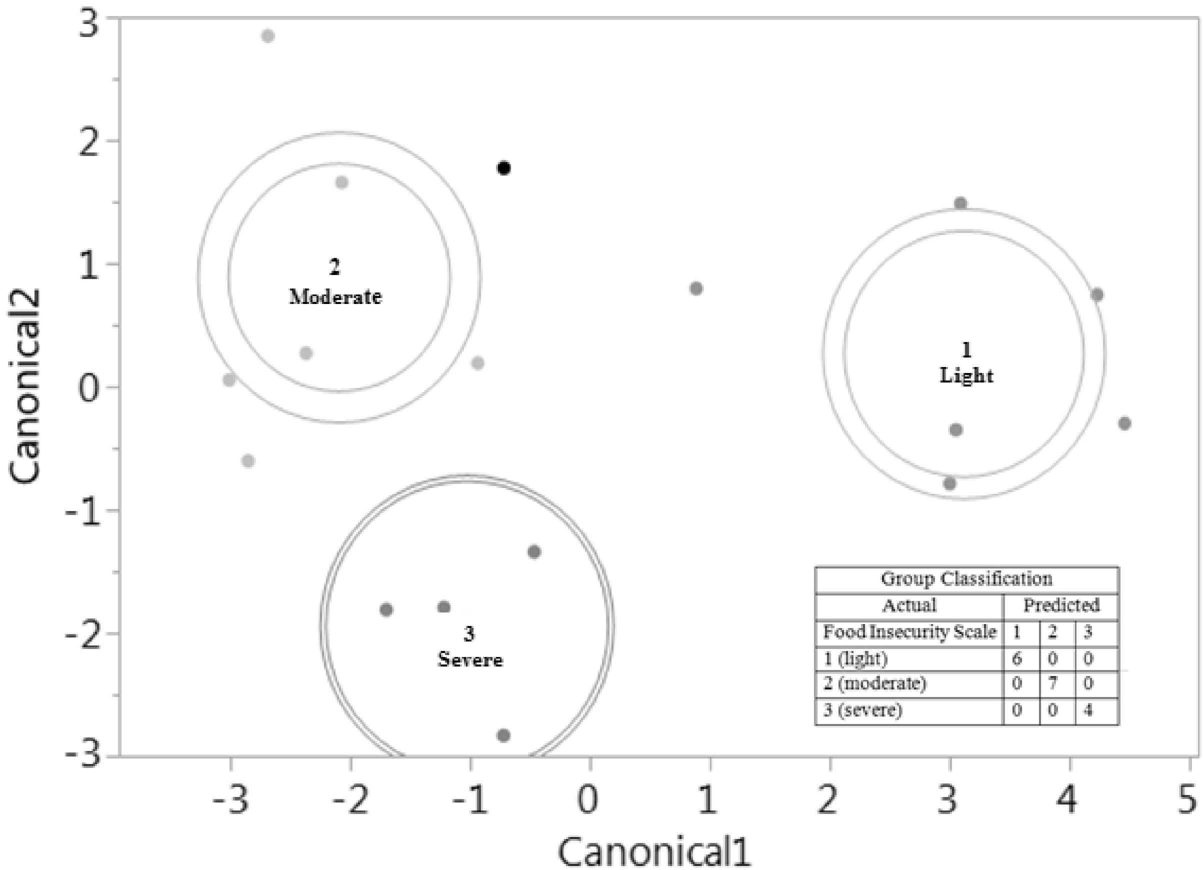


Figure 4.5: Results from a discriminate analysis conducted to determine with what accuracy soil health indicators of a farm could predict the food security grouping of that farm household (N=17). The following soil health indicators were included in the analysis as the predictor variables: aggregate stability, active carbon, soil respiration, pH, P, K, Ca, Mg, Na, CEC, % BS, % OM, Cu, Fe, Mn, Mg, Zn. The groupings were determined based on the results of the household food security surveys

# V. An Example for Integrating Field Trials and Participatory Action Research

**Abstract**

Smallholder farmers make up a significant portion of the world's population, representing 85% of the world's farms. Agricultural outreach and education programs for smallholder farmers have been cut in many countries and research has shifted to focus on large-scale export crops and breeding programs, further marginalizing smallholder farmers. Sustained improvement to the livelihoods of poor farmers requires a different type of approach and focus in agricultural research. Participatory Action Research (PAR) is engaged research that aims to benefit all people involved, build collaborative relationships between researchers and participants, and facilitates reflection by all parties. The overall goal of this paper was to apply the key principles of PAR processes to a field trial case study, where farmers are fully involved from the research design to the evaluation of data. The specific objectives of this field trial was to assess, from the perspective of farmers and researcher, if incorporating soil conservation and organic fertility treatments into traditional hillside corn farming systems impacted corn growth and yield. The experiment consisted of a fully factorial design with two levels of soil conservation and two levels of organic fertility addition, carried out in the fields of the eight farmers, so that the farm was the experimental unit, with a total of eight replications. Results from both the farmer evaluations and researcher data demonstrate that the soil conservation treatment improved whole ear weight of corn. Furthermore, farmers chose the organic fertility and soil conservation techniques as their treatments and were part of the research process and evaluation, demonstrating new ways to evaluate farm trials from a farmer perspective. This study adds an important perspective from the farmers about these soil conservation and organic fertility strategies.

## 1. Introduction

Smallholder farmers make up a significant portion of the world's population, with approximately 450-500 million smallholder farmers worldwide, representing 85% of the world's farms (Nagayet, 2005). Moreover, smallholder farmers are thought to represent half of the world's hungry (Sanchez and Swaminathan, 2005). Thus, the fate of smallholder farmers is tied to reducing poverty and hunger worldwide and achieving global food security. Despite years of technological advances and millions invested in research and education, hunger and malnutrition are prevalent, food insecurity is increasing globally (FSIN, March 2017) and environmental degradation on farmland continues. There is growing consensus that the industrial food system model has been destructive for rural communities and smallholder farmers in developing countries (Gliessman, 2009; Gliessman, 2012; Vanhaute, 2010). The production methods advocated by conventional agriculture disrupt traditional livelihoods and accelerate indebtedness while increasing the risk of the small farmer (Altieri, 2009). Moreover, agricultural outreach and education programs for smallholder farmers have been cut in many countries and research has shifted to focus on large-scale export crops and breeding programs, further marginalizing smallholder farmers. Thus, much of the current agricultural research and extension programs are not benefiting the smallholder farmer in developing countries.

Sustained improvement to the livelihoods of poor farmers in developing countries, many located in tropical regions, requires a different type of approach and focus in agricultural research. It should enhance the capacity of rural people to adapt to changing conditions, rather than delivering "finished technologies" (Sayer and Campbell, 2001). Sayer and Campbell (2001) identified participatory approaches to research as crucial for increased adoption by farmers. Participatory Action Research (PAR) is engaged research that aims to benefit all people involved, build collaborative relationships between researchers and participants, and facilitates reflection by all parties (McIntyre, 2008). It emerged as a response to the traditional top-down approach to rural development and agricultural research (Ellis, 2000). By involving community members or farmers in the research process, participatory methods have the potential to generate more appropriate and long-term solutions and adoption than top-down extractive research, since participants have ownership and investment in the project (Mayoux and Chambers, 2005).

In the last 20 years, PAR has gained support as a valid and important research approach in a variety of disciplines (Kindon et al., 2007). Although PAR is most commonly practiced in the social sciences, it is becoming more utilized in natural resources and agricultural fields (Castellanet and Jordan, 2002). Participatory action research approaches and methodologies are more common in the field of agroecology research which promotes the blending of local knowledge and scientific knowledge (Altieri, 1999; GREENWOOD et al., 1993; Guzman et al., 2013b; Kindon et al., 2007). Participatory agricultural projects, for example, utilize external technologies and innovations when appropriate to enhance rather than replace local capacity and technologies (Guzman Casado et al., 2000). However, PAR approaches have been used in a various ways in research, some involving farmers in the whole process and some just utilize on-farm research. Truly participatory projects involve local people and organizations not only in the collection of information but also in project planning, design, and monitoring (Guijt, 1998). A key criterion in any PAR process is that participating community members make decisions and determine the direction a project takes, and projects are designed with participants based on their needs and priorities (Selener 1997). A recent review of PAR identified some key principles of successful PAR processes (Mendez et al., 2017) that include:

- Shared interest in research – All partners in the PAR process are convinced the research beneficial and contributes to their interests.
- Belief in collective power – All partners in the process are valuable contributors and share ownership and decision making abilities.
- Commitment to participation – All partners are fully engaged, moving beyond just showing up, and participate in the research design, data collection, analysis and action steps.
- Trust and accountability – Trust is the base for collaboration among all partners and leadership is shared.
- Humility – The limitations of each partners' knowledge is acknowledged, as well as the expertise of each partner
- Communication – The voices of those traditionally marginalized or ignored are included and results are disseminated in multiple formats to increase accessibility.

However, PAR models are still by no means mainstream methods of research (Probst 2002). Compared to traditional research methods and rural development, there has been relatively little research on PAR and its implementation in agriculture, especially in field and farm settings. Moreover, few studies have documented the unique opportunities and challenges of utilizing a PAR process in agricultural research, and there is no clear consensus on how to integrate participatory research methods with traditional agronomic research. Therefore, the overall goal of this paper was to apply the key principles of PAR processes to a field trial case study, where farmers are fully involved from the research design to the evaluation of data. Furthermore, few studies have examined techniques for improving smallholder production from the perspective of the farmers. It is important to identify which challenges, solutions, and opportunities farmers actually perceive, as only the perception of an impact will lead farmers to make changes in production (Bacon et al., 2005).

