Fall 2018

La tierra aquí es amable: Soil macrofauna density and producer perceptions of agricultural soil fertility in Cerro Punta, Chiriquí

Clara Fernandez Odell
SIT Study Abroad

La tierra aquí es amable: Soil macrofauna density and producer perceptions of agricultural soil fertility in Cerro Punta, Chiriquí

Clara Fernandez Odell

-

Barnard College

Department of Environmental Science

SIT Panama: Tropical Ecology

December 2018

Abstract

Ethnopedology, as a subfield of ethnoecology, is the study of localized symbols and values, knowledge, and practices relating to soils. One key framework for ethnopedological studies is the *Kosmos-Corpus-Praxis* model, which synthesizes local and traditional ecological into three overlapping, interrelated spheres. Cerro Punta, Chiriquí is the primary vegetable-growing region in Panama, an industry highly dependent on the region's fertile volcanic soils. Semi-structured interviews (n=8) and soil macrofauna density surveys as an indicator of soil fertility (n=9) were used to gather information regarding producers' beliefs, knowledge, and decisions about soil fertility.

Among producers in Cerro Punta, religious beliefs and land symbolism shaped understandings of soil fertility and management practices. Practices were also informed by assessments of soil fertility using predominantly qualitative indicators, which showed informal correlation with soil macrofauna density. Although there was some significant difference in macrofauna between conventional and organic sites, methods used to evaluate and manage soil fertility did not vary greatly between the two production methods, with most producers using a variety of indicators and practices to meet their soil fertility needs. More research on the ways in which symbolism and cosmovisions, cognition, and practice interact in localized natural resource management is needed, especially in areas with significant agricultural use such as Cerro Punta.

Acknowledgments

I'd like to thank the wonderful staff of SIT Panama – Aly Dagang, Rhay Perez, and Yari Jimenez – for keeping us safe, happy, fed, and learning. Special thanks to Aly for challenging and encouraging me, as an Academic Director and an advisor.

Thanks to Maya, Mackenzie, and Julia for accompanying me through the wild world of interviewing; Damaris Sanchez for her hospitality, humor, and vital community connections, without which this research would never have happened; FUNDICCEP, AMIPILA, and GORACE for offering incredible support and resources; Helena, Billy, and Ben for moral support and fact-checking throughout the writing process; and my friends and family, for their love and support.

Most of all, thank you to the farmers of Cerro Punta who participated in this study. Your kindness, knowledge, observation, and hard work feed people every day and I'm very grateful to share in a little piece of that work with you.

Table of Contents

Introduction

Ethnopedology: The formation of soil knowledge

Knowledge about natural and agricultural systems is formed in diverse ways and comes from a wide array of sources. Traditional ecological knowledge, localized and informal knowledge systems, and the scientific process are all valid and potentially complementary systems for forming the environmental knowledge that is used to inform natural resource management (Raymond et al. 2010). Historically, scientific methods have been privileged over other ways of knowing in the fields of ecology and sustainability; however, the conventional "objective" measures of sustainability, ecosystem health, and quality of life have the unfortunate tendency to decontextualize and universalize unique and localized processes (Altieri 2002; Nazarea et al. 1998).

The study of traditional, indigenous, and localized soil knowledge and management is known as ethnopedology, a sub-field of ethnoecology that seeks to understand and support local soil management practices, especially in ecologically vulnerable areas (WinklerPrins and Barrera-Bassols 2004). Ethnopedology can take the form of asking local people (including but not limited to landowners, farmers, ranchers, and other people who work directly or indirectly with soils) to create soil type maps, evaluate soil quality, or explain their understanding of soil's physical, chemical, and biological properties (WinklerPrins and Barrera-Bassols 2004; Laekemariam et al. 2017; Pauli et al. 2016).

One ethnoecological model that can be applied to ethnopedological studies is the *Kosmos-Corpus-Praxis* or K-C-P model, which attempts to elicit and synthesize symbols and beliefs about land and soil (*Kosmos*), cognition and knowledge about soils (*Corpus*), and soil management practices (*Praxis*) (WinklerPrins and Barrera-Bassols 2004). These aspects of knowledge and practice in conjunction form indigenous and local systems of soil knowledge, and inform soil management. The K-C-P model provides a useful framework for understanding local ethnopedologies and for making comparisons and finding commonalities between ethnopedologies at regional and global scales (Barrera-Bassols et al. 2006b).

Localized soil management practices are often (although not always) knowledge-intensive rather than input-intensive. In some tropical agricultural contexts, output to input ratios are higher in low-input systems than in comparable mechanized, agrochemical-reliant systems (Altieri 2002). Substantial research with smallholder producers in tropical systems supports the notion that traditional, localized, and informal knowledge of soil types, soil quality evaluation, and soil management provide a rich resource for the development of dynamic, locally adapted, and lower-input agricultural systems (Altieri 2002; Abera and Belachew 2011; Kome et al. 2018).

At their best, traditional ecological knowledge, localized knowledge systems, and scientific knowledge can be complementary, creating hybrid knowledge. Hybrid knowledge refers to the ways of knowing and novel understandings that come either from integration of pre-existing knowledge or from trans-disciplinary research (Raymond et al. 2010). In soil science, this can look like integrating conventional quantitative methods of describing soil types and processes and evaluating soil quality with the quantitative and qualitative processes that local and indigenous groups use to describe, evaluate, and manage soils.

Soil fertility: Foundations of life

One of the key aspects of agricultural soil quality is soil fertility. In a formal scientific context, soil fertility refers to the productive capacity of soils – their ability to support and sustain life. A soil is fertile if it fulfills the ecosystem services promoting the growth of bacteria, fungi, plants, and animals. Soil fertility is a product of physical and chemical processes heavily influenced by the macroscopic and microscopic organisms that live in soil (Stockdale et al. 2002). These organisms help create fertile soils, but they are also influenced – and restricted – by the fertility of the soil they inhabit.

