Assessing Soil Quality and Preferred Agricultural Methods and their Implications in Overall Sustainability in a Rural Guatemalan Community

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Abstract:

While agricultural sustainability has been a concern for many years, factors such as global climate change, increasing populations, and the continuous degradation of natural resources have made the development of more sustainable agricultural systems a top priority. Analysis of current agricultural methods will be necessary in order to provide appropriate recommendations that will improve the environmental and community health in populations around the world. The current study aimed to conduct soil nutrient analysis and interview farmers in the rural Guatemalan community of Nuevo Horizonte in order to assess the impact that agricultural techniques have on soil nutrient concentrations and overall crop yield. The soil analysis conducted provided an overview of the pH and levels of the primary plant nutrients nitrogen, phosphorus, and potassium in various agricultural fields within Nuevo Horizonte and interviews with farmers provided insight regarding the range of agricultural methods employed, the thoughts and perceptions of various agricultural methods, and willingness to alter agricultural methods to potentially increase sustainability. It was hypothesized that farmers who implemented more organic agricultural methods would have more optimum soil nutrient levels and a greater overall agricultural yield than farmers who implemented more conventional agricultural techniques.

Introduction:

Overview:

In recent years there have been increasing concerns surrounding the inherent unsustainable nature of many agricultural practices. Agricultural sustainability is particularly important to study in areas of Latin America as there are many agriculturally driven environmental issues such as deforestation, soil degradation and erosion, and chemical pollution (Altieri, 1992; Pretty, 2008). The objective of this study was to conduct soil testing and record observations regarding different agricultural practices in the rural community of Nuevo Horizonte, Guatemala to assess levels of sustainability in the community and attempt to develop practices that maximize agricultural output while minimizing environmental damage.

The primary purpose of this study was to evaluate soil conservation applications in the rural agricultural community of Nuevo Horizonte, Guatemala by conducting soil nutrient analysis and interviewing farmers in the community to identify agricultural practices used as well as willingness to alter practices in order to potentially increase sustainability. It was hypothesized that farmers who employed more organic agricultural practices would have higher levels of the nutrients nitrogen, potassium, and phosphorus and would have a higher overall crop yield than farmers implementing more traditional agricultural methods. Ultimately one of the main objectives of conducting the research was to develop practical sustainable agricultural methods that could be employed in Nuevo Horizonte to increase crop yield without increasing inputs of chemicals such as fertilizers and pesticides.

Need for Sustainable Agriculture

Concerns regarding agricultural sustainability have been exacerbated in recent years as factors such as global climate change and increasing populations threaten to alter current agricultural systems and increase rates of malnutrition. Croplands, pastures, and forests cover about 60% of the Earth's surface, however they are increasingly at risk of being altered due to effects of global climate change (Food and Agriculture Organization of the United Nations). Global climate change has had different regional effects and there is reason to be concerned about the effects that variation in temperature, precipitation, storm intensity and frequency, flooding, and droughts will have on agricultural production, particularly in areas of the world already facing malnourishment issues (Food and Agriculture Organization of the United Nations). The mismanagement of land and soil has been a major contributor to the degradation of soils, leading to decreases in the net primary productivity and simultaneous increases in greenhouse gas emissions (Lal, Kimble, Levine & Stewart, 1995). Human activities such as the application of synthetic fertilizers have altered global nutrient cycles and while it is difficult to estimate the exact repercussions, there is widespread concern over the effects that alterations in carbon and nitrogen levels in soils will have in increases of greenhouse gases (Lal, Kimble, Levine & Stewart, 1995).

The challenges climate change will present in agricultural production will be exacerbated by population growth, particularly in regions of the world where poverty already limits access to food (Lappe & Bailey, 2002). Scarcities of inputs such as land and water necessary for agriculture have been identified regionally and degradation is expected to worsen with continued human activities (Smil, 2000). The global population was estimated to be about 6.1 billion people in 2000 and some projections indicate this figure could grow to nearly 9 billion people by the year 2050 (United Nations Population Division). Concerns regarding the stress agricultural production is currently placing on the environment combined with issues such as limited regional access to food, global population growth, and effects of global climate change require efforts to be made for both more sustainable agriculture and reclamation of already degraded land.

Issues with Agriculture in Low-Income and Humid-Tropical Countries

Agricultural sustainability is particularly important to study in resource-poor countries, where many citizens depend on agriculture for livelihood and current agricultural methods are leading to the widespread destruction of natural resources (Brussaard & Ferrera-Cerrato, 1997; National Research Council). Many countries located in tropical areas are already considered vulnerable for agricultural production because they contain poor soils that may be unusable for agriculture (National Research Council, World Bank Research Observer). Soil erosion has been identified as one of the primary concerns in the degradation of global agricultural systems, however these concerns are far worse in resource-poor tropical areas where ecosystems are already more vulnerable and economic, political, and infrastructural constraints leave little room for alternatives (National Research Council; Smil, 2000).

Subsistence agriculture in low-income areas often involves practices such as continuous cropping on fragile lands and is considered a major contributor to soil degradation and the net emission of carbon from soil (Lal, Kimble, Levine & Stewart, 1995). While carbon emissions from soils are of major global concern due to their connections in the greenhouse effect, it is estimated that soils and plants in tropical regions emit about ten times more carbon than those in temperate areas (Lal, Kimble, Levine & Stewart, 1995). It is currently estimated that climate change could affect up to 11% of arable land in developing countries, where populations are already struggling to combat agriculturally driven environmental issues (Food and Agriculture Organization of the United Nations). Issues such as deforestation, soil degradation, erosion, desertification, and chemical pollution have already been identified as negative outcomes of agriculture in many low-income countries and global climate change threatens to intensify these problems (National Research Council; Lal, Kimble, Levine & Stewart, 1995).

Issues of degradation of land and natural resources are worsened as populations in low-income countries continue to increase, meaning agricultural intensity and the amount of land needed for cultivation will both need to increase in order to produce more food

(Brussaard & Ferrera-Cerrato, 1997). The amount of land used for agriculture has risen by 21% in developing countries since the 1960s, during which the intensity of agricultural production has also increased on lands that were already extremely environmentally sensitive (Pretty, 2008; Hazell & Wood, 2008). Because of issues such as the increasing need to feed larger populations and the current state of resource degradation in humid-tropical countries, the development of sustainable agricultural systems will be necessary in any attempts to improve environmental and community health.

While resource-intensive agriculture has increased in many parts of the world, malnourishment persists in many low-income countries and there is widespread concern regarding the declining productivity of soils in tropical countries with rapidly growing populations (National Research Council, 1991). While it was estimated in 2002 that global food production was great enough to provide each person with 4.3 pounds of food daily, astonishing rates malnourishment persist regionally and new policies and methods need to be introduced to increase equitable distribution of food (Lappe & Bailey, 2002). The current juxtaposition between overconsumption in many developed countries and malnourishment in developing countries suggests that rather than focusing on producing more food globally, issues such as regional inequality and poverty need to be highlighted in attempts to reduce malnourishment. It can ultimately be concluded that in addition to improvements to conservation, efforts need to be made provide economic incentives for agricultural production in developing countries (Lappe & Bailey, 2002). The continued production of food on fragile land in resource-poor areas experiencing population growth will require the introduction of new agricultural methods simply to maintain current levels of malnourishment; in order to decrease malnourishment levels in these areas, innovative technological, economic, and political reform will be necessary to support farmers.

Farming practices in tropical locations are determined by numerous environmental, social, cultural, and economic factors (National Research Council, 1993). While it has been determined that current practices are leading to issues such as declining land fertility and increased soil erosion, farmers in low-income countries have limited access to resources and the development of new technologies is restricted by infrastructural and economic issues (Food and Agriculture Organization of the United Nations; National Research Council, 1993). In addition to infrastructural barriers, the increasing costs of agricultural inputs has decreased accessibility to items such as fertilizers and high quality seeds, affecting the ability of subsistence farmers to increase outputs (Brussaard & Ferrera-Cerrato, 1997; World Food Programme). Agriculture in many tropical countries could be considered inherently unsustainable because of the rapid exhaustion of land and resources, however many farmers are constricted by socioeconomic barriers and lack alternatives (National Research Council, 1993). The need for more sustainable agriculture in low-income countries is intensified by issues such as increasing population growth and intensified land use, yet alternatives are difficult to implement within economic and infrastructural restraints (National Research Council, 1991).