The specific objectives of this study was to assess, from the perspective of farmers and researcher, if incorporating soil conservation and organic fertility treatments into traditional hillside corn farming systems impacted corn growth and yield. The research process was a PAR process from beginning to end with the end goal of improving production for smallholder farmers.

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## 2. Background and research approach

El Salvador was chosen as a research location because the majority of agricultural output in the country is produced by smallholder farmers (Arias Penate, 2014) and improving yield for smallholder farmers could have a national impact. Furthermore, soil erosion and degradation is a major environmental threat in El Salvador that has required the country to take a nation-wide investment in decreasing erosion and improving sustainable agriculture production. Thus, understanding how to effectively and appropriately improve soil conservation and fertility techniques on smallholder farms is a critical need in El Salvador. In addition, the lead researcher had an established relationship and built a foundation of mutual trust with a local non-governmental organization, Fundacion Hermano Mercedes Ruiz (FUNDAHMER) and farmers in the area, facilitating the development of the PAR process in this research.

*2.1. Timeline*

To better define the process, it is divided into four phases (Figure 5.1), based on the work outlined in (Guzman et al., 2013b), including an initial reflection phase (phase 1), diagnostic phase (phase 2), research and reflection phase (phase 3) and an action phase (phase 4). The focus for this paper is phase four (action phase) of the PAR process and the description of the first three phases will be condensed (see Chapters 2, 3 and 4 for more details of the first three phases). In addition, reflection with farmers and researchers was intentionally built into all four phases, emphasizing that neither the research nor the action cycles are complete without reflection. The reflection component of all PAR processes is key to addressing issues of power, knowledge and subjectivity. Throughout the research process a session of reflection was held with participants in order to discuss a number of topics, including research questions, design, power relations, learning processes, participation, etc. (Kindon et al., 2007).

<u>2.2.1. Phase 1 – Reflection: Building relationships, understanding context (2013-2014)</u>

The first phase of the PAR process involved exploratory research with farmers and the partner organization, FUNDAHMER to establish research opportunities, roles and potential objectives. The lead researcher reached out to the leaders at FUNDAHMER to act as potential collaborators in the research process. The organization was selected for its deep and long history of working with smallholder farmers in the northeastern part of El Salvador for more than twenty years and success in organizing farmers. The relationship with FUNDAHMER was transparent. The lead researcher explained personal benefits of the research, and how the potential research could benefit the organization and farmers. FUNDAHMER outlined areas of need for both the organization and for the farmers and helped organize listening sessions with farmers. This phase of the PAR process has also been called “preflection” because it is a period of preparation and planning, critical for building trust, establishing expectations, and refining the research questions (Mendez et al., 2017).

#### 2.2.2. Phase 2 – Diagnostic: Conducting research surveys (2014-2015)

This phase consisted of the lead researcher conducting semi-structured interviews with both male and female heads of household for 43 regional farms. The interviews gathered data on household demographics, migration, household infrastructure, farm management, and production (see Appendix A for survey). Questions also focused on farmer perceptions of challenges to production and feeding their family, as well as gauging farmer interest in learning and trying new agricultural production techniques. It was clear that farmers perceived lack of fertilizers and climate change to be the main constraints to improving production. However, from a researcher perspective, farmers were applying sufficient fertilizers and another agronomic factor is limiting yields. Farmers showed an interest in trying out organic fertilizers as a potential alternative fertilizer and a method to save money.

In addition, from a researcher perspective after visiting the farms and conducting the interviews, soil conservation techniques appeared to be rarely utilized on the land of younger farmers, but from the steeply sloping land and heavy rains, soil conservation could have significant impacts on improving yields and decreasing environmental degradation. Surveys showed farmers to have moderate interest in applying soil conservation techniques on their farms (see Chapter 2 for detailed results).

### 2.2.3. Phase 3 – Research and Reflection: Focus Groups, Discussions with FUNDAHMER, Soil tests (2015)

This stage of the PAR process had two main objectives: 1) continue the reflection process through focus groups with the farmers to share the results of the interviews and confirm results; 2) conduct soil tests on a subset of farms from the region, in order to better understand potential soil constraints to production.

A year after the initial interviews, focus groups (see Chapter 2 for details on focus groups) were conducted to discuss results from the interviews and identify main perceived challenges to improving production and household food security. During the focus groups, farmers had the opportunity to ask questions about their yield data and use of agrochemicals and discuss the reactions as a group. Conducting the focus groups a year after the interviews also helped understand if perceived challenges to production and household food security might change from year to year. Confirming the survey results, farmers agreed that fertilizers (specifically money to buy more fertilizers) were a main limitation to production, as well as the unpredictable climate resulting from climate change When the lead researcher discussed the finding that farmers were applying sufficient nitrogen fertilizers, farmers disagreed with this, but agreed they would like to try organic fertility sources in order to save money.

The second objective, in depth soil testing on a subset of farms (N=17), was more research focused, but was conducted with the hopes of better understanding potential soil related production constraints for smallholder farmers in the region. The soil testing demonstrated that production constraints on the farm were mostly chemical and sometimes physical on many farms and that increasing addition of organic matter had high potential for improving overall soil health on the farms.

2.2.4. Phase 4 – Action: participatory field trials with farmers (focus of current study; 2016)

This stage (the stage the current study focuses on) was built upon the results of the previous three phases and would not have been possible without the research, reflection and action that resulted from the first three phases of this PAR process. After farmers had expressed interest in learning about and utilizing organic fertilizers and the researcher had documented over-use of synthetic N fertilizers, it was decided the next action step would be to do field trials with different fertility and conservation strategies. This phase focused on the implementation of these on-farm field trials with a subset of regional farmers (N=8). The first task was to identify “testers” or farmer participants that were willing to engage in experimentation, with the hope that it would lead to adoption of studied practices for other community members as they observed the outcomes on the farms of the testers (Mendez et al., 2017) who then voted on the details of the field trial treatments. The specific methods and results of these field trials are outlined in this paper, as well as the opportunities and challenges of utilizing a PAR process for the research (see Figure 5.2 for details of each step in this PAR phase).

*2.2. Application of PAR key principles*

a) *Shared interest in research* – The lead researcher pursued a relationship with FUNDAHMER and local farmers from the beginning of the process and all partners were involved in setting the research objectives. Partners understood the value of the agricultural research and shared an interest in improving agroecological production for smallholder farmers. However, because not all parts of the research were of interest or benefit to the partners, it was important to continually negotiate a mutually beneficial relationship for all parties involved. For example, in depth soil health testing was conducted on all farms participating in the field trials. To ensure the soil testing was of benefit to the farmers, the lead researcher met with all farmers and went over their soil test results and management recommendations. In addition, all partners involved received copies of soil testing results and personalized management recommendations for all farms.

b) *Collective power* – For the success of the on farm field trials, it was important to establish tangible benefits to participation for all parties. Furthermore, almost all decision making was done collectively, and researchers and farmers were part of setting the research objectives, designing the experiment and evaluating the results (see Figure 5.2).

c) *Commitment to participation* – Levels of participation and commitments changed as the research process evolved. For the on farm field trials portion of the research, farmers and researcher negotiated full participation early on and all farmers agreed to participate knowing the details of the commitment. Establishing mutually beneficial goals was essential to guarantee full farmer participation.

d) *Trust and accountability* – Starting with the first meeting, the researcher described the study openly. Farmers and researcher created goals to be accountable for each month. The commitment to accountability was re-visited on a monthly basis in the regular farmer workshops and reflection meetings. Farmers provided updates and lessons learned on their own farms each month as a related to the project objectives, which proved to be a method to build trust in the group and create a space for accountability. The lead researcher visited each farm and farmer on a regular basis, helping establish a relationship built on trust.

e) *Communication* – The commitment to clear and constant communication was made early on. It required a significant time commitment for the researcher, in phone calls and in-person farm visits to often distant farms. In addition, it was important to facilitate communication for the farmers, sometimes providing transportation or meals after they walked long distances to attend meetings.

## 3. Methods

### *3.1. Description of study area*

The study was conducted between April and October 2016 on eight farms located in the municipality of Cacaopera (13.7721° N, 88.0766° W) in the Department of Morazán in the northeastern part of El Salvador. Soils in the study area are classified as Andic Argiustolls within the USDA soil taxonomy system and are well-drained Mollisols with high organic matter. The climate in El Salvador is a rainy season between May and October and a dry season with no rain from November through April. Average annual precipitation is approximately 2000 mm (Ministerio de Medio Ambiente Y Recursos Naturales (MARN), 2015). The natural vegetation of the region is classified as a humid, subtropical forest. All farms were located at elevations between 500 and 800 meters above sea level (masl) and were between 5 and 10 km from a town with dirt roads, intermittent access to electricity and no running water. Electricity is available to the households that are closest to the main road, but the majority of households did not have electricity. The farming communities have schools up to 6th grade.

All households in the study maintain subsistence plots of corn and beans, referred to as *milpas*, which are staples in their diet and some plots contain a small amount of other vegetables for consumption or occasional sale. Some families sell corn and beans, if there is excess yields, while others only grow it for their own consumption. These milpa plots are commonly located on steep slopes with maize and beans intercropped. Average farm size in El Salvador is 0.7 ha with an average of 6 people per household (Ministerio de Economia, 2009).

### *3.2. Experimental design*

Eight farmers were selected and agreed to participate in the Cacaopera municipality of Morazán based on interviews, as well as interest and willingness to try new techniques. Young farmers were the target audience because FUNDAHMER had previously identified the need for young farmers to increase awareness and application of soil and water conservation techniques. The goal was to have representation from both male and female farmers, as well as households that vary according to a number of important criteria, including family size, off-farm employment status, and educational status. Each farmer committed to growing four trial plots (25 $m^2$) during the 2016 growing season.