In the agricultural sciences, fertility can be defined as the capacity of the soil to produce the desired crop yield by supplying the required amount of nutrients (Watson et al. 2002). However, this definition simplifies the complex web of processes and actors that contribute to the fertility of a soil. It can be useful to understand soil fertility in the context of agricultural systems and soil quality in general as ecosystem concepts. Evaluations of soil's diverse functions and properties can be integrated to form a holistic plan for managing fertility (Biswas et al. 2014).

Many traditional or local definitions of soil fertility held by producers the production of a high crop yield as one of the defining properties of a fertile soil (Dawoe et al. 2012). Other factors often included in local definitions of soil fertility include dark color, high water retention, the presence of macrofauna or macrofauna evidence (such as worm casts), and vigorous, large-leafed plants (Dawoe et al. 2012; Laekemariam et al. 2017). It is interesting to note that while the agricultural science definition of soil fertility is based primarily on the relationship between crop yield and nutrients, most producers in several studies cited soil color, texture, and macrofauna as the most important factors in identifying fertile soils – over crop production (Abera and Belachew 2011; Dawoe et al. 2012; Laekemariam et al. 2017).

Soil fertility management: Approaches and conflicts

The management of soil fertility is of particular concern to producers in the humid and sub-humid tropics, where agricultural soils are generally nutrient poor. Among smallholder farms in tropical regions, a variety of approaches have been taken to improve soil fertility. According to van Beek et al. (2017), two general approaches can be used to address issues with soil fertility: a producer can either increase the total amount of nutrients in their system or increase the bioavailability of existing nutrients in the system. Each approach comes with advantages, challenges for producers, and potential environmental consequences.

Broadly, addition of soil nutrients is associated with conventional approaches of applying inorganic fertilizer. In tropical agricultural systems, the use of mineral and chemical fertilizers is growing (van Beek et al. 2017; Kome et al. 2018). However, many smallholder farmers are either unable to accumulate the capital necessary to purchase mineral or chemical fertilizers or must use credit to do so, making them economically problematic (Kome et al. 2018). The use of organic fertilizers such as farm yard manure, maize stover, and compost, both alone and in combination with inorganic fertilizers, also increases the abundance of soil nutrients and may be more cost-effective for farmers than an all-chemical or mineral approach to fertilization. However, many approaches that involve adding artificially high levels of nutrients to the soil potentially alter the equilibrium of nutrient cycling in soil and can carry possible consequences for future soil fertility (Ayuke et al. 2011).

Approaches to soil fertility management that involve increasing or preserving the bioavailability of existing soil nutrients are generally associated with alternative soil management practices and soil conservation methods. Mulching and cover-cropping are used to increase the nutrient-holding capacity of soils, although in some cases they can also add nutrients to the system (for instance, through nitrogen fixation by leguminous crops). Soil amendments, commonly called "soil primers" or "compost starters", are generally organic materials that are applied to increase microbial activity. This encourages the release of native nutrients in the soil without adding additional nutrients to the system (van Beek et al. 2017). Preserving the availability of existing soil nutrients can also come in the form of erosion control, which prevents the loss of valuable nutrient-rich topsoil in regions with high slope or wind erosion (Kome et al. 2018).

It is important to note that these approaches to improving soil fertility are not necessarily mutually exclusive; in many tropical regions, Integrated Soil Fertility Management (ISFM) has been successful in restoring and preserving fertility in degraded agricultural soils. ISFM is a multi-pronged approach that combines organic and inorganic fertilizers with soil conservation and amendment practices to promote sustainable nutrient management (Ayuke et al. 2011). At its best, ISFM draws on local knowledge, traditional agricultural practices, and scientific analysis to provide soil fertility management frameworks that adapt to the local cultural, economic, and ecological needs of individual regions and producers (Agegnehu and Amede 2017). ISFM attempts to avoid the overarching, top-down recommendations for soil fertility management depending on only one epistemological framework of understanding soil dynamics that have characterized many attempts to improve tropical agricultural soil fertility (Ayuke et al. 2011).

Soil macrofauna and fertility: Drivers and indicators

One of the key indicators of soil fertility in both scientific and traditional knowledge frameworks is the presence, abundance, and species richness of soil macrofauna. In the humid and sub-humid tropics, earthworms are the most influential macrofauna in determining a soil's fertility (Lal 1988). Earthworms increase pore space, aid in nutrient cycling, reduce soil moisture, and retain soil organic matter. All of these processes, particularly nutrient cycling and the retention of soil organic matter, influence soil fertility (Bhadauria and Saxena 2010).

The impacts of macrofauna on agricultural soil fertility are well established. Increased abundance and diversity of earthworms has a strong positive correlation with increased production on pasture and cultivated land (Schon et al. 2017). Other macrofauna found in agricultural soils also provide valuable contributions to soil fertility. Termites, for example, influence soil aggregation and physical structure through burrowing and the production of feces and saliva (Ayuke et al. 2011). Leaf-cutter ants can add organic matter to soil by leaving decomposing plant tissue on the soil surface (Pauli et al. 2016).

Soil macrofauna such as earthworms are ecosystem engineers that create soil fertility; however, their abundance and diversity are also affected by the physical and chemical parameters that create soil fertility. Silt-heavy soils that are high in potassium and organic carbon and low in sand generally have the greatest earthworm abundance and diversity. Organic carbon in particular is a critical factor in determining earthworm distribution, density, and abundance (Singh et al. 2016).