Background on Guatemala: Civil War

One of the primary factors that still contributes to modern poverty and inequality inflicting Guatemala is the country's devastating civil war that lasted from 1960 to 1996, in which an estimated 200,000 people died (Miller, 2011). The war was largely fought between state military groups and leftist guerilla groups that formed throughout the 36-year battle (Miller, 2011). While war officially ended with the signing of the Peace Accords in 1996, there have been lasting tangible effects from the conflict, with "violence and intimidation" persisting in politics and widespread inequality and resentment among the country's numerous ethnic groups (Miller, 2011).

Despite attempts as early as the 1950s to create more equitable land distribution that would benefit rural and indigenous farmers throughout the country, Guatemalan politics have perpetuated inequity and discrimination for decades, fueling class conflicts. President Jacobo Arbenz introduced the Agrarian Reform Law of 1952, otherwise known as Decree 900, with the goal of redistributing land from large landowners to poor farmers across the country (Viscidi, 2004). Despite benefiting an estimated 100,000 Guatemalan families by redistributing 603,704 hectares of land, the United States feared Arbenz's connection with the communist party and his attempts to nationalize plantations owned by the North American United Fruit Company (Miller, 2011). Subsequently, a CIA-orchestrated coup removed Arbenz from his position in 1954 (Trefzger, 2002). Arbenz was replaced with the U.S.-backed Colonel Carlos Castilllo Armas, resulting in the newly proportionated land being returned to its original owners (Trefzger, 2002). Armas continued policies that discriminated against indigenous and poor populations, such as supporting the removal of voting rights for illiterate Guatemalans, and was subsequently murdered in 1958, leading to the start of a gruesome civil war in 1960 (Miller, 2011).

While the effectiveness of the 1952 Agrarian Reform Law is debated because it was only in effect for two years, this movement remains one of the only attempts at increasing equitable land distribution Guatemalan farmers, plantation owners, and foreign companies owning land in the country, despite promises from the Guatemalan government following the war. Throughout the violent 36-year war, leftist guerilla groups fought the state military groups in attempts to highlight issues such as unequal land distribution, discrimination against indigenous populations, and unacceptable state violence (Conciliation Resources). The conflict was finally ended in 1996 with the signing of the Peace Accords, which included constitutional reforms that aimed to address economic and social issues (Mersky, 2005). While the Accord indicated an understanding of the multi-decade battle for land equity and highlighted the reform's commitments in the improvement of the country, few policies have resulted and land distribution remains one of the most significant issues in contemporary Guatemala (Mersky, 2005).

Background on Guatemala: Importance of Agriculture and Barriers to Sustainable Development

The agricultural sector employs about 38% of Guatemala's economy and accounts for about 13.5% of the country's GDP (Central Intelligence Agency). In addition to economic implications, it has been estimated that 60% of the country's population depends on agriculture for survival (Viscidi, 2004). The agricultural sector is thus vital to the country's future, however global climate change threatens to intensify existing issues related to the widespread unsustainable use of natural resources. In 2001 it was estimated that if adaptations were not made to combat the predicted 2.5°C increase in mean temperature globally, Latin America would have a $0.76 \pm 0.60\%$ decrease in Gross Agricultural Product (Tol, 2002). Guatemala is characterized by rugged terrain and the vast mountains and forests allow little room for land that is devoted to agriculture, leaving many farmers to rely on landscapes with steep slopes that can lead to higher levels of erosion (International Fund for Agricultural Development (IFAD)).

Like many areas of Latin America, Guatemala is facing many issues with population growth and poverty, which will place further strains on agricultural production. Guatemala is the most populous and fastest growing country in Latin America and it is estimated that about half of the population under 5 are chronically malnourished (Central Intelligence Agency). In 2011 it was estimated that about 54% the country's total population lived below the poverty line, however multiple studies have indicated that poverty is far greater in rural and indigenous populations (Central Intelligence Agency; United Nations Development Programme). A study in 2009 showed that rural areas of Guatemala experienced levels of poverty affecting up to 72% of the population (United Nations Development Programme). In order to keep pace with growing impoverished populations and increase access to food, it will thus be necessary to increase agricultural production on environmentally sensitive land, requiring the implementation of more sustainable agricultural practices (National Research Council, 1991).

In addition to poverty, Guatemala inequality and land-use issues persist as major barriers to sustainable development in Guatemala. One measure of the inequality of a country is Gini Index, which provides an illustration of the distribution of income within a country, with a value of 0 indicating complete income equality, and a value of 100 indicating complete income inequality (World Bank). Guatemala's Gini coefficient is considered "very high" at 55.1 and a study conducted by the United Nations Development Programme in May 2009 indicated it was the second highest Gini coefficient in Central America (United Nations Development Programme). The study also showed that just 20% of Guatemala's population owned 64% of the income in the country (United Nations Development Programme).

While the levels of income inequality throughout Guatemala are severe, modern statistics regarding inequitable land distribution are even more shocking and have severe implications in the country's ability to implement policies and initiatives for more sustainable agriculture. It has been argued that Guatemala has one of the "most skewed land distribution patterns in the world", with just 2% of the population owning 70% of the productive farmland (Viscidi, 2004). A report by the World Bank furthermore indicated that the Gini Index for land distribution within Guatemala is 85.9, much higher than the already concerning economic Gini Coefficient for the country (World Bank, 1995). While the majority of the population depends on small areas of land for subsistence, much of the suitable agricultural land within the country is still taken up by sugar cane and coffee plantations (Mersky, 2005).

Issues presented by poverty and inequality in Guatemala are worsened by numerous social and cultural barriers facing the country. Guatemala is a culturally diverse country, however indigenous groups have been disproportionately discriminated against and currently face higher levels of poverty and isolation from politics than other groups (IFAD). The country's landscape further inhibits cooperation among various ethnic groups as mountains, forests, and undeveloped highways present physical barriers isolating communities (IFAD). Because of issues regarding resource degradation, poverty, and malnourishment, it will be necessary to work within the economic, social, and infrastructural constraints in Guatemala to develop alternative farming methods that will increase crop yields without high-input intensive agriculture.

Background on Nuevo Horizonte

Nuevo Horizonte is a community in the department of Petén, Guatemala that was founded in 1998 with the signing of the Peace Accords by a group of guerilla soldiers that fought in the country's Civil War. Today the community has about 450 people and is organized in numerous levels; there is an Assembly that consists of 100 people and a Board of Directors that consists of 5 people that are elected by the Assembly every 2-3 years. In addition there is a General Manager and administrative team that is responsible for administering community projects, which include collective and individual projects such as reforestation, fish farming, raising livestock, and solidarity tourism.

Because the guerilla soldiers and the families that founded Nuevo Horizonte largely lived in Guatemala's vast jungles and depended on the country's natural resources for survival while they were fighting, one of the core values in the community is respect for nature. While the community constantly attempts to work with nature and increase sustainability, the lack of formal education, particularly among older generations, has presented a barrier in implementing more sustainable agricultural practices. Each family in Nuevo Horizonte receives about a one-acre plot of land, referred to as a "milpa", located in the northwest region of the community. While they depend on the food produced in the milpa for subsistence and commerce, there is widespread concern regarding the lack of government and educational resources, and thus the agricultural methods used are largely a result of experimentation or family history. The implementation of more sustainable agricultural systems that could potentially increase crop yield will thus have numerous benefits in terms of environmental sustainability and the livelihood of the community.