The experiment consisted of a fully factorial design with two levels of soil conservation (+ SC; - SC) and two levels of organic fertility addition (+ORG; -ORG), carried out in the fields of the eight farmers, so that the farm was the experimental unit, with a total of eight replications. Treatments for the farm experiments were collectively selected by the farmers from a selection of scientifically proven best practices by the University of El Salvador for hillside farming in the tropics (Table 5.1). Farmers chose two best practices to implement on the trial plots on their farms (see Figure 5.2 for detailed process), including one organic fertility practice, addition of bokashi (+ ORG), and one soil conservation practice, known in Latin America as *acequias* (+ SC), and often referred to in English as contour ditches. Each plot was randomly assigned a location at each farm chosen by the farmer and verified by the researcher. For the two plots with no added organic amendments (-ORG) a 15N-15P-15K fertilizer was used to add the equivalent of 100 kg N $ha^{-1}$ of fertilizer per plot. Synthetic fertilizer was applied by hand at the surface (in the traditional method for the region): half at 2 weeks after planting and half at flowering. This level of fertilizer was added based on previous research in the area (see Chapter 2) and was the average amount of fertilizer applied by farmers in the area. For the two plots with added organic amendments (+ORG), half of the synthetic fertilizer was added with the 15N-15P-15K fertilizer, for a total of 50 kg N $ha^{-1}$. In addition, the equivalent of 25 kg N $ha^{-1}$ and 24 kg P $ha^{-1}$ was added to the +ORG plots the day of planting in the form of bokashi. The organic bokashi amendment had the following makeup: 1.24% N, 0.78% P, 1.56% K, 5.17% Ca, 0.81 % Mg, 34 ppm S, 3.61% Fe, 42 ppm Cu, 822 ppm Mn, and 8.23 pH. The +ORG and –ORG plots had different levels of total N and P added, but the lower amounts (in the –ORG) plots were still more nutrients than needed with the expected yield.

Bokashi, an organic fertilizer used widely in Latin America, is derived from a Japanese technique where organic matter is fermented with the addition of yeasts and sugars (Boechat et al., 2013). Bokashi is versatile as it can be prepared by mixing almost any available agricultural byproduct with yeasts, usually common bread yeasts, and sugar from sugarcane (Boechat et al., 2013). Studies have shown that the decomposition of the bokashi, that can include animal manures or plant residues, increases diversity of the microbial community (Park and Kremer, 2010) +increases P and N nutrients, and increases organic carbon (Pacheco Lima et al., 2015). Moreover, most of these byproducts are readily available in most rural areas, making bokashi a sought after organic amendment that can be prepared in situ at very low cost and by farmers directly. The bokashi in this study was made with all local ingredients, including cow manure, chicken manure, corn stover, sugar, bagasse from sugar cane, locally made charcoal and ashes, as well as egg shells. The contour ditches (*acequias*) constructed for the plots with soil conservation were dug 10 cm above each trial plot following local recommendations (a trench 20 cm deep by 20 cm wide). Across all plots, soil response variables (Table 5.2) were measured before planting and then again after harvest including infiltration rates, earthworm counts, and erosion rates. In addition, various crop response (Table 5.2) variables were measured on each trial plot throughout the growing season including: soil available water, crop growth rates, and plant shoot nutrients. Soil samples were taken before planting and at harvest for analyses. Farmers were trained to collect the in-field analyses and assisted the lead researcher all research data collection. During the growing season, each farm hosted one farm tour where all participant farmers had the chance to visit each farm with on-farm research and participant farmers shared their experiences with bokashi and contour ditches with other farmers. At the end of the growing season, a participatory evaluation was conducted, reviewing the data, skills learned, and overall process. In addition, farmers ranked the different techniques on the trial plots according to their perceived benefits and feasibility.

The on-farm field trials were designed to not only improve yields and fertilizer use for farmers, but also to conserve natural resources. Field visits by the researcher were done once or twice monthly and information-sharing and reflection meetings with farmer participants were held monthly. Field notebooks and evaluation sheets (Figure 5.3) were given to each farmer to record data. At the end of the crop season, results were shared and evaluated using criteria developed by the farmers. Most of the experimental design – planting date, planting distance, corn variety – were discussed among all farmers and decided by consensus (see Figure 5.2).

### *3.4. Participatory farmer evaluations*

The basic assumption of farmer led-experimentation is that the farmer is an important evaluator for selection of research criteria and responses. The farmers who participated in the evaluation exercises were the same farmers participating in the field trials and part of the monthly reflection and information sharing gatherings. Farmer participatory evaluations were conducted using a one to five (with five being the highest) Likert scale. The evaluations of each field trial (N=8) were all conducted on a single day with all the farmers evaluating each field trial. Group field evaluations were conducted twice during the growing season. The monthly reflection meetings were used to develop the criteria that farmers used in the participatory evaluations. Farmers voted to evaluate the field trials during growing season based on five indicators (Table 5.1): corn height, stalk width, leaf color, and soil moisture. At the end of the growing season, farmers evaluated the field trials based on three indicators: overall corn yield, whole ear size, whole ear weight.

### *3.5. Corn selection, planting and response variables*

A local variety of *criollo* yellow corn seed (*maiz amarillo*) was planted on all farms the first week of June 2016 and harvested the last week of September 2016. Participating farmers voted to adhere to the local traditional planting practice, with a planting distance of approximately 70 cm between planting rows and 50 cm between plants and were hand planted with the traditional method, planting three corn seeds in each hole. Plant height, measured to the last fully extended leaf, was measured at the V6, V8, and V10 growth stages. Five plants were randomly selected from the inner rows of each plot to measure height. At V8, the two youngest and fully expanded leaves of five different plants on each plot were cut and sent to the laboratory at the Salvadoran National Center for Agricultural and Forestry Technology (Centro Nacional de Tecnologia Agropecuaria y Forestal – CENTA) located in San Salvador, El Salvador for percent nitrogen analysis.

### *3.6. Soil sampling and soil health analyses*

Initial soil samples were collected in May of 2016 before planting and the final soil samples were collected after harvest over a 10 day period between the end of September and first week of October 2016. At each farm, each plot was sampled. Each sampling location consisted of taking ten 0 -15 cm samples with a soil auger, compositing these samples, mixing thoroughly and sub-sampling a ~1L volume of soil for analyses. At each sampling location, a Garmin GPSMAP 64s handheld GPS was used to record location and elevation. A Suunto PM-5 Clinometer (Vantaa, Finland) was used to measure slope at each sampling location. Surface (0-15cm) penetration resistance was assessed using a pocket penetrometer (ELE International). The mean penetration resistance of five sampling points was recorded. Earthworm populations were measured within a 25 $cm^2$ area (25cm x 25cm) and a depth of 25 cm. All the soil in the observed area was removed and sieved for earthworms and the total number of earthworms present was recorded. Infiltration was measured using a single ring cylinder methodology adapted from the NRCS Soil Quality Test Kit Guide (NRCS 2001) and Lowery et al. (1996). The sampling area was cleared of vegetation and a 30cm diameter ring was driven into the ground to a depth of 7.5 cm. The time it took for 1L of water to infiltrate the surface inside the ring was recorded. Soil moisture using a Dynamax SM150 (Dynamax Inc; Houston, TX) was measured every two weeks after planting at a 0 to 5cm and 5 to 10cm soil depth.

One sample from each plot was air-dried and shipped to the Cornell University Soil Health Testing Lab, Ithaca, NY, USA for the Basic Soil Health Comprehensive Testing. The Cornell Soil Health Testing Lab developed a Soil Health Assessment report for each soil sample, which includes values and ratings for each soil indicator, as well as a comprehensive soil health score for each sample. The Basic Soil Health Comprehensive Testing included the following soil indicators: surface hardness, subsurface hardness, aggregate stability, percent organic matter, soil respiration, pH, extractable P, extractable K, Mg, Fe, Mn, and Zn, as well as a comprehensive soil health score and rating for each indicator.

### *3.7. Statistical analyses*

All statistical analyses were conducted in JMP Pro 12 (SAS Institute, Cary, NC). All corn growth, field data and soil health variables were analyzed using a mixed model fully factorial analysis with the two main treatments (soil conservation and organic amendment) and their interaction as the main model fixed effects and farm as a random effect. The same analysis was used for the farmer evaluations except that both farmer evaluator and farm name were added as random effects in the model. One farm was removed from all statistical analyses because it was the only farm with less than a 15% slope and the soil conservation technique of contour ditches is only recommended for use on hillsides with greater than 15% slopes.

## 4. Results

### *4.1. Farmer evaluations*

The farmer evaluations of the field trials showed that the incorporation of the soil conservation treatment (+SC) significantly improved stalk size ($P = 0.0297$; Table 5.3), leaf color ($P = 0.0049$; Table 5.3), whole ear weight ($P < 0.0001$; Table 5.3), and whole ear size ($P = 0.0002$). The +SC did not impact corn height or soil moisture. The farmer evaluations also showed that the organic fertility treatment significantly improved stalk size ($P < 0.0001$), corn height ($P < 0.0001$), leaf color ($P = 0.0027$), soil moisture ($P = 0.0141$), and whole ear size ($P = 0.0208$). The organic fertility treatment did not impact whole ear weight. No interactions between the soil conservation and organic amendment treatments were found.

### *4.2. Corn growth and field parameters*

The soil conservation treatment was only found to significantly increase whole ear weight ($P = 0.0411$; Table 5.4), but the organic amendment treatment did not impact whole ear weight. Neither soil conservation nor organic amendment as main treatments impacted any other growth or field variable, including weight of 100 seeds (g), % shoot N, corn height, and soil moisture. No interactions between treatments were found.

### *4.3. Soil health*

The soil conservation treatment was the only treatment to impact any soil health indicators. Soil respiration, Mn, and K all had lower levels in the treatment with contour ditches (+SC; Appendix C). The organic amendment treatment with bokashi did not impact any measured soil health indicators.