Within agricultural systems, macrofauna abundance and diversity can be positively affected by the application of soil treatments including farmyard manure, maize stover, and compost (Bartz et al. 2013). Organic practices, particularly the absence of mineral fertilizer and chemical herbicides, are positively correlated with macrofauna abundance (Birkhoffer et al. 2008). The use of organic soil fertility management practices and macrofauna abundance are also both positively correlated with other indicators of soil fertility such as organic carbon and nitrogen content and soil organic matter (Bartz et al. 2013). Conversely, certain commonly used pesticides and herbicides can cause macrofauna abundance and species richness to decline, especially when combined with heavy or frequent mechanical tillage (Crittenden et al. 2014).

Since abundance and diversity of soil macrofauna like earthworms are linked to soil management practices and correlate with other factors affecting fertility, soil macrofauna are generally good indicators of soil fertility. Measurements of earthworm abundance and biomass are particularly relevant indicators in cultivated areas and areas generally associated with agricultural activity (Pérès et al. 2011).

When using macrofauna – and particularly earthworms – as indicators, it is important to bear in mind the positive feedback relationship between earthworms and soil fertility, wherein earthworm abundance and diversity are affected by soil fertility and create soil fertility (Schon et al. 2017). Additionally, it is important to use regionally relevant indices when interpreting the implications of earthworm abundance and diversity; high density and species richness for temperate regions may be low for tropical and sub-tropical areas (Bartz et al. 2013).

Many producers in tropical regions cite macrofauna – and specifically presence of earthworms and worm casts – as key qualitative indicators of soil fertility (Dawoe et al. 2012). Farmers in the tropics report awareness of the role of macrofauna in nutrient cycling and the manipulation of macrofaunal presence to increase soil fertility selectively (Pauli et al. 2012). Traditional and local knowledge systems regarding macrofauna activity in agricultural soils are largely untapped resources; the body of ethnopedological research related to macrofauna is relatively small and focused on a few geographical areas. Further research into farmer understandings of soil-macrofauna interactions is urgent and important, especially as traditional knowledge about soil systems is becoming less frequently transmitted in many regions (Pauli et al. 2016).

Applications in Cerro Punta, Chiriquí

Chiriquí is the predominant agricultural region of Panama, representing the majority of the nation's domestic food output. Cerro Punta in particular is notable for producing around eighty percent of Panama's vegetables (Shah 2006). Cerro Punta has a wet climate with an annual average precipitation of approximately 2300 millimeters (Guiterrez-Guiterrez and Muñoz 2009). The soils in and around Cerro Punta are predominantly Andisols, which are characterized by the domination of short-range-order minerals and a high content of volcanic glass. Andisols have a high capacity to hold both nutrients and water, making them unusually fertile compared to most other tropical soils (Wambeke 1992).

Most of the agricultural activity in Cerro Punta takes the form of small commercial or mixed commercial-subsistence plots, which are predominantly situated on steep, terraced slopes (Organic Producer 1, pers. comm., 12 November 2018). Producers generally employ few or no soil conservation practices; because of this, soils are degraded and nutrients are lost through erosion and leeching due to increasingly intensified cultivation (Shah 2006). Similar problems of soil loss and degradation, especially in mountainous areas, are well-documented throughout the tropics (Scopel et al. 2013).

Because most producers are smallholders and rely on a limited land area, their crop yield (and therefore their incomes) depend on the fertility of their soils. Globally, poor soil fertility is one of the primary factors limiting smallholder productivity. Inequities in wealth and access to institutions that provide agricultural extensions and soil fertility treatments create disparities in smallholder soil fertility along socioeconomic lines (Tittonell et al. 2005). When producers in smallholder-dominated agroecosystems such as Cerro Punta are able to define, assess, and manage their soil fertility through indicators like macrofauna abundance, the entire system benefits economically and ecologically.

Little literature is available about macrofauna communities in Panama's agroecosystems. Generally in Central America, earthworm family and species richness are lower in cultivated land than in pasture and forested land (Lavelle et al. 1995). However, it is unclear if these results can be applied to the western Panamanian highlands specifically. Similarly, no parameters exist for "good" and "poor" macrofaunal abundance in agricultural soils in Central American Highlands, although parameters exist for other tropical ecosystems (Bartz et al. 2013). For macrofauna abundance to be a meaningful soil fertility indicator in Cerro Punta, it is important to compare abundance and density between study sites and with producers' evaluations of their soils fertility.

There is a dearth of ethnopedologic research in Panama generally, and in the Chiriquí highlands specifically. Since Cerro Punta and the surrounding cultivated regions are so agriculturally important, and since much of the land in this area has been intensively cultivated for over 60 years, it seems evident that producers – especially long-time producers – have developed local frameworks for classifying soils and evaluating soil fertility. While some producers use laboratory services for soil testing, most rely on qualitative indicators of fertility either solely or in complement to laboratory testing (Conventional Producer 2, pers. comm., 9 November 2018). Research into the symbolic, cognitive, and practical frameworks that producers use to evaluate and manage soil fertility is relevant to everyone working in or making decisions about agriculture in Cerro Punta.

Methods

The objective of this study was to create an ethnopedology of soil fertility among conventional and organic producers in Cerro Punta, Chiriquí. This was achieved by exploring producer beliefs and perceptions, knowledge, and practices relating to soil fertility through interviews and by surveying macrofauna density in cultivated soils on sites under organic and conventional production practices.