Though there are various barriers facing members of Nuevo Horizonte, the community's ability to take advantage of the resources that are available will be pivotal in the implementation of more sustainable agricultural practices. While Guatemala faces overwhelming issues with land distribution, Nuevo Horizonte has abundant space and thus has the ability to produce food that has been taken away from many Guatemalan families. Furthermore, one of the original projects in Nuevo Horizonte was to reforest an area of 145 hectares with Guatemalan pine in the northern areas of the community. While the project originally seemed impossible, through the appropriate use of natural resources and an understanding of the importance of maintaining the ecosystem, the area was successfully reforested. The community thus has natural resources, such as land, and the motivation to learn about various agricultural methods to improve the wellbeing of the community, however additional resources, particularly education, will be required.

Nutrient Availability and Soil Fertility

Nitrogen, phosphorus, and potassium are essential macronutrients plants require in order to grow that can be obtained from the soil or from added fertilizers (Manahan, 2009).

Nitrogen is an essential nutrient for soil fertility and is an important component of all living matter because it is involved in numerous biochemical processes necessary for vitality, such as its role in the formation of proteins (Manahan, 2009). Though nitrogen composes about 80% of the atmosphere, organisms such as bacteria in the soil have to convert the nutrient to ammonia, the form of nitrogen that is usable by plants in the process of nitrogen fixation (Friedland, Relyea, Courard-Hauri, 2011; LaMotte).

The conversion from N_2 atmospheric nitrogen to $NH4^+$ ammonia can be accomplished biologically due to the actions of vital bacteria found in the soil (Manahan, 2009). There are certain types of plants called legumes where bacteria have formed a mutualistic relationship with the roots of the plants in structures called nodules (Manahan, 2009). The bacteria living in root nodules are able to fix atmospheric nitrogen and provide the soil with up to 10 pounds of nitrogen per acre per year (Manahan, 2009). Examples of common legumes that can be planted to help provide nitrogen to the soil include soybeans, alfalfa, and clover (Manahan, 2009).

In addition to planting legumes, a common agricultural practice used to provide plants with ammonium salts is the application of synthetic fertilizers (Manahan, 2009). One of the greatest potential dangers of the use of synthetic fertilizers is that they contain added levels of nitrogen, which can lead to increase concentrations of atmospheric nitrogen and an overabundance of nitrogen in the soil (Friedland, Relyea, Courard-Hauri, 2011). Because nitrogen is such a vital nutrient and is often found in limited amounts, many farmers add synthetic nitrogen to their fields in fertilizers. The overuse of fertilizers containing nitrogen has severe impacts on the environment such as eutrophication, delayed crop maturity, air and water pollution, soil acidification, and changes in species composition and diversity in an ecosystem (Friedland, Relyea, Courard-Hauri, 2011; LaMotte; Liu et al., 2010). Furthermore, conventional inorganic fertilizers contain many synthetic components such as anhydrous ammonia and ammonium nitrate that can be dangerous to humans (Charles, Dan, 2013).

Phosphorus is another macronutrient that is essential for proper plant growth and plays vital roles in encouraging root development of plants, increasing crop yield, and stimulating rapid cell development that increases plant resistance to disease (Manahan, 2009; LaMotte). Plants use phosphorus in the form of orthophosphate ions (PO_4^{3-}), which are generally most readily available to plants in soils with a neutral or near neutral pH (Manahan, 2009). In soils that are too acidic or too alkaline, orthophosphate can easily react with other ions or be precipitated from the soil (Manahan, 2009). A major issue in agriculture is that continuous cropping can deplete levels of phosphorus available to plants, threatening maximum yield (LaMotte). Phosphorus is considered a limiting nutrient and is often added to agricultural fields via manure and synthetic fertilizers (LaMotte, United States Department of Agriculture).

In addition to nitrogen and phosphorus, potassium is considered another macronutrient that is necessary in agriculture as one of the nutrient's primary benefits is the aid in disease resistance through the strengthening of stalks and stems as well as a thicker cuticle on plant leaves (LaMotte). Other roles potassium can play in promoting plant growth and vitality is the activation of various enzymes and the control of turgor pressure that prevents wilting (LaMotte, Manahan, 2009). A major concern when considering the amount of potassium available for agricultural applications is that the nutrient can easily be depleted from soils or "fixed" in different soil layers, making it unavailable to plants (LaMotte). Furthermore, the addition of fertilizers to increase levels of nutrients such as nitrogen can further deplete potassium levels, causing it to become a limiting nutrient in some soils (Manahan, 2009).

Sustainable Agriculture Options

In order to enhance soil fertility in low-resource tropical areas without increasing chemical inputs, it is necessary to take measures that promote soil biological activity, nutrient cycling, and increase soil organic matter content (National Research Council, 1991). While various economic, social, and political factors have acted as barriers to implementing more sustainable agriculture techniques in communities like Nuevo Horizonte, the overall health and wellbeing of both the community and the environment require the implementation of innovative and culturally appropriate solutions.

An example of an innovative agricultural method that has been implemented in countries throughout the world to decrease dependence on chemical inputs is the use of Integrated Pest Management (IPM) (Francis, Poincelot, & Bird, 2006). IPM techniques are constantly evolving with the goal to develop pest management strategies that are complemented by ecosystem monitoring in order to ultimately decrease or terminate the use of synthetic pesticides (Francis, Poincelot, & Bird, 2006). IPM techniques are varied and should ideally be targeted to address the specific environmental factors affecting an area (Environmental Protection Agency (EPA), 2014). The ultimate goal of IPM is to develop an understanding of the lifecycles of the pests in a particular ecosystem in order to develop methods and control methods that provide the greatest economic benefit while minimizing negative effects on humans and the environment (EPA, 2014).

The United States Environmental Protection Agency (EPA) suggests a four-tiered approach to implementing an IPM program. The first step is to evaluate pest populations and environmental conditions and identify at what level the population of pests will become an economic threat (EPA, 2014). The second step is to monitor what types of pests are present in order to identify what type of control method would be needed, as not all pests are necessarily harmful (EPA, 2014). After the first two steps have been completed, the third portion of an IPM program involves the implementation of various techniques that will prevent the crops from even becoming a target for the pests (EPA, 2014). Various methods can be employed and largely include crop rotation and the use of modified seeds that are resistant to pests (EPA, 2014). The final step in an IPM program is to evaluate the prevention methods in order to identify proper control methods to be employed (EPA, 2014). The first control methods to be employed include the application of highly targeted chemicals and the mechanical removal of pests through trapping and weeding (EPA, 2014). The EPA indicates that "broadcast spraying of non-specific pesticides" should only be considered as a last resort (EPA, 2014). The success of IPM programs can be varied and there may be various initial conversion costs, meaning that positive economic returns may be experienced more in the long-term as opposed to the short-term (Francis, Poincelot, & Bird, 2006). This point is an important factor to consider when implementing IPM programs in areas such as Nuveo Horizonte, where the loss of short-term economic profits directly affects the livelihood of farmers.

Common alternatives to IPM techniques are more conventional methods such as the application of synthetic pesticides, which can have negative effects on the environment and human health. Though their use is intended to increase crop yields by preventing crop damage, the use of synthetic pesticides cause severe environmental degradation and some studies have indicated that they can have a negative effect on crop yield because of their ability to cause secondary outbreaks of pest-resistant insects (Pretty et al., 2006). One of the greatest dangers of pesticides is the positive feedback system created in the development of a pesticide treadmill in which some pests will survive after pesticides are applied to a field and become resistant to the pestidice, requiring scientists and farmers to develop and apply new chemicals that can have more severe consequences on the environment and human health (Friedland, Relyea, Courard-Hauri, 2011). Furthermore, many pesticides are persistent and can bioaccumulate in the fatty tissues of organisms over time (Friedland, Relyea, Courard-Hauri, 2011).