## 5. Discussion

### *5.1. Consistent results among farmers and researchers*

Results from both the farmer evaluations and researcher data demonstrate that the soil conservation treatment (+SC; contour ditches) improved whole ear weight of corn. Unfortunately, overall yield data was not obtained for the trial plots because of significant animal damage in most of the plots around the time of harvest. Whole ear weight was successfully obtained because five random ears of corn were chosen for evaluation several days before the full plot harvest. However, ear weight is consistently correlated with yield and an increase in ear weight often correlates with an increase in yield (Haag et al., 2017; Lu Hai-dong et al., 2017). Our results support previous studies showing that soil conservation practices, specifically contour farming, can improve grain yields (Uphoff, 2002) The uniqueness of this study is that it demonstrates that farmers also perceive contour farming to have significant positive impacts on the corn crop. Farmers also perceived that the soil conservation treatment improved other corn growth indicators, including stalk size, leaf color and whole ear size, which were indicators that farmers traditionally use to evaluate corn growth. Furthermore, farmers chose the organic fertility and soil conservation techniques as their treatments and were part of the research process and evaluation, demonstrating new ways to evaluate farm trial from a farmer perspective. If farmers perceive the changes as positive, then they are more likely to adopt the production changes long term. The researcher did not evaluate any of these other indicators because stalk size is not typically evaluated in research and resource limitations made it difficult to quantitatively measure changes in leaf color. However, it is noteworthy that percent tissue N, which would explain the darker green leaf color, documented by the farmers, demonstrated a trend that was also found to be higher in the soil conservation treatments ($P = 0.07$).

The bokashi treatment (+ORG) was not found to have any significant impacts from the researcher collected data, but all the trends observed by the researcher (though not significant) were the same as those noted by the farmers. It is not surprising that farmers found the differences to be significant given their observations were all subjective and their evaluations were done by walking around the corn field observing and taking notes – as they would do in their corn fields. The goal was not to train farmers to conduct research and use quantitative data collection methods and statistics, but to evaluate potential strategies in collaboration with the farmers to address the problem of high erosion and low yields.

Contrary to our expectations, neither treatment was found to increase soil moisture levels by the farmers or the researcher, which contradicts previous research where both increasing organic matter additions and contour farming have been found to increase water holding capacity (Bunch, 2000; Uphoff, 2002). The benefit of these treatments would be most prevalent during extended dry periods of the growing season, which will be increasingly prevalent in the future with the changing climate. A likely explanation for the lacking increase in soil moisture is there was no extended dry period during the 2016 growing season (late May through September) in the region where the studies were conducted. There was no period longer than six days without some rain. Thus, the bokashi and contour ditches may in fact increase soil moisture in steep corn field, but differences will only be seen during dry spells. During a high rain growing season, as in 2016, bokashi additions and contour ditches may not have any benefits to soil moisture, but future research should evaluate these strategies with farmers during a drier period of time.

### *5.2. Utilizing the farmer perspective in research*

One of the greatest strengths of participatory research approaches that projects are tailored to local priorities and contexts (McIntyre, 2008). Because this research project was in part designed, carried out by and evaluated with the full participation of young local farmers, it is much more likely these techniques are potential solutions that will be adopted by smallholder farmers in the region.

This study adds an important perspective from the farmers about these soil conservation and organic fertility strategies. We must get closer to providing realistic interventions for those who need it most - the poor, hungry and disadvantaged, living on soils that are sensitive and lack resilience (Stocking, 2003). It is becoming more accepted that simple linear and traditional top-down models of research are not adequate, particularly for agricultural production technologies aimed at improving the well-being of poor farmers in developing countries (Douthwaite et al. 2002). The only way to achieve realistic solutions and long term adoption is by involving farmers in the research. Our study demonstrates that agroecological field trials can be done with full farmer participation using a PAR methodology and provides a model for future PAR agricultural research. In addition, this case study demonstrates there is a role for both the researcher and the farmer in this PAR model.

### *5.2. Key lessons learned from applying PAR in agroecological field trials*

From conducting this case study and PAR process we learned the following six important points that can be utilized in studies in the future.

- <u>Full participation increases farmer engagement</u>

When farmers are able to participate fully in deciding research details, assist with planning and evaluation, they are more engaged in the research, concurring with previous results from Mendez et al. (2017)

- <u>The right local partner is crucial</u>

A strong local partners is essential for building relationships and long term sustainability of the research. FUNDAHMER was crucial to the success of this project, from the initial reflection phase in 2013 to the field trials in 2016.

- <u>Identifying the right participants, or "testers"</u>

Having strong participants who believe in the research and are locally respected can greatly impact the success of the research and project. Having the researcher, the local partner, and community leaders evaluate the participants lead to enthusiastic young leaders as participants that positively impacted the research in many ways.

- PAR research can be economical

Involving farmers in the research process may decrease the overall economic costs of the research. The majority of farmers supply all the labor on their own land, which means less is spent on field technicians, research assistants and management costs required for research stations. More resources are allocated towards farmer training, transportation and meals, but overall expenses may be less.

- Begin the process with relationship building research

Beginning the research process with surveys and interviews and visiting many local families in their homes built a strong base for the rest of the process and continuing with reflection (through focus groups) lead to more successful agricultural research.

- Intentional collaboration with young farmers

Young farmers are often marginalized and under-represented, and incorporating them into the research process increased creativity and enthusiasm for the research.

# REFERENCES

Altieri, M. 1999. Applying agroecology to enhance the productivity of peasant farming systems in latin america. Environment, Development and Sustainability 1:197-217.

Altieri, M.A. 2009. Agroecology, small farms, and food sovereignty. Mon. Rev. -Indep. Social. Mag. 61:102-113.

Altieri, M.A., F.R. Funes-Monzote and P. Petersen. 2012. Agroecologically efficient agricultural systems for smallholder farmers: Contributions to food sovereignty. Agron. Sustain. Dev. 32:1-13.

Arias Penate, J.S. 2014. Agricultura familiar e industrializacion sustentable: Un nuevo modelo de desarrollo agropecuario para el salvador. ADESES, San Salvador, El Salvador.

Bacon, C.M., W.A. Sundstrom, M.E.F. Gomez, V.E. Mendez, R. Santos, B. Goldoftas and I. Dougherty. 2014. Explaining the 'hungry farmer paradox': Smallholders and fair trade cooperatives navigate seasonality and change in Nicaragua's corn and coffee markets. Glob. Environ. Change-Human Policy Dimens. 25:133-149.

Bacon, C.M., V.E. Mendez and M. BROWN. 2005. Participatory action research and support for community development and conservation:  Examples from shade coffee landscapes in nicaragua and el salvador. Rep. Brief #6. Center for Agroecology and Sustainabile Food Systems, University of California, Santa Cruz, Santa Cruz, CA.

Beets, W.C. 1990. Raising and sustaining productivity of smallholder farming systems in the tropics : A handbook of sustainable agricultural development. AgBé Pub, Alkmaar, Holland.

Boechat, C.L., J.A. Gonzaga Santos and A.M. de Aguiar Accioly. 2013. Net mineralization nitrogen and soil chemical changes with application of organic wastes with 'fermented bokashi compost'. Acta Sci. -Agron. 35:257-264.

Branca, G., L. Lipper, N. McCarthy and M.C. Jolejole. 2013. Food security, climate change, and sustainable land management. A review. Agron. Sustain. Dev. 33:635-650.

Bryant, R. L. and S. Bailey. 1997. Third World political ecology. Routledge, New York.

Bunch, R. 2000. Keeping it simple: What resource-poor farmers will need from agricultural engineers during the next decade. J. Agric. Eng. Res. 76:305-308.

Castellanet, C. and C.F. Jordan. 2002. Participatory action reseach in natural resource management:  A critique of the method based on five years' experience in the trasamazonica region of brazil. Taylor & Francis, New York.

Ellis, F. 2000. Rural livelihoods and diversity in developing countries. Oxford University Press, New York.

FSIN. March 2017. Global report on food crises 2017. Food Security Information Network, .

Gliessman, S. 2012. A voice for sustainability from latin america. J. Sustainable Agric. 36:1-2.

Gliessman, S. 2009. Editorial: Community-based participatory action research with agroecology. J. Sustainable Agric. 33:799-800.

GREENWOOD, D., W. WHYTE and I. HARKAVY. 1993. Participatory action research as a process and as a goal. Hum. Relat. 46:175-192.

Guijt, I. 1998. Participatory monitoring and impact assessment of sustainable agriculture initiatives: An introduction to key elements. IIED, London.

Guzman Casado, G., M. Gonzales de Molina and E. Sevilla Guzman. 2000. Introduccion a la agroecologia como desarrollo rural sostenible. Ediciones Mundi-Prensa, Madrid.

Guzman, G.I., D. Lopez, L. Roman and A.M. Alonso. 2013. Participatory action research in agroecology: Building local organic food networks in spain. Agroecol. Sustain. Food Syst. 37:127-146.

Haag, L.A., J.D. Holman, J. Ransom, T. Roberts, S. Maxwell, M.E. Zarnstorff and L. Murray. 2017. Compensation of corn yield components to late-season stand reductions in the central and northern great plains. Agron. J. 109:524-531.

Kindon, S., R. Pain and M. Kesby (eds.) 2007. Participatory action research appreaches and methods. Routledge, .

Lu Hai-dong, Xue Ji-quan and Guo Dong-wei. 2017. Efficacy of planting date adjustment as a cultivation strategy to cope with drought stress and increase rainfed maize yield and water-use efficiency. Agric. Water Manage. 179:227-235.

Mayoux, L. and R. Chambers. 2005. Reversing the paradigm: Quantification, participatory methods and pro-poor impact assessment. Journal of International Development 17:271-298.