Site selection and participant identification

To identify producers who would be willing to participate in the study, I used purposeful sampling to identify producers who were willing to volunteer as participants and who met study criterion (Palinkas, 2013). For some producers, I obtained contact information from lists kept by local organizations including Amigos del Parque Internacional La Amistad (AMIPILA), Fundación para el Desarrollo Integral Comunitario y Conservación de los Ecosistemas en Panamá (FUNDICCEP), and Grupo Orgánico de Agricultores Cerropunteños (GORACE). Producers from these lists were contacted to check if they were interested in participating. Other producers were identified through casual introductions, either by a community member or by meeting in a public place such as the producer's vegetable stand or the agrochemical store. After I made initial contact with producers, I used the snowball method outlined in Bernard (2018) to identify additional suitable participants.

Once producers were contacted, I asked a series of preliminary screening questions to verify that potential participants met study specifications. Participants must be actively farming a cultivated area of at least one hectare within five kilometers of Cerro Punta. I did not specifically seek out the owners of the land, but I asked each potential participant if he or she was the person who made decisions about crops and land use. In order to more effectively narrow down the pool of participants, I asked potential participants if their cultivated land was for commercial use only, personal and commercial use, or personal use only. I then selected only participants who used their land either solely commercially or for personal and commercial use.

After identifying willing and suitable participants, I presented each participant with a short synopsis of the study topic and goals. I then asked the participant for verbal informed consent. If the participant agreed to the interview and sampling process, we then arranged either a time to conduct both sampling and an interview or a time to interview and a second time to visit their cultivated land for sampling, depending on participant availability and the location of the participant's farm.

Interviewing

I used semi-structured individual interviews to assess producer perceptions of what soil fertility is, the perceived fertility of their cultivated land, and the methods (qualitative or quantitative) that they use to assess soil fertility (Abera and Belachew 2011). Producers were asked to outline indicators that they used to evaluate the fertility of their soils and how they use these indicators to make decisions about soil management and conservation. They were also asked if they had a soil conservation plan, and if so, what was included. Additionally, farmers were asked to numerically rate the fertility of their soil on a scale of 1 (least fertile) to 5 (most fertile). The purpose of this question was to assess the congruence between farmer perceptions of soil fertility and the fertility of soils as indicated by macrofauna abundance and density (Laekemariam et al. 2017). Additionally, farmers were asked to provide personal definitions of soil fertility and descriptions of soil-macrofauna interactions.

Producers were also asked about soil management history, soil amendments or additions (timing, type, and amount), fertilizer application (timing, type, and amount), pesticide and herbicide application (type, timing, and amount), and tillage practices. The purpose of these questions is to understand variables that might potentially affect soil fertility and macrofauna density. Questions about soil amendments, fertilizer, pesticides, and herbicides were phrased broadly to include both conventional agrochemicals and alternative fertility and pest control methods. Each interview is paired with a soil sample.

During most interviews, I used both voice recordings and written notes to aid recall and ensure accuracy in transcription (Bernard 2018). Affirmative consent was always obtained prior to beginning a voice recording or taking notes, in addition to the informed consent that accompanied each interview. Information from interviews or casual conversation where there was no affirmative consent to record or take notes is not included in the study results, although some of this information helped guide subsequent interviews.

All interview methods underwent IRB/LRB review to ensure that no harm was done to participants and were approved prior to beginning research.

Sample collection and analysis

For macroinvertebrate density, five representative sampling points were randomly selected at each producer's farm. For producers with only one field, all five points were sampled at the same field; for producers with more than one field, five fields were selected at random (allowing repeats). Points were randomized by standing at the center of each field, randomly generating a compass bearing, and then randomly generating a number of meters between 5 and 20. This process was repeated five times until all five sampling points were selected and marked, at which point sampling could begin. Points within five meters of a mulch or compost pile were not included because of the disproportionate influence of these factors on macroinvertebrate density. All sampling points were at least 10 meters apart (Bartz et al. 2013).

To measure macroinvertebrate density, I established a 10 centimeter by 10 centimeter plot next to each point and excavated 10 centimeters down throughout the plot (Bartz et al. 2013). Sample soil (1000 cubic centimeters) was placed in a plastic bag for transport. Macroinvertebrate samples were hand-sorted and counted within five hours on the same day that the sample was collected. Macroinvertebrates were counted and separated into broad taxonomic groups (e.g. *Annelida*, *Isoptera*, *Myriapoda*). However, species or family richness within taxa was not assessed.

Data analysis

Interview data was analyzed using categorical analysis (Bernard 2018). The different soil fertility indicators and soil fertility management strategies mentioned in interviews were listed and then grouped by type (qualitative and quantitative for fertility indicators; nutrient addition, nutrient enhancement, and soil conservation for fertility management strategies). The number of organic and conventional producers who reported using each indicator or strategy was divided by the total number of producers in that group to obtain the percentage of producers in each group who reported using each indicator or strategy. Total (combined conventional and organic) use of each indicator or strategy was also reported.

Thematic analysis was used to find common threads in producer definitions of soil fertility and explanations of soil fertility importance and macrofauna-soil interactions. Thematic analysis in ethnoecology involves identifying intersecting or common logic, symbols, and themes in explanations of environmental facts, concepts, and processes (Medeiros et al. 2014). These thematic findings are briefly mentioned as results and are expanded upon further in discussion with the Kosmos-Corpus-Praxis framework of ethnopedology (WinklerPrins and Barrera-Bassols 2004).

Soil macrofauna data was analyzed to find total mean density and mean density of each taxa per square meter for each sample site. Mean macrofauna and mean *Annelida* densities per square meter were calculated for organic and conventional producers. Two-tailed unequal variance ttests were conducted to determine if the difference of mean densities between organic and conventional producers was statistically significant.

Results

A total of 8 producers participated in the study, 6 conventional and 2 organic. A total of 9 sites were surveyed for macrofauna density. One organic producer worked on two farms with separate evaluations of fertility, so macrofauna density surveys and soil management information were collected for both and entered as separate farms.