An important method that could increase soil fertility, control weeds, and prevent soil erosion from wind and water is the use of cover crops (Francis, Poincelot, & Bird, 2006). The use of cover crops can be particularly beneficial in eliminating weeds, diseases, and pests if crops are diversified and the use of continuous mono cropping is avoided (Francis, Poincelot, & Bird, 2006). While the use of cover crops cannot provide full weed control, it has been found that the increased biomass from cover crops is effective in suppressing weeds, particularly early in the season (Teasdale, 2013). It has been argued that one of the greatest benefits of using cover crops is the enhancement of long-term soil fertility and stability, particularly in areas where soil is easily eroded (Teasdale, 2013). Other benefits of using cover crops include providing nitrogen and increasing the total amount of organic matter in the soil (Hartwig & Ulrich Ammon, 2002). Because of the ability to increase soil fertility and provide the soil with nutrients and organic matter, the use of cover crops can be considered a key component of sustainable agriculture, particularly when a common alternative to this method is burning crop residues from a previous harvest in order to clear the land for the new harvest, which can lead to increased soil erosion.

It was hypothesized that farmers that received a higher environmental rank based on their interview responses would have high nutrient levels in their fields and a higher overall crop yield. The null hypothesis is that there is no relationship between the environmental rank a farmer received, the nutrient levels in his soil samples, and his self-reported crop yield.

Methods:

Interviews with Nuevo Horizonte Farmers

Interviews were conducted with the ten farmers in Nuevo Horizonte, Guatemala between May 2013 and July 2013. Interviews were recorded and questions addressed crops planted, crop yield, frequency of application of synthetic fertilizers, synthetic pesticides, or organic fertilizers, implementation of crop rotation, intercropping, or other integrated pest management techniques. Interview questions also aimed to assess the willingness to alter agricultural techniques to potentially increase sustainability and protect human health. Farmers were also asked how much they paid for each input including synthetic or organic fertilizers and pesticides. Appendix I provides an example of a survey used to interview farmers.

After identifying a lack of knowledge of various agricultural practices and overall low nutrient levels in soil samples, further research was conducted in Nuevo Horizonte in July 2014 in order to better identify barriers to sustainable agriculture and potential solutions. Between July 28th and 30th, 2014, additional interviews were conducted with six farmers in Nuevo Horizonte. Five of the farmers who were interviewed in 2014 had also been interviewed in 2013. The same interview was used in 2013 and 2014 with slight modifications; in 2014 additional questions were added asking farmers what type of seed they used, if the seed was reused each year or if they purchased seeds each harvest, how much they paid for the seeds they used, whether or not they used genetically modified items, and their general thoughts regarding the use of genetically modified seeds and organisms.

After completing all of the interviews and soil analysis for both 2013 and 2014, each farmer was given an environmental rank based off of their responses in the interviews. Those who practiced more sustainable and organic agricultural techniques received a higher rank and those who practiced more traditional and chemical-intensive agricultural techniques received a lower environmental rank. Scores were calculated by dividing the questions from the survey into subunits pertaining to synthetic fertilizer use, organic fertilizer use, pesticide use, and implementation of crop rotation or intercropping. For each category, a farmer received a score between 1 and 3, with 1 being considered the least sustainable and 3 being considered the most sustainable. The categories were totaled so that farmers received an overall score between 4 and 12 and the farmers were given a subsequent environmental ranking.

Soil Nutrient Analysis

Between May 2013 and July 2013, soil samples were collected and analyzed from the ten fields belonging to each of the farmers interviewed in 2013. A soil agar was used to collect soil cores from a depth of 12 inches beneath the surface. In each of the ten fields sampled, five soil cores were collected-one from each of the four corners and the center of the field. Each soil core was placed in a separate Ziploc bag and labeled with a field number 1-10 and sample letter A-E. This means that between May and July 2013, 50 total soil samples were collected and were labeled with a number and letter corresponding to the field and sample collected. Each of the soil cores collected from the fields was analyzed for the pH and levels of nitrogen, phosphorus, and potassium using a LaMotte soil testing kit Code 5679-01. Soil analysis was conducted in Nuevo Horizonte and took place within three days of the sampling date.

In order to determine the pH of the samples, the provided test tube was filled to line 4 with pH indicator 5701 solution and 1.5 grams of soil sample was added. The tube was capped and after mixing gently for one minute, the tube stood for 10 minutes to let the soil settle. The resulting color reaction was matched with the pH color chart 1353 and the results were recorded.

To identify the level of phosphorus in the samples, the provided test tube was filled to line 6 with Phosphorus Extracting Solution 5704 and 1.5 grams of sample was added. The tube was capped, mixed gently for one minute, and then uncapped and allowed to stand until the liquid above the soil turned clear. After the solution turned clear, a pipet was used to transfer the clear liquid to line 3 on a second test tube. Six drops of Phosphorus Indicator Reagent were added to the second tube, which was then capped and mixed. One phosphorus test tablet was added to the second tube, which was then capped and mixed until the tablet dissolved. The blue color that developed was compared with the Phosphorus Color Chart 1372 and the results were recorded.

Nitrogen levels in each of the samples was measured by filling the provided test tube to line 7 with Nitrogen Extracting Solution and adding 1.0 grams of soil sample. After capping the test tube and shaking gently for one minute, the cap was removed so the soil would settle. A pipet was used to transfer the clear liquid to line 3 on a second test tube. After the liquid was added, 0.5 grams of Nitrogen Indictor Powder 5703 were added to the soil extract in the second test tube, which was then capped and gently mixed. The tube was allowed to settle for 5 minutes and the pink color that developed above the powder was compared to the Nitrogen Color Chart and the results were recorded.

The potassium in the samples were determined by filling the provided test tube to line 7 with Potassium Extracting Solution 5707 and adding 2.0 grams of soil sample. The test tube was capped and shaken vigorously for one minute. The cap was removed so the soil could settle and a clean pipet was used to transfer the clear liquid to line 5 on a second test tube. A Potassium Indicator Tablet was added to the soil extract in the second tube and the tube was capped and mixed until the tablet dissolved. Potassium Test Solution 5709 was added two drops at a time until the solution turned from purple to blue. The number of drops added to the solution was recorded and the Potassium End Point Color Chart was used to determine the level of potassium in the sample.

In June 2014, soil permit P330-14-00196 was received from the United States Department of Agriculture (United States Department of Agriculture) that allowed soil to be shipped to the United States from a foreign country. Between July 28th and 30th 2014, soil samples were collected from six fields in Nuevo Horizonte corresponding to the six farmers who were interviewed. Five of the fields were sites that had been sampled the previous year and one field had not been sampled the previous year. A soil agar was used to collect soil samples from each field. The sampling design was altered from the method used in 2013; instead of collecting samples from the four corners and center of the field, random point sampling was employed to collect five samples throughout the field. Starting at one of the corners of the field, a six-sided die was used to determine the number of steps to take to the location for the samples. For example, if the die was rolled to show the number six and subsequently rolled to show the number three, six steps would be taken in the East/West direction and three steps would be taken in the North/South direction and a soil sample would be collected using the soil agar at that spot. This sampling technique was repeated four times in each field until a total of five samples from each field.

Each of the five samples collected from an individual field were placed in an individual Ziploc bag and labeled with the field number. The samples in the six Ziploc bags representing the six fields tested were subsequently transferred to a small glass jar that was labeled with the field number. The six glass jars were placed in a cardboard shipping box containing the permit information and the box was sent to a USDA plant inspection station in El Segundo, California for sterilization in August 2014.

Following the sterilization of the six soil samples at the USDA plant inspection station, the soil samples were shipped to the home address provided on the permit in Marshfield, Wisconsin. The samples were then shipped to Carthage College for analytical nutrient analysis.

Nitrate Analysis

Nitrate levels were determined in each of the samples collected in 2014 using the Nitrate Electrode Method proposed by Griffin et al. Prior to nitrate analysis, an Ionic Strength Adjustor (ISA) solution, a preservative solution, and a 1000 ppm NO_3^- solution were prepared using analytical instruments and reagent grade chemicals to ensure precision and accuracy. All solutions were prepared using volumetric flasks and volumetric pipets to maximize accuracy. All equipment was cleaned by rinsing three times with deionized water.