McIntyre, A. 2008. Participatory action research. Sage Publications, Los Angeles.

Mendez, V.E., M. Caswell, S. Gliessman and R. Cohen. 2017. Integrating agroecology and participatory action resarch (PAR): Lessons from central america. Sustainability forthcoming:.

Ministerio de Economia. 2009. Encuesta de hogares de propositos multiples (EHPM). Gobierno de El Salvador, Direccion General de Estadistica y Censos, .

Ministerio de Medio Ambiente Y Recursos Naturales (MARN). 2015. Boletin climatologico anual. Gobierno de El Salvador, El Salvador.

Nagayet, O. 2005. Small farms:  current status and key trends. p. 355-367. *In* IFPRI (ed.) The future of small farms: Proceedings of a research workshop. International Food Policy Research Institute, Washington, DC.

Pacheco Lima, C.E., M.R. Fontenelle, L.R. Borba Silva, D.C. Soares, A.W. Moita, D.B. Zandonadi, R.B. Souza and C.A. Lopes. 2015. Short-term changes in fertility attributes and soil organic matter caused by the addition of EM bokashis in two tropical soils. Int. J. Agron.754298.

Park, K. and R.J. Kremer. 2010. Establishment of an inoculated bacterial strain on plant root surfaces in soils with different microbial community. J. Korean Soc. Appl. Biol. Chem. 53:379-383.

Probst, K. 2002. Participatory monitoring and evaluation: A promising concept in participatory research? Lessons from two case studies in Honduras. Weikersheim: Margraf Publishers.

Sanchez, P. and M. Swaminathan. 2005. Hunger in africa: The link between unhealthy people and unhealthy soils. Lancet 365:442-444.

Sayer, J. A. and B. Campbell. 2001. Research to integrate productivity enhancement, environmental protection, and human development. Conservation Ecology 5(2): 32.

Stocking, M. 2003. Tropical soils and food security: The next 50 years. Science 302:1356-1359.

Uphoff, N. (ed.) 2002. Agroecological innovations: Increasing food production with participatory development. Earthscan, Sterling, VA.

Vanhaute, E. 2010. Famine: A short history. J. Glob. Hist. 5:182-183.

Table 5.1. Selection of agroecological best practices, recommended by the University of El Salvador, for hillside farming in the tropics that researcher presented to farmers. Farmers voted on two of these practices to implement on their own farms as part of the on-farm field trials.

| Practice | Benefits | Citations | Potential Challenges |
|---|---|---|---|
| Cover crops | Improved SOM[1]<br>Increased fertility<br>Decreased expenses on fertilizers, herbicides & pesticides, | Branca et al., 2013; Bunch, 2000 | High labor requirements<br>Access to seed Lower yield compared to grain staples |
| Modified crop spacing | Yield increases<br>Decreased erosion | Beets, 1990 | Cultural/tradition challenges<br>Lack of extension/ outreach services |
| Crop diversity/ Polycultures | Decreased risk<br>Increased nutrition<br>Decreased disease/pest pressure | Altieri et al., 2012 | Access to seeds<br>Increased land needed |
| Organic fertilizers | Yield increases<br>Increased SOM<br>Increased water holding capacity<br>Decreased erosion | Bunch, 2002 | Manure availability and access |
| Contour ditches<br>Living fences<br>Rock terraces | Decreased erosion and soil degradation<br>Long term yield increases<br>Increased water retention | Uphoff, 2002 | High labor requirements<br>Access to seeds for living fences |

[1] Soil organic matter

Table 5.2. Summary of all crop and soil response variables measured by both farmers and researchers during the 2016 on farm field trials with 8 farmers in northeastern El Salvador.

| Response Variable | Farmer Measured | Researcher Measured |
|---|---|---|
| SOIL | | |
| Soil nutrients (P, K, Mg, Mn, Zn, Fe) | | X |
| Cation exchange capacity | | X |
| pH | | X |
| Active carbon (mg C $kg^{-1}$) | | X |
| Soil respiration (total mg $CO_2$ g $soil^{-1}$) | | X |
| Aggregate stability (%) | | X |
| Soil moisture | X | X |
| Earthworm counts | X | X |
| Surface hardness | | X |
| Infiltration rate | X | X |
| CROP | | |
| Whole ear weight (g) - 6 representative plants from each plot | X | X |
| Whole ear size | X | |
| Seed weight (g 100 $seeds^{-1}$) | | X |
| Crop growth rates (6 representative plants from each plot @ V6, V8, V10) | X | X |
| Leaf Color | X | |
| Stalk size | X | |
| Leaf tissue % N | | X |

Table 5.3. Results from farmer evaluations on a 1-5 likert scale of different corn growth and field conditions from a two-factor factorial experiment (organic amendment and soil conservation) with on farm field trials.

| Treatment | Stalk Size | Corn Height | Leaf Color | Soil Moisture | Whole ear weight | Whole ear size |
|---|---|---|---|---|---|---|
| Organic Amendment | *** | *** | ** | * | - | * |
| Soil Conservation | * | - | ** | - | *** | ** |

* $P < 0.05$
** $P < 0.01$
*** $P < 0.0001$

Table 5.4. Results from on farm field trials of corn growth and yield during 2016 growing season (± standard error).

| Treatment | Plot | Cob Weight (g) | g/100 seeds (g) | % tissue N | Corn Height V6 (cm) | Corn Height V10 (cm) | 0-5 cm %SM | 5-10 cm %SM |
|---|---|---|---|---|---|---|---|---|
| Organic fertility | +ORG | 121.2 ±7.7 | 33.6 ±1.8 | 2.5 ±0.13 | 177 ±17 | 244 ±11 | 32.5 ±2.6 | 20.7 ±2.0 |
| | -ORG | 105.9 ±7.7 | 31.9 ±1.8 | 2.7 ±0.13 | 165 ± 17 | 233 ±11 | 32.4 ±2.6 | 21.0 ±2.1 |
| Soil Conservation | +SC | 102.9 ±7.2 | 33.4 ±1.7 | 2.7 ±0.13 | 170 ±17 | 239 ±11 | 32.6 ±2.6 | 20.8 ±2.1 |
| | -SC | 124.2 ±8.6* | 32.1 ±1.8 | 2.5 ±0.13 | 172 ±17 | 238 ±11 | 32.4 ±2.6 | 21.0 ±2.1 |

* $P < 0.05$
** $P < 0.01$
*** $P < 0.0001$

Table 5.5. Summary of specific opportunities and challenges of a Participatory Action Research (PAR) approach compared to a traditional research approach experienced in this study.

| PAR | | Traditional research approach | |
|---|---|---|---|
| Opportunity | Challenge | Opportunity | Challenge |
| Increased farmer adoption | Increased time and resources from researcher | Increased control of research by researcher allowing for more complex experiments | Harder to engage farmers |
| Potentially less expensive | Research techniques must be simplified for participants | Fewer random variables | Low adoption rates |
| Builds collaborations with marginalized groups | Need for long-term funding | Focus on meeting research objectives | Focus on meeting research objectives |
| Farmer driven | Increased amounts of planning beforehand | | Research and extension are viewed separately |
| Increased flexibility with research objectives | | | |

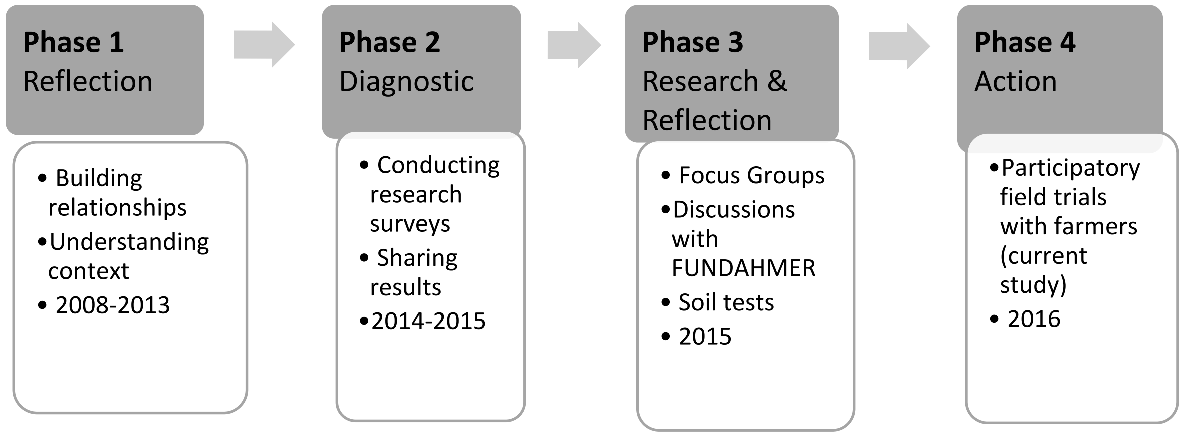
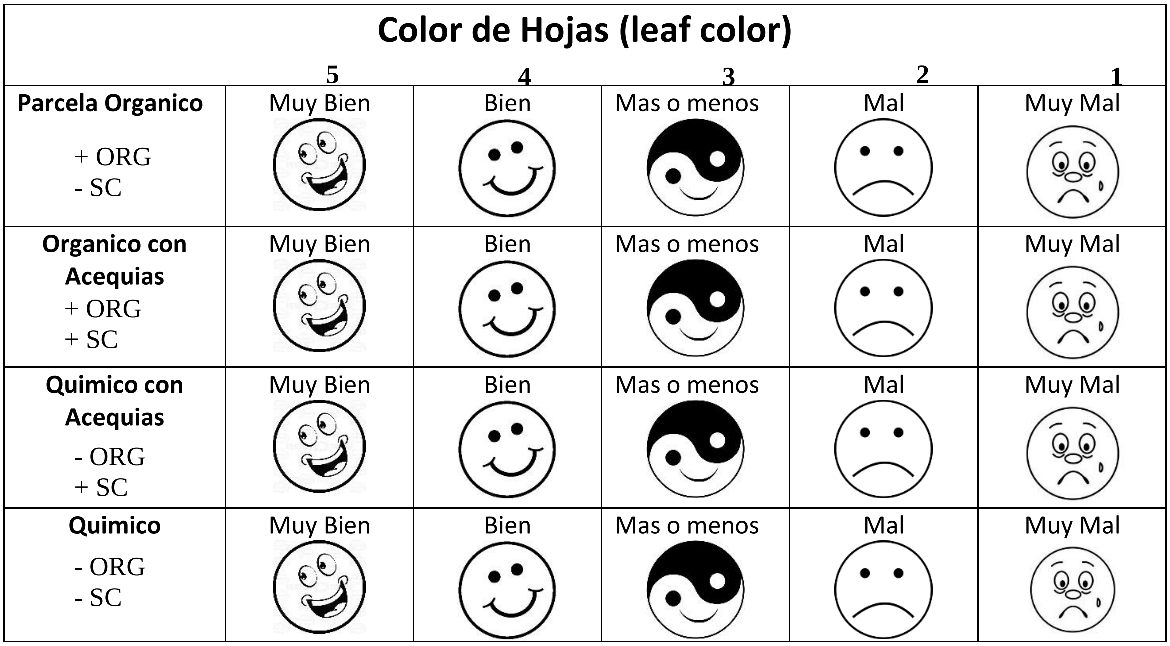