The results of this study are limited by the small sample size, especially of the organic group, and the non-random selection of participants. Because participant and site availability depended on the availability of producers and their willingness to conduct an interview, sampling was not truly random. Although sampling points for macrofauna density were generated randomly, some producers were unable to make all their fields available for sampling; therefore some macrofauna survey data may present an incomplete picture of the sampling site as a whole. It is also important to note that soil fertility and macrofauna density are highly heterogeneous within fields and even within rows (Pérès et al. 2011). While randomization accounts for some of this heterogeneity, it is difficult to establish representative macrofauna surveys with a high degree of confidence.

Interviews

Producers included in the study had worked in agriculture between 18 and 58 years, with a mean of 36 years. The cultivated land included in the study for macrofauna sampling had been under cultivation between 6 and 43 years, with a mean of 23. Farm sites were distributed throughout the basin surrounding Cerro Punta. Producers farmed in Guadalupe (n=3), Nueva Suiza (n=2), Bajo Grande (n=1), Cerro Punta town (n=1), and Las Nubes (n=1).

All producers included in the study reported growing diversified vegetables on their land. The most commonly reported crops were onion (n=4), potato (n=4), lettuce (n=3), parsley (n=3), and broccoli (n=3). 38% of producers also reported growing perennial fruit trees, including *Solanum betaceum* (tree tomato, n=3) and *Ficus carica* (n=1). Each producer reported growing at least three crops over the course of a regular calendar year. Most producers primarily used hand tillage every 3 to 4 months (n=6), although estimated frequency of tillage ranged from every month to every 6 months. Two producers reported using machine tillage (tractor or rototiller) to supplement hand-tillage.

All conventional producers reported using chemical pesticides, herbicides, or fungicides on all or most of their cultivated land (n=6). Of these, two emphasized the minimal use of agrochemical pest deterrents. Among organic and conventional users, alternative pest and disease management strategies included growing pest-resistant crops such as parsley and garlic (n=3), application of garlic oil to crops (n=2), hand-removal of pests (n=2), and application of fermented coffee grounds (n=1).

When asked to define soil fertility and its importance, producers mentioned higher crop yield (n=6), improved plant health (n=5), on and off-farm biodiversity (n=2), and easier tillage (n=2) as advantages of a fertile soil. Some producers (n=2) conceptualized soils and soil fertility as part of an ecosystem concept that includes developed, cultivated, and undeveloped or protected land. Multiple producers also linked soil fertility and their role in soil fertility management to land symbolism (n=2) or to religious beliefs (n=3).

Producers reported using a variety of strategies and indicators to evaluate soil fertility. The most commonly used indicators of soil fertility were color (n=6), texture (n=5), and plant health (n=4). All producers reported using qualitative indicators to assess soil fertility. Additionally, two producers reported quantitative approaches to soil fertility evaluation that included laboratory analysis. Indicators used to evaluate soil fertility are summarized in Table 1.

Table 1. Producer use of quantitative and qualitative soil fertility indicators, by organic and conventional producers.

Type	Indicator	% Organic	% Conventional	% Total
Quantitative	Nutrient content	0%	33%	25%
	Macrofauna*	0%	16%	13%
Qualitative	Color	100%	66%	75%
	Texture	100%	50%	63%
	Porosity	50%	33%	38%
	Plant health	100%	33%	50%
	Macrofauna*	100%	16%	38%

*Note that macrofauna is included as both a qualitative and quantitative indicator. Quantitative use of macrofauna as an indicator refers to systematic abundance and species richness surveys. Qualitative use of macrofauna as an indicator refers to informal or non-systematic use of macrofaunal presence or abundance as an indicator of soil fertility.

In terms of soil fertility management and fertilizer application, reported producer approaches were divided into three broad categories: nutrient addition, nutrient enhancement, and soil conservation. Nutrient addition refers to practices that add foreign nutrients into the soil (e.g. organic and conventional fertilizers), nutrient enhancement refers to practices that improve the bioavailability of already present nutrients or improve the soil's nutrient-holding capacity (e.g. soil amendments such as coffee grounds and bone meal), and soil conservation refers to practices that aim to retain already nutrient-rich soil (e.g. erosion control). All producers used at least two of these approaches in managing their soil fertility. The different soil fertility management approaches taken by producers are summarized in Table 2.

Table 2. Producer approaches and practices for soil fertility management, by organic and conventional producers.

Approach	Practice	% Organic	% Conventional	% Total
Nutrient addition	Chemical fertilizer	0%	83%	63%
	Gallinaza	100%	100%	100%
	Bokashi	100%	33%	50%
	Compost (food scraps)	50%	33%	38%
Nutrient enhancement	Soil amendments	50%	17%	25%
	Cover cropping	50%	33%	38%
	Crop rotation	100%	83%	88%
	Mulch (residue, weeds, cover crops)	100%	50%	63%
Soil conservation	Erosion control	100%	83%	88%
	Leeching prevention	50%	67%	63%

When asked to evaluate the fertility of their own land, most producers (n=6) mentioned the inter-plot and within-plot variability of soil fertility. On a scale of 1 (least fertile) to 5 (most fertile), the most common approximations of soil fertility rating were 2 (n=3) and 3 (n=3). The mean soil fertility estimate reported by organic producers was 4.3 and the mean soil fertility reported by conventional producers was 2.6 (two-tailed t-test, p=0.006). However, the small sample size and non-random selection of both groups limits the validity of the statistical significance of this figure.

When asked to describe the types of macrofauna present in cultivated soils, producers identified earthworms (*Annelida*, n=8), ants (*Isoptera*, n=4), and millipedes and centipedes (*Myriapoda*, n=3). Multiple producers (n=3) differentiated between earthworm taxa, describing larger brown or dark-colored earthworms found throughout cultivated soils and smaller, red earthworms found only in bokashi or compost piles. One producer differentiated between leaf-cutter ants (genera *Atta* and *Acromyrex*) and other ant genera in terms of their impacts on soil processes. Other producers (n=3) stated that ants were rare or not present in and around Cerro Punta.