A 2*M* Ionic Strength Adjustor (ISA) was made by dissolving 26.407 g of Sigma-Aldrich $(NH_4)_2SO_4$ in a 100.00 mL volumetric flask and diluting to the mark with deionized water. The flask was capped and inverted thirteen times. The 1*M* preservative solution was prepared by dissolving 6.2205 g of Sigma-Aldrich H_3BO_3 in 100.00 mL of boiling deionized water, which was then cooled and transferred to a 100.00 mL volumetric flask. The flask was diluted to the mark with deionized water, capped, and inverted thirteen times. A 0.04*M* $(NH_4)_2SO_4$ extracting solution was prepared by adding 20.00 mL of the ISA solution and 10.00 mL of the preservative solution to a 1.00 L volumetric flask, which was then diluted to the mark with deionized water, capped, and inverted three times.

Three working standard nitrogen solutions were originally prepared in order to calibrate the nitrate electrode. A 1000.00 ppm NO_3^-N standard solution was prepared by dissolving 7.2228 g of Sigma-Aldrich KNO_3 in a 1.00 L volumetric flask, which was then diluted to the mark with deionized water, capped, and inverted three times. A 4.00 ppm NO_3^-N working standard was prepared by pipetting 2.00 mL of the 1000.00 ppm NO_3^-N standard solution, 10.00 mL of ISA solution, and 5.00 mL of preservative solution into a 500.00 mL volumetric flask, which was then diluted to the mark with deionized water, capped, and inverted three times. A 10.00 ppm NO_3^-N working standard was prepared by pipetting 5.00 mL of the 1000.00 ppm NO_3^-N standard solution, 10.00 mL of ISA solution, and 5.00 mL of the preservative solution into a 500.00 mL volumetric flask, which was then diluted to the mark with deionized water, capped, and inverted three times. A 40.00 ppm NO_3^-N working standard was prepared by pipetting 20.00 mL of the 1000.00 ppm NO_3^-N standard solution, 10.00 mL of ISA solution, and 5.00 mL of the preservative solution into a 500.00 mL volumetric flask, which was then diluted to the mark with deionized water, capped, and inverted three times.

After making the 4.00 ppm, 10.00 ppm, and 40.00 ppm standards and constructing the calibration curve of mV versus log of the nitrate concentration, it was determined that additional standards should be made due to the expected low concentration of nitrate in the collected samples. Following the procedure above, 0.500 ppm, 1.00 ppm, and 2.00 ppm standards were created, measured in triplicate, and added to the calibration curve.

In order to extract the nitrate from the soil samples, 20.0 g of air-dried, sieved soil and 50.00 mL of the 0.04 M $(NH_4)_2SO_4$ extracting solution were added to separate 125 mL Erlenmeyer flasks. The flasks were placed in a reciprocating shaker for 15 minutes at 200 oscillations per minute. Because gravity filtration did not provide a clear filtrate, the soil suspensions were filtered using a vacuum filter and Whatman filter paper to provide a clear filtrate.

Each sample was measured in triplicate using a Cole Parmer Nitrate Combination electrode. Each millivolt reading was recorded and the mean for each sample was calculated and the equation from the calibration curve was used to determine the concentration of nitrate in the sample.

Statistical Analysis

The software program SPSS Statistics Student Edition 22 was used to record the results from the interviews and soil analysis and to conduct statistical analysis. After each farmer interviewed in 2013 received an Environmental Rank based on their interview responses, results were recorded in SPSS regarding the levels of nutrients in the soil samples from the LaMotte soil testing kits. The "General Linear Model-Univariate" function was used in SPSS to produce an ANOVA in order to analyze the relationship between soil nutrient levels of each of the three nutrients analyzed and environmental rank. In each analysis, the nutrient being analyzed was entered as the dependent variable and Environment Rank was entered as the independent variable. Post-Hoc tests were conducted in which Environmental Rank was entered in the "Tests for" box and Bonferroni and Tukey values were reported.

A linear regression was conducted in order to analyze the relationship between the environmental rank assigned to the six farmers interviewed in 2014 and the concentration of nitrate in the samples collected in 2014. In this analysis, environmental rank was entered as the independent variable and nitrate concentration was entered as the dependent variable. A linear regression was then performed in which environmental rank was entered as the independent variable and crop yield was entered as the dependent variable. Another regression was also done in which nitrate concentration was entered as the independent variable and crop yield was entered as the dependent variable in order to fully understand the relationship between environmental rank, nitrate concentration, and self-reported crop yield for the farmers interviewed in 2014.

Results:

Overall, interviews with farmers indicated that there was a concern among farmers regarding the lack of government resources and agricultural education in the community. While the original founders of the community worked the Guatemalan government to obtain the land that is now Nuevo Horizonte, they have not received any type of government resources or support for farming. Common reasons for implementing a certain agricultural method included previous experimentation or former family practices, however in general there was little scientific knowledge regarding various practices and their potential costs and benefits.

Interviews with Nuevo Horizonte Farmers

Interviews in both 2013 and 2014 indicated a wide range of agricultural techniques being employed in Nuevo Horizonte. Table 1 indicates responses to a few of the questions from some of the farmers interviewed in each year. Not all questions and responses are included; Appendix 1 provides the actual interview questions used and Appendix II provides an expanded description of interview responses.

Table 1. Examples of interview responses from a selection of farmers interviewed in 2013 and 2014

Year	Farmer	Implementation of Crop Rotation/Intercropping?	Organic Items Applied to Field	Annual Crop Yield (Quntiales per Manzana)
2013	Victor	Neither	Velvet Bean	36-40
2013	Tono	Crop Rotation	Velvet Bean	70
2013	Fernando	Intercropping	Chicken Droppings	80
2014	Rony	Both	Crop Residues/Corn Stalks; Ash	90
2014	Otoniel	Crop Rotation	Nothing	160

Because the environmental rankings among the 10 farmers interviewed in 2013 were clustered closely, three different groups were generated: Low, Medium, and High. Farmers in the "High" group were considered the most sustainable and farmers in the "Low" group were considered the least sustainable. Figure 1 illustrates each of the 10 farmers labeled with L, M, or H and a number, indicating which group the belonged to according to their environmental rank. The numbers associated with the L, M, and H do not necessarily mean they are ranked higher than another and are simply used to distinguish farmers within each group. The blue line in Figure 1 illustrates the overall crop yield reported by each farmer and the red bars indicate the average level of nitrogen, phosphorus, and potassium in the fields.

Soil Nutrient Analysis

Because nutrient levels from the LaMotte soil testing kit are reported in values of trace, low, medium, and high, rather than quantitative values, a value between 1 and 4 was assigned to each nutrient level for ease of statistical analysis. A result of "Trace" was recorded as 1, "Low" was recorded as 2, "Medium" was recorded as 3, and "High" was recorded as 4 for each of the three nutrients analyzed. The nutrient values assigned were averaged for each farmer and are illustrated in Figure 1. Thus, if the results had aligned with the hypothesis that farmers with a greater environmental rank would have greater nutrient levels from soil samples and a greater crop yield, the red bars and blue line would increase from left to right, or from farmers with a lower environmental rank to farmers with a higher environmental rank.