Figure 5.1. A summary of the Participatory Action Research process with smallholder corn and bean farmers in El Salvador that led to the current study (phase 4).

| Key Steps | Description |
|---|---|
| 1 | • Farmers applied to participate in field trials<br>• Lead researcher, FUNDAHMER, and community representative evaluate farmer applicants to participate in field trials |
| 2 | • Initial explanation of research and field trials<br>• Both researcher and farmers commit to fully participate |
| 3 | • Farmer participants vote on two treatments for field trials<br>• 1 organic fertilizer treatment (bokashi)<br>• 1 soil conservation treatment ( contour ditches) |
| 4 | • Farmers and lead researcher lay out trial plots on land owned by farmer<br>• Educational workshops for making bokashi and building proper contour ditches |
| 5 | • Farmers vote on seed variety, planting distances and fertilization rates |
| 6 | • Farmers and researcher dig contour ditches for trial plots<br>• Apply bokashi (made in communal workshop)<br>• Everyone plants the same week |
| 7 | • Lead researcher visits every farm monthly (farmer and researcher co-collect growth and field data)<br>• Montly reflection and training meetings with all farmer participants |
| 8 | • Group of farmers visit each farm participating to evaluate corn growth<br>• Group reflection and evaluation of plots |
| 9 | • At harvest, each farmer brings 5 randomly selectd ears of corn to group meeting for group evaluation<br>• Lead researcher dries and weighs corn |
| 10 | • Lead researcher compiles and shares results of farmer evaluations with farmers and FUNDAHMER |

Figure 5.2. Summary of Participatory Action Research steps utilized in the design and implementation of the field trials with corn and bean farmers in Cacaopera, Morazan during the 2016 growing season (phase 4 of the PAR process)



**Color de Hojas (leaf color)**

| | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| **Parcela Organico** + ORG - SC | Muy Bien | Bien | Mas o menos | Mal | Muy Mal |
| **Organico con Acequias** + ORG + SC | Muy Bien | Bien | Mas o menos | Mal | Muy Mal |
| **Quimico con Acequias** - ORG + SC | Muy Bien | Bien | Mas o menos | Mal | Muy Mal |
| **Quimico** - ORG - SC | Muy Bien | Bien | Mas o menos | Mal | Muy Mal |

Figure 5.3. Example of the farmer evaluations that farmers filled out during the on-farm field trials. Instead of the 1-5 numbers traditionally utilized in a likert scale, happy faces and simple description words were utilized.

# VI. Conclusions

Today, one third of El Salvador's rural population lives in extreme poverty (de Ferranti et al. 2005). Many global efforts aimed at improving livelihood improvements with conventional agriculture methods have failed, in part because their primary concentration was on global concerns rather than the immediate local needs of the households (Bryant and Bailey 1997). There is growing consensus that the industrial food system model has been destructive for rural communities and smallholder farmers. (Vanhaute 2010; Gliessman 2007). The conventional model is productive in terms of yield per hectare and creates wealth for well-capitalized growers (mostly foreign) but it often results in further impoverishment of smallholder farmers and rising food prices for urban consumers. Furthermore, export markets that many organizations and governments are emphasizing tend to favor secure tenure and economies of scale only possible with large land owners, leading to the exclusion of subsistence farmers (Rosa et al. 2004).

There is ample research demonstrating that smallholder farmers are the backbone of the food economy in many less developed countries. However, there has been less research documenting and analyzing ways to improve food security and yields of specifically subsistence farmers in Central America. This dissertation attempted to first examine production and food security challenges from the perspective of the farmer, then evaluate potential solutions to improve food security and production for smallholder farmers in northeastern El Salvador. The overall dissertation process was guided by a Participatory Action Research (PAR) approach where I, as the researcher, collaborated closely with community partners, including a local non-governmental organization and many local farmers, to design, implement and analyze results of the research. This was done with the goal of ensuring results would be useful to community partners.

Outlined below are the specific research objectives analyzed through this dissertation and conclusions we reached.

*I. Determine the current household food security rates, production practices, and perceived agroecological barriers to improving production and food security in northeastern El Salvador*

Future agricultural development programs in El Salvador need to be inclusive of climate change adaptation and adopt soil and water conservation strategies suitable for a variety of climates to increase the resilience of these small farms (Branca et al. 2013). Results from this study suggest that increasing corn yields, and thus household food security, is not going to be achieved solely by adding more synthetic nitrogen fertilizers to the system. this study shows that some of the smallholder subsistence farmers in El Salvador, who suffer relatively high food insecurity levels, also have low corn and bean yields, even with high levels of application of chemical fertilizers. Access to chemical fertilizers and improved seeds does not appear to be a limiting factor in improving the agricultural production of these small farmers because yields are not improved by more fertilizer application or improved seed use. Still, farmers perceive lack of synthetic fertilizers as the biggest challenge for better yields. It is clear that agricultural development programs should incorporate more agricultural education on agroecological management for farmers in order to achieve desired results. In addition, climate change is a primary concern of small farmers, both as a threat to their families' food security and agricultural production.

*II. Evaluate the baseline soil health status for smallholder farms in northeastern El Salvador and assess three different soil health assessments as potential tools for use in smallholder farming communities*

The three soil health assessments demonstrated clearly different overall soil health scores, especially the CATIE and CASH methods in regards to both overall scores and individual indicators. All three methods have unique opportunities and challenges. Because soil constraints in the humid tropics are mostly chemical, further demonstrated by our study, it is important to include at least some chemical indicators in future soil health assessments. Thus, a clear need exists for increased access to soil testing laboratories or increased access to accurate and affordable field-testing equipment in Central American research and extension settings. Our study also demonstrates that soil biological indicators, such as soil respiration or even earthworm counts, are important indicators to include in future soil health assessments. In addition, many smallholder farms in Central America have unique production challenges characterized by steep slopes and thin soils. The CATIE assessment is the only method that incorporates erosion control and soil management into the overall soil health score, which may be especially beneficial when working with farmers. Future research should examine how to better integrate the three different assessments and adapt them to specific situations.

*III. Evaluate the relationship between soil health on farms and household food security in smallholder farming communities of northeastern El Salvador*

Household food security is a significant struggle for many smallholder subsistence farmers and both, the MIAHFP and ELCSA methods of assessing food security appear to be valid for assessing food security in smallholder farming communities of Central America. The uniqueness of this study is that it incorporated both food security and soil health at the farm level, where decisions regarding soil management are made. Our results suggest that improving soil health may directly improve food security for smallholder farmers. Acknowledging our results are a preliminary case study, we recommend future work expand upon our results in a larger region and larger time frame as our results are only a snapshot in time. This study may serve as a model for future work examining soil health and food security for smallholder farmers in degraded areas of the tropics.

*IV. Apply PAR principles to agroecological field trials and utilize both farmer and researcher perspectives to evaluate organic fertility and soil conservation treatments on corn yield.*

Results from both the farmer evaluations and researcher data demonstrate that the soil conservation treatment (+SC; contour ditches) improved whole ear weight of corn. The uniqueness of this study is that it demonstrates that farmers also perceive contour farming to have significant positive impacts on the corn crop. Furthermore, farmers chose the organic fertility and soil conservation techniques as their treatments and were part of the research process and evaluation, demonstrating new ways to evaluate farm trial from a farmer perspective. Our study demonstrates that agroecological field trials can be done with full farmer participation using a PAR methodology and provides a model for future PAR agricultural research. In addition, this case study demonstrates there is a role for both the researcher and the farmer in this PAR model.

## REFERENCES

de Ferranti, D., G. E. Perry, W. Foster, D. Lederman, and A. Valdes. 2005. Beyond the City: The rural contribution to development. The World Bank, Washington, D.C.