Discussing microfauna-soil interactions on soil properties, most producers identified improved soil fertility (n=7) and plant health (n=4) as impacts of soil macrofauna presence. Some producers also indicated that earthworms change the texture of the soil, improving its friability (n=3). Mentioned negative impacts of macrofauna presence include damage to crops by ants, centipedes, and millipedes (n=3).

Soil macrofauna

Mean macrofauna density across all sampled sites was 233 individuals per square meter, with a standard deviation of 76. The taxon with the highest density was order *Annelida*, with a mean density of 133 individuals per square meter, with a standard deviation of 64.

The mean macrofauna density among all sampled sites under organic production practices (n=3) was 307 individuals per square meter, with a standard deviation of 62. The mean macrofauna density for sites under conventional production practices (n=6) was 196 individuals per square meter with a standard deviation of 53. A two-tailed equal variance t-test for comparison of means gives a p-value of 0.04.

The mean density of individuals in the phylum *Annelida* among all sites under organic production practices was 213 individuals per square meter, with a standard deviation of 68. The mean *Annelida* density among sites under conventional production practices was 123 individuals per square meter, with a standard deviation of 33. A two-tailed equal variance t-test for comparison of means gives a p-value of 0.05.

Annelida density and the total macrofaunal density across all sites have a positive linear correlation with a Pearson product moment correlation of 0.92. Among sampling sites using conventional production practices, the Pearson correlation between *Annelida* density and total macrofaunal density is 0.75. Among sampling sites using organic production practices, the Pearson correlation between *Annelida* density and total macrofaunal density is 0.99 (Figure 1).

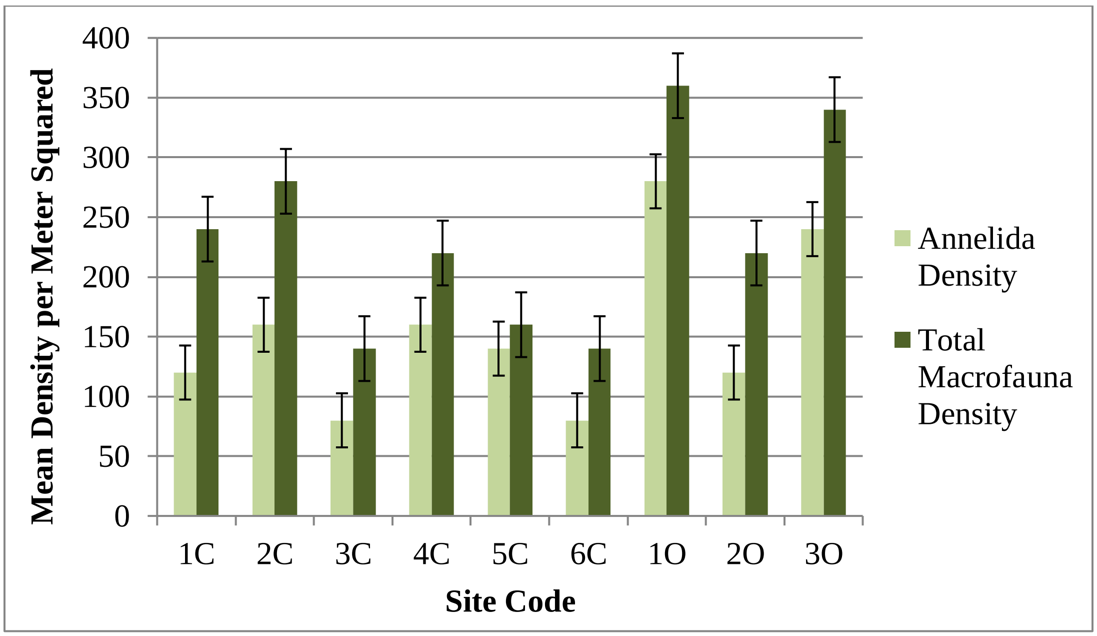

Figure 1. Mean *Annelida* density and mean total macrofaunal density at each sampled site. Sites ending in C are conventional and sites ending in O are organic.

There was a correlation between mean macrofaunal density and producer evaluations of soil fertility on a scale of 1 to 5. Linear regression analysis shows a strong positive correlation with an R^2 of 0.98. However, the non-random nature of interview selection limits the statistical significance of this relationship.