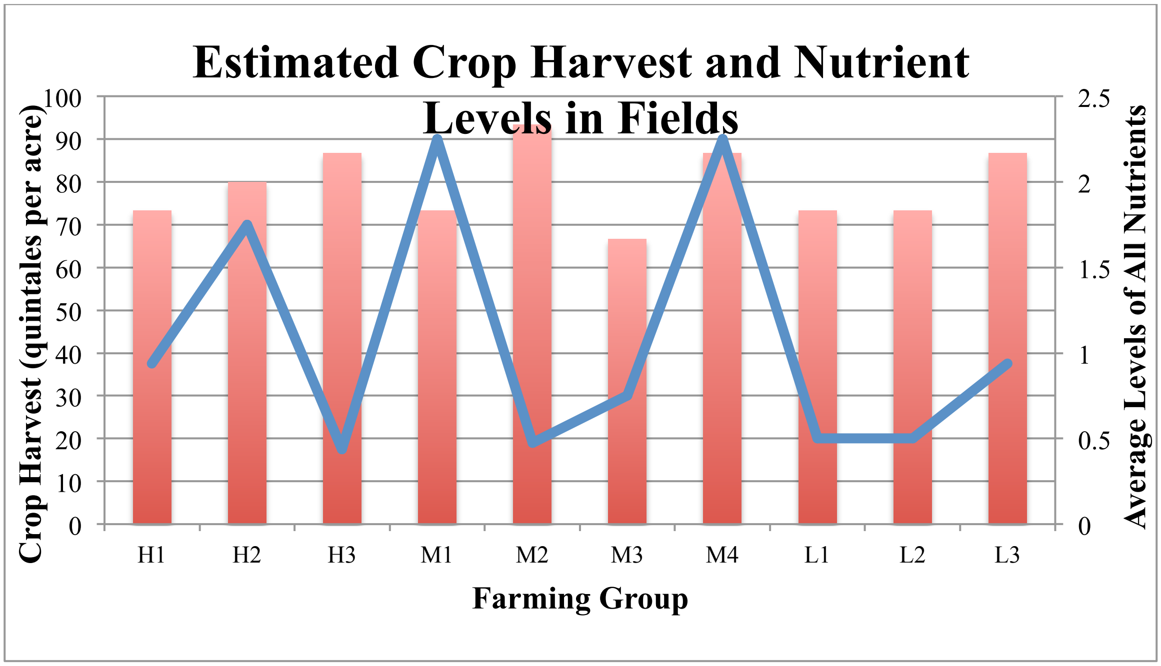

Figure 1. Environmental rank of farmers, average level of soil nutrients, and overall crop yield

Table 2 shows the average crop yield and the average levels of Nitrogen, Phosphorus, Potassium, and pH for the farmers and their corresponding field analyzed in 2013. Table 3 shows the results of the SPSS analysis conducted in order to analyze the relationship between the environmental rank of the farmers interviewed in 2013 and the levels of Nitrogen, Phosphorus, and Potassium in soil samples analyzed in 2013.

Table 2. Soil nutrients and environmental rank of farmers in 2013

Environmental Rank	**Nitrogen**	**Phosphorus**	**Potassium**	**pH**	**Crop Yield (Quintales per Manzana)**
1	Low	Medium	Very Low	6.2	25-50
2	Trace	Low	Medium	6.9	80-100
3	Low	Low	Medium	7.2	70
4	Low	Low	Low	6.1	18-20
5	Low	Low	Medium	7.5	35-40
6	Trace	Low	Medium	7.0	30
7	Trace	Trace	Medium	6.3	15-20
8	Low	Low	Medium	6.9	35
8	Trace	Trace	Medium	6.6	20
10	Low	Low	Medium	6.6	20

Table 3. ANOVA analysis of soil nutrients and environmental rank of farmers in 2013

Nutrient	R-Squared Value	Adjusted R-Squared Value	P Value (Sig.)
Nitrogen	.375	.196	.193
Phosphorus	.258	.047	.351
Potassium	.008	-.276	.973

Figure 2 shows the calibration curve that was constructed after preparing the six NO_3^-N standards for the analysis of nitrate levels in the six samples collected in 2014. The equation of the line, y = -61.901x + 303.86 was used to determine the concentration of nitrate in each of the six collected soil samples. The concentration of each sample was computed using the equation 10^((Voltage Reading-303.86)/-61.901). Values of the voltage readings and nitrate concentrations in each of the samples are show in Tables 3 and 4. Rows on Tables 4 and 5 are labeled by the Environmental Rank assigned to the farmer, with 1 being the highest, or most sustainable rank.

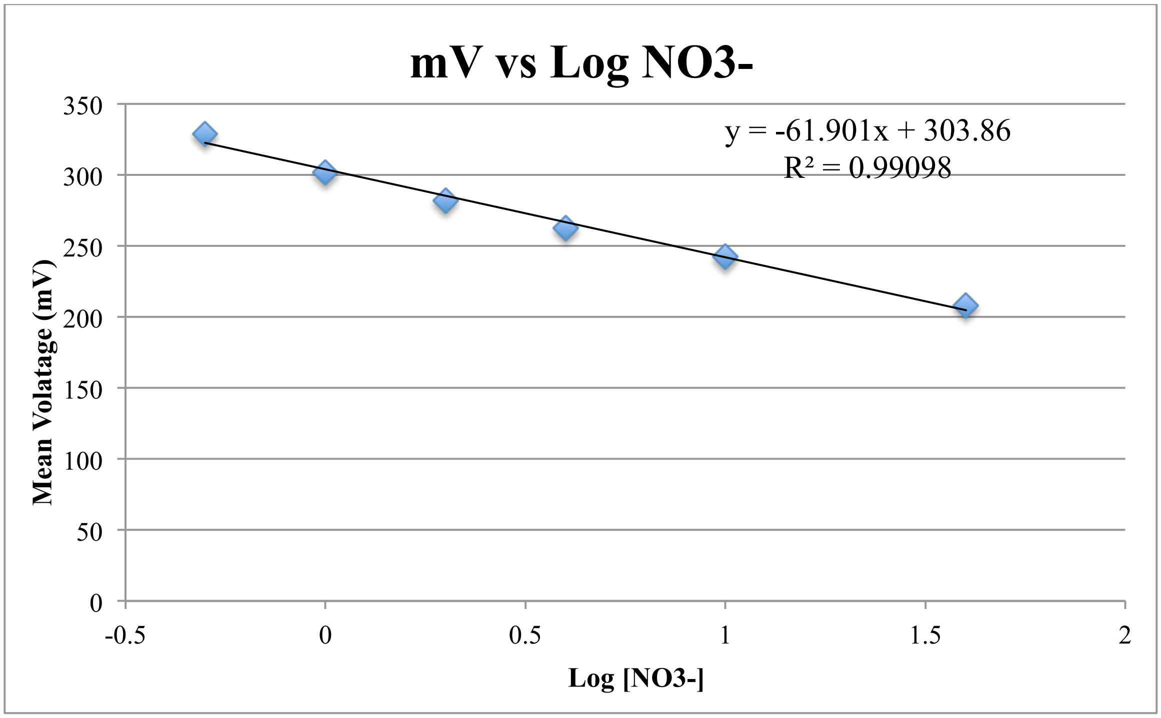

Figure 2. Calibration curve constructed for $[NO_3^-]$ analysis

Table 4. Voltage readings from nitrate analysis of samples collected in 2014

	Voltage Readings			
Environmental Rank	Voltage 1	Voltage 2	Voltage 3	Mean Voltage
Farmer 1	253.5	249.5	248.8	250.6
Farmer 2	231.7	230.5	230	230.7
Farmer 3	243.2	241.4	240.5	241.7
Farmer 4	297.8	298.9	295.5	297.4
Farmer 5	295.9	291.7	290	292.5
Farmer 6	243.2	241.4	240.5	241.7

Table 5. Nitrate concentration of samples collected in 2014

	Nitrate Concentration			
Environmental Rank	$[NO_3^-]$, ppm Trial 1	$[NO_3^-]$, ppm Trial 2	$[NO_3^-]$, ppm Trial3	Mean $[NO_3^-]$, ppm
Farmer 1	6.51	7.55	7.75	7.27 $\pm$ 0.67 ppm
Farmer 2	14.64	15.31	15.60	15.19 $\pm$ 0.49 ppm
Farmer 3	9.55	10.21	10.56	10.11 $\pm$ 0.51 ppm
Farmer 4	1.25	1.20	1.36	1.27 $\pm$ 0.08 ppm
Farmer 5	1.34	1.57	1.67	1.53 $\pm$ 0.17 ppm
Farmer 6	0.73	0.76	0.81	0.77 $\pm$ 0.44 ppm

Figure 3 illustrates the environmental rank each of the six farmers interviewed in 2014 and the nitrate concentration of the soil sample analyzed. There are three values for each farmer, indicating the reading in each of the three replicates during the analysis. The farmers are aligned on the x axis according to environmental rank, with the farmer receiving the highest environmental rank on the left and the farmer receiving the lowest environmental rank on the right. A linear trendline and R^2 value were added to the graph in order to illustrate the level of significance of the relationship between the environmental rank of a farmer and the nitrate concentration in his soil samples.