# VII. APPENDICES

Appendix A

**Household Survey and Semi-Structured Interview Guide (English)**

**Date: ___________ Start Time: __________ Interviewer: _______________**
**Interviewee #: ____________________ Community: _______________**

**Food Security & Socioeconomic Survey**
*Women in the household will be interviewed for this portion*

1. Family History (where are you from):
    a. Number of years living in present location
2. What are the primary sources of income for the family (circle all that apply):
    - Agriculture
    - Artisan work
    - Employment
    - Other
3. Do you have any immediate family members in the US? Yes_____ No______
    a. Do you receive remittances? Yes________ No______
4. Family Demographics

| Sex | Age | Education | Employed | Daily Wage |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |

5. Access to Resources and Infrastructure (in your community)
    a. Electricity Yes ______ No________
    b. Potable Waters Yes ______ No________
    c. School Yes ______ No ________
        i. If yes, until what grade __________

6. Who is in charge of growing most of the food?
    a. Corn     (male/female head of household)
    b. Garden (male/female head of household)

7. Which of the following categories best describes your household?
    a. We grow more than enough to feed our family in our farm _____
    b. We grow just adequate to feed our family in our farm ______
    c. What we grow in our farm is not adequate to feed our family____

8. Do you have a family garden:     Yes_____     No______
    i. If yes, what do you grow?

9. Types of food regularly purchased:

10. Latin American & Caribbean Food Security Survey

| **During the last 3 months…** | | |
|---|---|---|
| **Questions referring to adults in the household** | **Yes** | **No** |
| Were you worried about running out of food? | | |
| Did your home run out of food at any time? | | |
| Was your home unable to eat at any time the kinds of food that make you healthy? | | |
| Did you or anyone in your home usually have to eat the same foods almost every day ? | | |
| Was there any day that you or any adult in your home skipped a meal because of lack of food? | | |
| Did any adult in your home eat less food than what they needed because there wasn't enough food? | | |
| Was there any day when you or any other adult in your home felt hungry but did not eat because there wasn't enough food? | | |
| Was there any day when you or another adult in the home didn't eat for a whole day or just ate once during the day because there wasn't enough food? | | |
| Did you do things that you would have preferred not to do, such as begging or sending children to work to get food? | | |
| **Questions referring to children in the household** | | |
| Were you unable to provide the children in your home with the kinds of food they need to be healthy? | | |
| Did any children in your home eat less food than what s/he needed because there wasn't enough food? | | |
| Did you have to serve less food to any child because there wasn't enough food? | | |
| Was there any day where any child in your home felt hungry but was not fed because there was not enough food? | | |
| Did any child in your home go to bed hungry because of lack of food? | | |
| Was there any day when any child didn't eat for a whole day or just ate once because of lack of food? | | |

11. What is the biggest challenge for you to feed your family?

## Agriculture Section

12. How much land do you own?

13. How much land do you plant?

14. How much land do you rent?

15. Details about production for the previous year (2013):

| Product | Área (Mz) | Yield (qq) | | | Details about sales | |
|---|---|---|---|---|---|---|
| | | | Family Consumption | Sale (qq) | Where was product sold | At what Price was product sold (qq) |
| | | | | | | |
| | | | | | | |
| | | | | | | |

16. What varieties of corn and beans do you plant?

| Product | Variety | Native or Certified | Where is it from? |
|---|---|---|---|
| Miaze | | | |
| Frijol | | | |

17. Why did you decide to plant these varieties?

18. Do you plant corn and beans in the same field or in separate locations?

19. Who taught you the production practices that you currently use?

20. What do you think are important agricultural practices to be a good farmer?

21. How have the harvests changed in the past few years?
    a. Improved _____ Worsened ______ Same ______ Depends on Climate________

22. What are your main challenges in improving production?

23. Do you own any animals? Yes________ No______
    a. If yes, do you use the manure for anything?

24. What do you think are important practices to maintain sustainable production on your land?

25. What do you think are important practices to improve your soil?

26. Do you use any soil conservation practices?
    - Yes
    - No
    - List:

27. What do you use to fertilize your crops?

    a. How much fertilizer do you use?

28. Do you use insecticides? Yes________ No______

a. What types?
b. Cost:

29. Do you use herbicides? Yes________ No______
    a. What types?
    b. Cost:

30. What costs do you have to prepare your land for planting?

31. Do you burn before planting? Yes________ No______

32. Do you leave the organic material? Yes________ No______

33. Is there any new technique, skill or knowledge on the farm that you would like to try out or learn about?\

Appendix B

## Encuesta de Hogares y Guía de entrevista estructurada

Introducción: Buenos días/tardes. Mi nombre es_____ Estoy trabajando en un estudio sobre soberanía alimentaria, la problemática de la falta de alimentos y la agricultura sostenible. Queremos pedirle su comprensión contestando a las preguntas que le haremos. Durará 1 hora aproximadamente. Las respuestas ayudaran a FUNDAHMER y académicos entender mejor la situación alimentaria y agrícola en las comunidades para planear mejor los proyectos de desarrollo. Los resultados del estudio también se va compartir con ustedes los socios

**Fecha: ______________________** **Entrevistador: _______________**

**Entrevistado: ________________** **Comunidad: _________________**

1. Historia Familiar (¿de dónde es):

2. ¿Cuantas personas, incluido usted, otros adultos y niños conforman su familia? ______

3. Cuál es el nivel de educación más alto obtenido por los jefes de su familia?

| Primaria (1º -6º) | Secundaria (7º-9º) | Bachillerato | Universidad |
|---|---|---|---|
| | | | |

4. ¿Hay miembros de su familia que han emigrado? **No___ (pasar a 2.1)** Si-llenar tabla si respuesta es **si**

| Parentesco con jefe/a de familia | Destino | Motivo del viaje (trabajo, estudio, etc.) | Temporal/ Definitiva | Reciben Remesas de este familiar (S/N) |
|---|---|---|---|---|
| | | | | |
| | | | | |

5. ¿Cuál de las siguientes categorías describe mejor su familia?
   a. Cultivamos más que suficiente para alimentar a nuestra familia en nuestra granja _____
   b. Cultivamos simplemente lo suficiente para alimentar a nuestra familia en nuestra granja ____
   c. Lo que cultivamos en nuestra finca no es suficiente para alimentar a nuestra familia____

6. ¿Tiene un huerto familiar: Sí_____ No______

7. ¿En que mes se termina la reserva de granos para alimentación que tienen almacenado?

**8.** En los últimos 12 meses, han habido meses en los que NO ha tenido alimentos suficiente para alimentar **adecuadamente** a su familia?. Si ___, **(Si es Si, anote los meses abajo)** No___ (**Si es No, Pase a la pregunta 8)**

| Ene | Feb | Mar | Abr | May | Jun | Jul | Ago | Sep | Oct | Nov | Dic |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | |

9. ¿Porqué no hubieron suficientes alimentos?

10. ¿Que estrategias usaron para enfrentar la escasez de alimentos?

11. ¿Qué le hubiera ayudado mejor enfrentar esta escasez de alimentos?

12. Ha escuchado el termino "seguridad alimentaria"? Si________ No_______

13. En sus palabras que significa la seguridad alimentaria?

14. En su opinión, piensas que su familia está segura en su alimentación? Tiene suficiente alimentos de su preferencia para toda la familia todo el año?

15. Has escuchado las palabras soberanía alimentaria? Si______ No ________

16. En sus palabras que significa la soberanía alimentaria?

17. En su opinión, piensas que su familia tiene soberanía alimentaria? Porqué y que se necesita para tenerlo?

18. Escala Latinoamericana y Caribeña de Seguridad Alimentaria (ELCSA)

| | | |
|---|---|---|
| **En los últimos 3 meses…** | | |
| Se refiere a los adultos en la casa… | Si | No |
| Por falta de dinero u otros recursos, ¿alguna vez usted se preocupó porque los alimentos se acabaran en su hogar? | | |
| ¿Alguna vez en su hogar se quedaron sin alimentos? | | |
| ¿Alguna vez en su hogar dejaron de tener una alimentación saludable*? | | |
| ¿Alguna vez usted o algún adulto en su hogar tuvo una alimentación basada en poca variedad de alimentos? | | |
| ¿Alguna vez usted o algún adulto en su hogar dejó de desayunar, almorzar o cenar? | | |
| ¿Alguna vez usted o algún adulto en su hogar comió menos de lo que debía comer? | | |
| ¿Alguna vez usted o algún adulto en su hogar sintió hambre pero no comió? | | |
| ¿Alguna vez usted o algún adulto en su hogar solo comió una vez al día o dejó de comer durante todo un día? | | |
| **Questions referring to children in the household** | | |
| ¿Alguna vez algún menor de 18 años en su hogar dejó de tener una alimentación saludable*? | | |
| ¿Alguna vez algún menor de 18 años en su hogar tuvo una alimentación basada en poca variedad de alimentos? | | |
| ¿Alguna vez algún menor de 18 años en su hogar dejó de desayunar, almorzar o cenar? | | |
| ¿Alguna vez algún menor de 18 años en su hogar comió menos de lo que debía? | | |
| ¿Alguna vez tuvieron que disminuir la cantidad servida en las comidas a algún menor de 18 años en su hogar? | | |
| ¿Alguna vez algún menor de 18 años en su hogar sintió hambre pero no comió? | | |
| ¿Alguna vez algún menor de 18 años en su hogar solo comió una vez al día o dejó de comer durante todo un día? | | |

19. ¿Cuál es el mayor reto para alimentar a su familia?