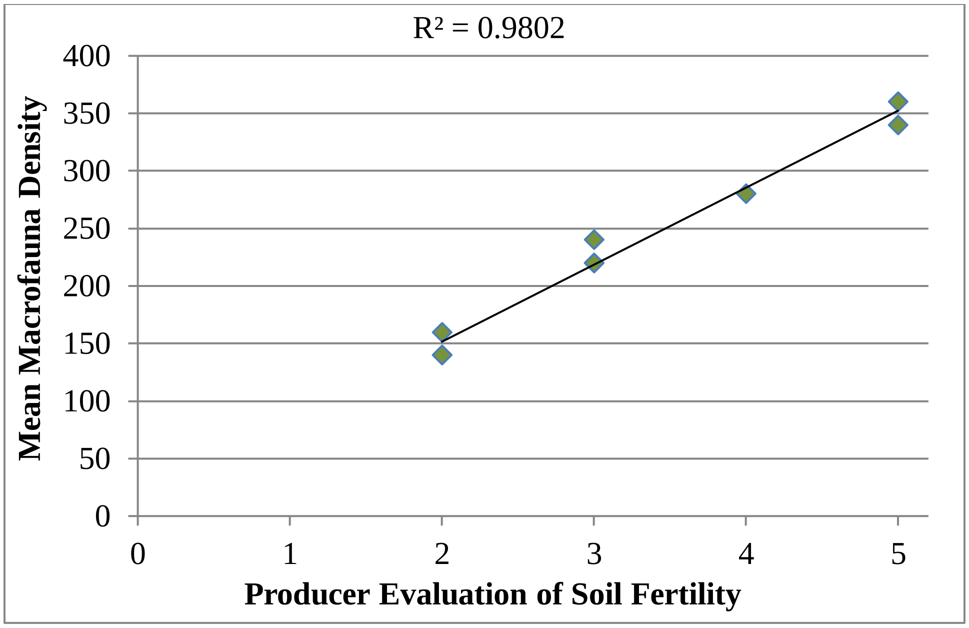

Figure 2. Producer evaluations of soil fertility and mean macrofaunal density per square meter at each sampled site, with linear regression.

Discussion

Kosmos

The aspect of ethnopedology exploring producer cosmovisions and spiritual beliefs and how they relate to soil fertility was the least probed in the study methodology. Questions regarding spirituality, religion, and symbolism of soil were not specifically included in the interview guide. Nonetheless, producers brought up their spiritual, religious, and symbolic concepts of soil fertility, emphasizing that these factors are a key aspect of the ways in which they view and make decisions about soil.

Multiple producers linked soil fertility definitions and practices to religious beliefs and practices; the Christian concept of stewardship as applied to soil fertility. The concept of stewardship as an original intention of humanity expressed in the Bible is applied by some producers to the concept of maintaining the quality and fertility of agricultural land. One producer cited Genesis 2:15, which states “And the Lord God took the man, and put him into the Garden of Eden to dress it and keep it” as a command to care for land by managing soil fertility (Organic Producer 2, pers. comm., 15 November 2018; Gen. 2:15 New Revised Standard Version).

The practices of crop rotation and leaving land fallow are seen by some producers as based in Biblical mandates to allow the land to rest, observing a “Sabbath year” similar to the human Sabbath day. A producer mentioned Leviticus 15:4, which says “but in the seventh year, there shall be a Sabbath of complete rest for your land, a Sabbath for the Lord; you shall not sow your field or prune your vineyard” as justification for leaving fields fallow to regenerate fertility

(Conventional Producer 2, pers. comm., 9 November 2018; Lev. 15:4 New Revised Standard Version).

Some producers who did not make reference to religious beliefs also symbolized and anthropomorphized the land, and used symbolism to justify soil management practices. Soil, like a living thing, works and is given time to rest. Producers referred to the generosity of the soil. One producer, in reference to the superior agricultural quality of the soil in the Chiriquí highlands relative to other parts of Panama, stated that “the land here is kind” (Organic Producer 1, pers. comm., 12 November 2018).

The tendency to symbolize and anthropomorphize agricultural soils has been found in other ethnopedological studies in Latin America as well. Purhépecha farmers in Mexico, for instance, recognize the agency of the land as an active participant in agricultural processes (WinklerPrins and Barrera-Bassols 2003). Soil is characterized as being strong and weak, hungry and thirsty, in need of work and rest. The health of the soil is the same as the health of the living beings – crops, wild plants, microorganisms, and macrofauna – that depend on it (Barrera-Bassols et al. 2006a).

The presence of soil macrofauna was also incorporated into land symbolism. The interconnectedness between living things, geological processes, and abiotic factors like precipitation was extended by multiple producers to include connection with spirituality and the concept of creation. One producer explained that they viewed soil processes and soil-macrofauna interactions as part of “a web that connects and underlies everything” (Organic Producer 1, pers. comm., 12 November 2018).

Another producer mentioned that the Biblical mandate of stewardship “applies to earthworms like humans” and that all living things that fundamentally alter the character of the land – including the soil – are obliged to care for it and each other (Conventional Producer 4, pers. comm., 14 November 2018). In this producer’s view, soil macrofauna have the same duty and purpose of land stewardship that human producers do, and their role in creating and maintaining soil fertility is similar to that of the producer.

Corpus

The Corpus sphere of ethnopedology refers to the knowledge of soil properties and processes that inform management decisions and perceptions of soil fertility. Generally, this includes indicator methods used to evaluate soil fertility and the local soil taxonomies that producers employ to categorize and assess soils.

Producers were asked to define soil fertility in their own terms and to assess its importance in their agricultural practices. Among interviewed producers, the most common defining factor of a fertile soil was soil with a high crop yield, a definition that reflects the formal definition of soil fertility as “the productive capacity of soils” (Stockdale et al. 2002). Some producers emphasized that soil fertility supports not only increased plant biomass, but also “more varied and healthier” plant life and linked on-farm plant health and diversity to biodiversity in the forested and fallow areas around cultivated land (Conventional Producer 4, pers. comm., 14 November 2018). Soil fertility has been linked to increased on- and off-farm biodiversity specifically in organic systems (Mader et al. 2002). In this study, however, some conventional and organic producers mentioned biodiversity as part of their soil fertility definitions.

Qualitative indicators of soil fertility were used by all producers to assess the level and variability of fertility within and between cultivated plots. Common indicators such as color, texture, and water retention were employed to create local, informal soil taxonomies expressing the variable fertility of agricultural soils. Some producers termed these variable soils “strong” and “weak” soils, and explained how variations in color, texture, and clay content could be used to distinguish between these soil types. Locally and worldwide, qualitative soil assessments are widely used by small-scale, non-industrial farmers to evaluate and make management decisions about agricultural soils (Abera and Belachew 2011).