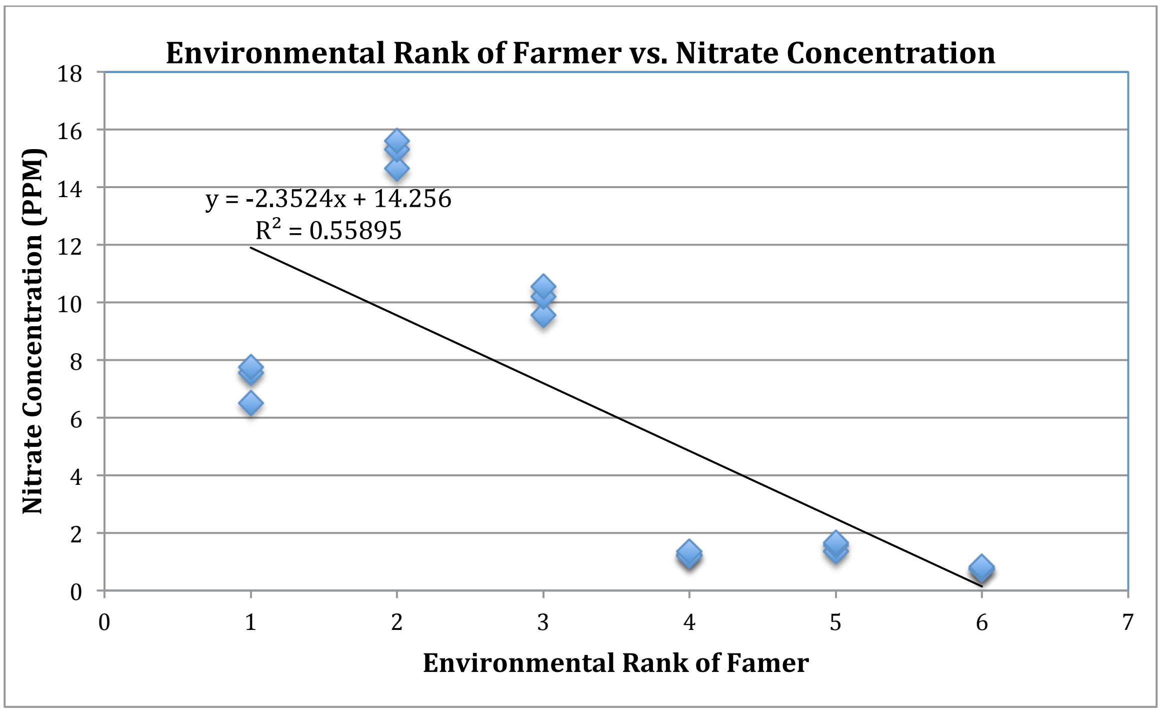

Figure 3. Environmental rank and nitrate concentration in analysis from 2014 analysis

In addition to the linear regression conducted to analyze the Environmental Rank of a farmer and the Nitrate Concentration in the soil samples collected in 2014, two additional linear regressions were conducted in order to gain a better understanding of the relationship between Environmental Rank, Nitrate Concentration in soil samples, and the self-reported crop yield. Table 6 provides these results.

Table 6. Significance of nitrate concentration compared to crop yield and environmental rank for 2014 analysis

Independent Variable	**Dependent Variable**	**R^2 Value**	**P Value (Sig.)**
Environmental Rank	Nitrate Concentration	.561	.087
Environmental Rank	Crop Yield	.109	.524
Nitrate Concentration	Crop Yield	.014	.821

Discussion:

One of the most important factors that needs to be considered in the analysis of the significance of the relationship between soil nutrient levels and the crop yield is that farmers self-reported an estimated crop yield and it was impossible to determine how accurate the estimation was. The third row in Table 5 indicates that a P value of 0.821 was found in the analysis of the correlation between nitrate concentration in the soil samples and the farmers interviewed in 2014. This value is far from the traditionally accepted p value of 0.05 that indicates that there could be a correlation between two variables and indicates that is unlikely that crop yield increases as nitrate concentration in the soil increases.

The p value shown in the first row of Table 5 is 0.087, which is still higher than the significance value of 0.05. This data means that the null hypothesis is accepted that there is no correlation between environmental rank of a farmer and the concentration of nitrate in soil samples form his field. While the alternative hypothesis is rejected because the p value is greater than 0.05, this p value is much lower than others found in this study and could suggest a trend in nitrate concentration and environmental rank. Because a great degree of uncertainty is involved when conducting environmental research, it can often be difficult to obtain results with an R^2 or p value that indicates a failure to reject the alternative hypothesis.

For the analysis that was conducted in both 2013 and 2014, the sample size of farmers interviewed and soil samples analyzed was small. More time, resources, and a larger number of soil samples would need to be collected in order to demonstrate a stronger trend between the environmental rank of a farmer, the level of nutrients in his soil samples, and the crop yield.

A factor that needs to be considered in the analysis of the soil nutrient levels reported is that soil samples were not dried immediately after collection. Ideally, soil samples would be dried in an oven for 24 hours after collection, however because sample collection took place in a resource-poor setting in Guatemala, such equipment was inaccessible. While microbial activity could have continued in the soil and altered nutrient levels between the time that the sample was collected and analyzed, it is expected that any microbial activity presented only minor fluctuations in nutrient levels reported.

Another major factor affecting the levels of nutrients found in the samples that needs to be considered when making recommendations for the application of fertilizers in the fields studied is that the crops were planted at different times in different fields and thus soil samples were taken when the crops were at different stages of growth. Nutrients are cycled throughout the growth of crops and are not uniform throughout the season and thus the varying stages of growth of the crops in the different fields could be acting as a confounding variable in the nutrient analysis part of this study. Because the study took place over a short period of time and access to resources was limited, it was not possible to control when the crops were planted to ensure that soil samples were taken at the same time in the growing season. In further studies, it would be ideal to more closely monitor crop planting and fertilizer application in order to prevent introducing other variables that complicate the analysis.

Because there was a lack of precision and accuracy in the soil nutrient analysis methods employed in 2013, attempts were made to employ a more accurate and precise nutrient analysis method. The nitrate electrode method was used to analyze the samples collected in 2014 because of its relative ease and availability. This method is considered a suitable when analyzing a small number of samples and is recommended by scientists because of its rapid analysis and low instrumentation cost. While the electrode is subject to small interferences, particularly in the calibration and handling of the equipment, extra caution was taken to avoid variances in readings when analyzing nitrate concentration. One step that was taken to avoid interference was the use of $(NH_4)_2SO_4$ as an extracting solution, rather than KCl or $CaCl_2$, as chloride can interfere with the ion selective electrode analysis of nitrate. Furthermore, the electrode was calibrated and all of the samples were analyzed on the same day in order to minimize experimental error.

It is important to note that Table 1, which is a small representation of interview responses, illustrates that a wide range of agricultural techniques are used in the community. Interviews revealed that reasons for practicing a particular method ranged from concern for sustainability, economic feasibility, and familial history. One of the overarching themes that resulted from the interviews in 2013 and 2014 is that farmers in Nuevo Horizonte would like to increase sustainable agricultural practices, however they are concerned about the lack of resources and education to do so.