**Medios de Vida – Financiero:**

Teniendo en cuenta todos los miembros de su familia, cuáles de las próximas fuentes de ingresos aplica a su hogar?

| **Fuente de ingresos** | | **¿Cuánto es el ingreso total que viene de esta fuente?** |
|---|---|---|
| Ingresos de la venta de café | Si___No__ | |
| Ingresos de la venta de maíz y/o frijol | Si___ No _ | |
| Ingresos de la venta de otros productos de la finca (hortanizas, frutales)<br>Cuales_________________________ | Si____No | |
| Trabajo agrícola fuera de la finca propia (jornalero) | Si_____No__ | |
| Artesania | Si ___<br>No___ | |
| Trabajo no agrícola fuera de finca (guardias, albañil, etc.) | Si_____No__ | |
| Negocio (además de venta de productos agrícolas de la finca) | Si_____No__ | |
| Remesas o regalos (dinero o en especies) | Si_____No__ | |
| Pago por servicios ambientales (en efectivo, o en especies, como ejemplo plántulas, herramientas, comida) | Si_____No__ | |
| Otros beneficios económicos a través de proyectos / gobierno, incluyendo dinero y aquellos en especie (ej. pensiones, ayuda de programas, subsidios, bonos,etc.) | Si_____No_ | |
| Prestamos/ crédito de un banco u otra institución formal (micro-crédito, programas, proyectos, asociaciones) | Si_____No__ | |
| Préstamo / crédito de una fuente informal (familiares) | Si_____No__ | |

**Agricultura**

**Almacenaje**

1. Como guardan los granos como el maíz, el frijol y otros?

Galpon ___ Silo metalico _____ Bolsa hermetica de plástico _____ bodega _____ tambos _____ sacos ______ botellas de plástico ____ al aire libre en el piso _________________ otro__________________________________

2. Con este tipo de almacenaje, hay pérdidas por ratones, gorgojos u otra plaga? Si___No___ ¿Que porcentaje? _______________________

3. ¿Cuánta tierra tiene?

4. ¿Se cultiva junto en la misma parcela y como cultivo asociado el maíz y el frijol o se cultivan separados? ¿Porque?

5. Detalle sobre producción de cada producto

| Cultivo(s) * | Area** **en manzana o tarea** | ¿Tenencia de tierra?*** | ¿Responsable de esta parcela? **** | ¿Pendiente? (plana, mediana, inclinada/ladera/ondulada) | ¿Como califica la calidad del suelo? (mala, medio, bueno) |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

*Cafetal, Maíz, Frijol, Milpa, Huerto, Potrero, Bosque; **poner fracción # de tarea/# brazadas por tarea, por ej. 1/12 ***Propia/Familia, Alquilado, Prestado, Otro (especifique) ****(esposo, esposa, hijo/a, toda la familia, etc.)

| Producto | Área (manzana) | ¿Cuánto produjo? | Cantidad destinada a: | | Detalles de venta | |
|---|---|---|---|---|---|---|
| | | | Consumo familiar | Venta | Donde Vendió Estos productos* | ¿En qué precio se vendió? |
| Maize | | | | | - | - |
| Frijol | | | | | - | - |

6. ¿Siente que es fácil vender sus productos?  Si____ No____

¿Por qué? ___________________________________________________________________________
___

7. ¿Si produce maíz o frijol diga que variedades siembra?

| Cultivo | Variedad/ Tipo | Area | ¿De dónde viene?* | Cual da mejor rendimiento |
|---|---|---|---|---|
| Miaze | 1.<br>2.<br>3. | 1.<br>2.<br>3. | | |
| Frijol | 1.<br>2.<br>3. | 1.<br>2.<br>3. | | |

8. Porque se escogió a sembrar estos variedades de maíz y frijol?
9. Resumen de cultivos sembrados:

| Cultivo | Si o No | Tipos |
|---|---|---|
| Tuberculos (Malanga, camote, yucca) | Si__ No__ | |
| Guineo/Platano | Si__ No__ | |
| Ramadas (ayote, pipian, maracuya, loroco…) | Si__ No__ | |
| Ornamentales (patio) | Si__ No__ | |
| Arboles frutales | Si__ No__ | |
| Arboles maderables | Si__ No__ | |
| Arboles de sombra/leña | Si__ No__ | |
| Hortalizas | Si__ No__ | |

10. ¿Cómo han cambiado las cosechas en los años recientes?
    a. Mejor______ Igual _________ Peor________

11. ¿Cuáles son sus principales dificultades de producción?

12. Que creas que ayudaría a mejorar sus cosechas?

13. ¿Que tipo de abonos uso el ano pasado?

| | Maiz | Frijol | Huertos | Otro |
|---|---|---|---|---|
| Fertilizante químico | | | | |
| Lombri composta | | | | |
| Bokashi | | | | |
| Estiércol | | | | |
| Foliares químicos | | | | |
| Foliares orgánicos | | | | |

14. Cuanto aplica de cada cosa?
    a. Formula: ______
    b. Sulfato: _______

15. ¿Ud. tiene animales? Sí________ No_____

a. Usa el estiércol para abono? Sí________ No_____

16. Crea Ud que gestión de suelo es importante para sus cosechas?

17. Que creas que podría hacer para mejorar la calidad de suelo?

**18.** Incidencia de plagas en el año pasado en Maíz

| | Tipo | Método de control (si usan Paraquat/gramoxone, cuantos L usaron) |
|---|---|---|
| Enfermedades | | |
| | | |
| | | |
| Insectos | | |
| | | |
| | | |
| Maleza/Monte | | |
| | | |

Incidencia de plagas en el año pasado en Frijol

| | Tipo a | Método de control |
|---|---|---|
| Enfermedades | | |
| | | |
| | | |
| Insectos | | |
| | | |
| | | |
| Maleza/Monte | | |
| | | |

Incidencia de plagas en el año pasado en Hortalizas

| | Tipo a | Método de control |
|---|---|---|
| Enfermedades | | |

| | | |
|---|---|---|
| | | |
| | | |
| Insectos | | |
| | | |
| | | |
| Maleza/Monte | | |
| | | |

**19.** Tiene sistema de almacenamiento de agua? Si______ No_______
Si tiene, ¿que tipo?:

a. Para que se usa?

20. ¿Tiene sistemas de riego? Si___ No___

21. Inventario de prácticas de conservación de suelo y agaua

| **Practica** | **Maíz** | **Frijol** | **Huertos/Patio** |
|---|---|---|---|
| Agroforestería – combinación de árboles con cultivos | Sí____ No_____<br>No sé_____ | Sí____ No_____<br>No sé_____ | Sí____<br>No_____<br>No sé_____ |
| Barreras vivas | Sí____ No_____<br>No sé_____ | Sí____ No_____<br>No sé_____ | Sí____<br>No_____<br>No sé_____ |
| Barreras muertas | Sí____ No_____<br>No sé_____ | Sí____ No_____<br>No sé_____ | Sí____<br>No_____<br>No sé_____ |
| Rastrojo | Sí____ No_____<br>No sé_____ | Sí____ No_____<br>No sé_____ | |
| Acequias | Sí____ No_____<br>No sé_____ | Sí____ No_____<br>No sé_____ | Sí____<br>No_____<br>No sé_____ |
| Usa rotación de cultivos? | Sí____ No_____<br>No sé_____ | Sí____ No_____<br>No sé_____ | Sí____<br>No_____<br>No sé_____ |
| Cultivo de cobertura o abono verde | Sí____ No_____<br>No sé_____ | Sí____ No_____<br>No sé_____ | Sí____<br>No_____<br>No sé_____ |

22. ¿Utiliza insecticidas? Sí________ No_____

23. ¿Utiliza herbicidas? Sí________ No_____

## Cambio Climatico:

24. Como han sentido usted y su familia los efectos o cambios en el clima, en los últimos 5 años. Por ejemplo, estos podrían ser más o menos lluvia, roya, sequías, inundaciones, etc.

| **Cambio o Efecto (p.e. mas viento, lluvia)** | **Cultivo Afectado*** | **¿Qué Hizo para Responder a Esto?** | **¿Dónde/Como Aprendió sobre Esto?** | **Resultados Mejor/Peor/Igual** |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |

25. ¿Qué le hubiera ayudado a mejor enfrentar este cambio?

## Activos de Medios de Vida – Políticos y Sociales

26. Por favor describa las organizaciones, instituciones, asociaciones, redes o individuos con las que ustedes colaboran, y de las cuales reciben cualquier tipo de apoyo. Por ejemplo,

| **Nombre de Organización/ Individuo** | **Tipo (ONG, OG, Cooperativa, Asociación, etc.)** | **Tipo de Apoyo** | **Cómo Valora la Relación (buena, media, mala)** |
|---|---|---|---|
| | | | |
| | | | |

**27.**
Hay alguna nueva técnica, habilidad o conocimiento **para mejorar la finca** que le gustaría probar o aprender?

## Appendix C

Results of soil health indicators measured from on farm field trials of corn during 2016 growing season. (± Standard Error)

| Treatment | Plot | SH (psi) | SSH (psi) | AS (%) | % OM | SR (mg $CO_2$/g soil) | pH | P | K | Mg | Fe | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Organic Amendment | +ORG | 198 ±33 | 247.9 ±29 | 57.7 ±4.7 | 9.2 ±0.8 | 0.54 ±0.05 | 5.67 ±.17 | 3.3 ±0.5 | 345 ±25 | 588 ±101 | 16.4 +3.9 | 22.5 ±3.5 |
| | -ORG | 193 ±33 | 222.9 ±29 | 56.7 ±4.4 | 9.1 ±0.8 | 0.54 ±0.05 | 5.59 ±0.2 | 3.3 ±0.3 | 306 ±25 | 542 ±97 | 18.1 +4.1 | 17.3 ±3.5 |
| Soil Conservation | +SC | 196 ±33 | 287.6 ±41 | 50.3 ±17 | 9.0 ±0.8 | 0.50 ±0.05** | 5.66 ±0.2 | 3.8 ±0.3 | 299 ±25* | 606 ±118 | 21.3 +4.3 | 14.8 ±3.5* |
| | -SC | 195 ±33 | 237.8 ±45 | 57.4 ±4.5 | 8.9 ±0.8 | 0.58 ±0.05** | 5.56 ±.18 | 3.3 ±0.3 | 352 ±25* | 598 ±122 | 17.5 +3.9 | 25.0 ±3.5* |

* P < 0.05
** P < 0.01
*** P < 0.0001