Conclusion

While the results of this study raise concerns regarding the overall low levels of soil nutrients and lack of agricultural education within Nuevo Horizonte, the time spent in this inspiring community also revealed a combination of perseverance, solidarity, and dedication to environmental protection that provide hope for promising innovations and transformations to increase sustainability. Analysis of the results from this study and literature highlighting common sustainable agricultural techniques in Latin America have led to three main recommendations that Nuevo Horizonte could implement to increase sustainability: implementing composting, developing "community agriculture" programs, and increasing education and training within the community. These recommendations are detailed more thoroughly in Appendix III and were developed to encompass the morals of Nuevo Horizonte in order to support future generations, while understanding restrictions such as lack of resources.

Works Cited:

Brussaard, L. & Ferrera-Cerrato, R. (1997). Soil ecology in sustainable agricultural systems (advances in agroecology). Boca Raton: CRC/Lewis Publishers

Central Intelligence Agency. (2014). *The world factbook: Guatemala*. Retrieved from https://www.cia.gov/library/publications/the-world-factbook/geos/gt.html on September 12, 2014

Conciliation Resources. (1997). *Negotiating rights: The Guatemala peace process*. Retreived from http://www.c-r.org/accord/guatemala November 5, 2014

Environmental Protection Agency (2014). *Integrated pest management (IPM) principles*. Pesticides: topical and chemical facts sheet. Retrieved from http://www.epa.gov/pesticides/factsheets/ipm.htm on November 12, 2014

Food and Agriculture Organization of the United Nations (2007). *Adaptation to climate change in agriculture, forestry and fishereis: Perspective, framework, and priorities*

Francis, Poincelot, & Bird. (2006). *Developing and extending sustainable agriculture: A new social contract*. New York: Haworth Food & Agricultural Product Press

Hartwig, N.L. & Ulrich Ammon, H. (2002). Cover crops and live mulches. *Weed Science, 50.6*, 688-699

Hazell, P. & Wood, S. (2008). Drivers of change in global agriculture. Philisophical Transactions of the Roayl Society 363, 495-515

International Fund for Agricultural Development (IFAD). *Rural poverty in Guatemala*. Retrieved from http://www.ruralpovertyportal.org/country/home/tags/guatemala November 5, 2014

Lal, R., Kimble, J.M., Levine, E.R., & Stewart B.A. (1995). Soils and Global Change. Boca Raton: Lewis Publishers

Lappe, M. & Bailey, B. (2002). Engineering the farm: the social and ethical aspects of agricultural biotechnology. Washington, D.C.: Island Press

Manahan, S.E. (2009). *Environmental chemistry, ninth edition*. Boca Raton: CRC Press. 466-474

Mersky, M. (2005). *Human rights in negotiating peace agreements: Guatemala*. International Council on Human Rights Policy. Belfast, 2005.

Miller, T. (2011). *Timeline: Guatemala's brutal civil war*. PBS Newshour. Retrieved from http://www.pbs.org/newshour/updates/latin_america-jan-june11-timeline_03-07/ November 5, 2014

National Research Council. *Sustainable Agriculture and the Environment in the Humid Tropics*. Washington, DC: The National Academies Press, 1993.

National Research Council. Toward Sustainability: Soil and Water Research Priorities for Developing Countries. Washington, DC: The National Academies Press, 1991.

Pretty, J. (2008). Agricultural sustainability: concepts, principles, and evidence. Philosophical Transactions of the Royal Society, 363, 447-465

Smil, V. (2000). Feeding the world: a challenge for the twenty-first century. Cambridge, Mass.: MIT Press

Teasdale, J.R. (2013). Contribution of cover crops to weed management in sustainable agricultural systems. *Journal of Production Agriculture, 9.4*, 475-479

Tol, R. (2002). Estimates of the damage costs of climate change. Part 1: benchmark estimates. 21, 47

Trefzger, D.W. (2002). *Guatemala's 1952 agrarian reform law: A critical assessment*. International Social Science Review, History Department, University of Miami

United Nations Development Programme. (2009). Assessment of development results: Guatemala. Retrieved from http://www.oecd.org/countries/guatemala/46820221.pdf September 2014

United States Department of Agriculture. "Soil Phosphorus. Soil Quality Kit-Guides for Educators". *United States Depeartment of Agriculture Natural Resources Conservation Service*. Pages 1-6. Retrieved from http://soils.usda.gov/sqi/assessment/files/phosphorus_guide.pdf on 14 April, 2013.

United Nations Population Division. *The World at Six Billion*. Retrieved from

http://www.un.org/esa/population/publications/sixbillion/sixbilpart1.pdf on October 3, 2014.
Viscidi, L. (2004). *Land reform and conflict in Guatemala*. Counterpunch.
World Bank (1995). *Guatemala: an assessment of poverty*. Report No. 12313-GU
World Bank Research Observer. (1999). 14, 277-293
World Bank, Development Research Group. GINI index. Retrieved from http://data.worldbank.org/indicator/SI.POV.GINI September 2014
World Food Programme. (2012). Guatemala. Retrieved from https://www.wfp.org/countries/guatemala/overview on September 22, 2014

Appendix 1: Interview Questions for Farmers

Background questions

1. What crops do you typically plant in your field?
    a. In the past 3-5 years, have you planted any different crops?
2. Can you estimate your regular crop yield?

Fertilizer/Organic materials

1. Do you apply synthetic fertilizers to your field?
    a. If yes, how often? (Times per week, month, year)
    b. Do you know how much is applied to the field each time you apply fertilizers?
        - Do you follow the packet provided with the fertilizers?
    c. Where do you buy the fertilizers you use?
    d. How often do you buy fertilizers and how much do you spend to buy the fertilizers?
    e. Why do you choose to use synthetic fertilizers on the fields?
2. Do you apply any organic materials to the fields, such as cow manure, organic compost, legumes, or plant residues to the fields?
    a. If yes, how often (Times per week, month, year)
    b. Why do you choose to apply organic items to the fields?
    c. Do you buy any of the organic materials you apply?
        - If yes, how much do you spend?
3. There is some scientific evidence that shows that the use of organic materials can provide adequate levels of nutrients to the field and avoid some potential issues found with the use of synthetic fertilizers.
    a. Knowing this, would you be willing to switch your agricultural techniques?
    b. Would you be willing to completely stop using synthetic fertilizers?
    c. Would you be more willing to use a mixture of synthetic fertilizers and organic materials?

Insecticides/Pesticides

1. Do you use any synthetic insecticides or pesticides?
    a. If yes, how often? (Times per week, month, year)
    b. Do you use them to apply just to the seeds planted, just to the fields, or both the seeds and the fields?
    c. Do you know how much is applied to the field each time you apply insecticides/pesticides?
        - Do you follow the packet provided with the insecticides/pesticides?
    d. Where do you buy the insecticides/pesticides you use?
    e. How often do you buy insecticides/pesticides and how much do you spend to buy them?
    f. Why do you choose to use synthetic insecticides/pesticides?
2. Do you practice any other techniques to guard against insects and pests?
    a. If yes, what techniques do you use?

3. There is some scientific evidence that says that the use of different synthetic insecticides and pesticides can have harmful effects to both the environment and human health. There is also some evidence that shows that the use of these chemicals can lead to further soil degradation and could even lead to lower crop yields because other pests that are resistant to the pesticides can develop.
    a. Knowing this, would you be willing to switch your agricultural techniques?
    b. Would you be willing to completely stop using synthetic insecticides and pesticides?
    c. Would you be willing to use less synthetic insecticides and pesticides?

Tillage/Crop Rotation

1. Do you regularly till the land you use or leave crop residues on the field?
    a. There is some scientific evidence that reducing the amount of tillage in fields can improve soil health by reducing erosion, improving moisture retention, and replenishing organic material. Knowing this, would you be willing to reduce the amount of tillage in your field?
2. Do you ever practice intercropping where two or more species are planted in a field at the same time?
3. Do you ever practice crop rotation where two or more species are planted in the same field at different seasons?
    a. There is some scientific evidence that intercropping and crop rotation can help reduce soil erosion. Given this information, would you be willing to practice these methods?

Additional comments/follow up questions