Interviews revealed some differences in the use of qualitative indicators of soil fertility between conventional and organic producers. A larger proportion of organic producers reported using soil color, texture, plant health, and macrofauna abundance to evaluate soil fertility. The difference between conventional and organic producers was particularly evident in the use of macrofauna as a fertility indicator; 100% of organic producers interviewed reported qualitative evaluations of macrofauna abundance, whereas 16% of conventional producers did. For organic producers, density of *Annelida* had a strong linear correlation with total macrofauna density, suggesting that systematic surveys of earthworms only could be a relatively reliable indicator of macrofauna health as a whole on sites under organic production practices.

Quantitative indicators of soil fertility were sparsely used among interviewed producers. Both producers who did use laboratory testing or home soil testing kits were conventional producers who stated that they used these indicators to adjust application of synthetic fertilizers (Conventional Producer 2, pers. comm., 9 November 2018; Conventional Producer 5, pers. comm., 16 November 2018). Producers who employed quantitative indicators of soil fertility expressed that they were used in complement with more informal, qualitative indicators such as soil quality and texture.

Producer reports of the macrofauna taxa present in their cultivated lands accurately reflected the taxa present in macrofauna surveys. All producers reported that *Annelida* (earthworms) were the most abundant macrofauna taxa; with a mean of 153 individuals per square meter across all sampled sites (conventional and organic), they were by far the densest macrofauna taxa. Producers who reported *Isoptera* (ants) said that they were absent or rare in most of Cerro Punta, a conclusion supported by a mean density of 2 individuals per square meter across all sites. Leaf cutter ants belonging to genera *Atta* and *Acromyrex* were observed on one organic site, but were not found in macrofauna surveys.

Explanations by producers of soil-macrofauna interactions, both negative and positive, showed clear knowledge of the role of macrofauna in creating and indicating soil fertility. All producers recognized *Annelida* as drivers of soil fertility, some stating that earthworm casts and excrement fertilized cultivated soils. Other mentioned benefits of earthworm presence included better space for root growth and improved indication of where to plant new crops. *Isoptera* were mentioned as both positive and negative; bites are painful for producers and colonies can damage crops, but leaf-cutter ants can also provide increased organic matter (via leaf detritus) to soil.

The taxa of soil macrofauna and the soil-macrofauna interactions that producers mentioned tended to be categorized as helpful or harmful to agricultural activities. *Annelida* were exclusively seen as helpful; *Isoptera*, conversely, were predominantly viewed as harmful. Studies on farmer perceptions of soil macrofauna suggest that producers generally are most familiar with taxa that have either a strong positive or strong negative effect on agriculture and are generally less familiar with taxa with a perceived neutral effect (Pauli et al. 2012).

Although the significance of the correlation is statistically limited, soil macrofauna density was positively correlated with producer evaluations of soil fertility. This suggests that producers are highly knowledgeable about the fertility of their own soil, and that their use of qualitative assessments of soil fertility reflects what would be found in quantitative evaluations of the same soil. The finding that small tropical producers understand, accurately assess, and exploit within and between-plot differences in soil fertility is supported by similar studies comparing quantitative indicators of soil fertility with producer assessments across continents (Abera and Belachew 2011; Laekemariam et al. 2017; Kome et al. 2018). Producers in Cerro Punta define, assess, and evaluate soil fertility, categorize soils using local soil taxonomy, and observe soil-macrofauna interactions. This body of knowledge – the *Corpus* – is used to make decisions about agricultural practices.

Praxis

All producers reported using primarily or exclusively hand tillage for seeding and transplanting. Multiple producers reported that, in areas where the soil is fertile (as assessed by the indicators discussed in the *Corpus* section) the texture is such that it is easy to till by hand, so machine tillage is not necessary. Although it appears that hand tillage is primarily used for traditional and economic reasons rather than as a conservation measure, some evidence suggests that electing hand-tillage over machine-tillage improves soil water storage, soil macrofauna density, and responses to fertilization (Radford et al. 1995).

The soil fertility management practices used by producers could be generally sorted into three broad categories. The first is nutrient addition, the input of outside nutrients (in either synthetic or organic form) into cultivated soils. The second category is nutrient enhancement, referring to practices intended to preserve, restore, or improve the bioavailability of already-present nutrients in the soil. The third is soil conservation, which refers to practices that prevent soil loss through erosion and nutrient leeching.

All interviewed producers used some form of nutrient addition, either organic or organic and inorganic, to manage their soil fertility. The most common form of nutrient addition, used by all producers in some form, was chicken manure. Chicken manure is effective in increasing soil fertility for vegetable production up to a threshold level; however, it can increase pest problems and potentially add bacteria including *E. coli*, salmonella, and cryptosporidium to soil (Dikinya and Mufwanzala 2010; Pareja and María 2005). Most conventional producers reported using some form of synthetic fertilizer in addition to gallinaza. All organic producers and some conventional producers reported using or having used bokashi, an organic fertilizer sold locally by AMIPILA. To others, the price and accessibility of bokashi was seen as a barrier to use. Some organic and conventional producers reported using composted food scraps as a way to complement other fertilizers; however, none relied on household compost as their primary form of nutrient addition.

The most common form of nutrient enhancement cited by producers was crop rotation. Specifically, many producers relied on strategic rotation to include nitrogen-fixing crops such as legumes and fallow periods to allow soil regeneration. Others stated that they used crop rotation and tried to vary which crops were planted on each plot, but did not specifically plan rotations to manage soil fertility. Cover-cropping with leguminous crops was another nitrogen-fixation strategy employed by some producers, both conventional and organic. Cover cropping and planned rotation can improve and conserve soil fertility in poor tropical soils, as well as assisting with pest management in some cases (Weiss 2015). Producers stated that they used soil fertility indicators such as color and texture to decide when and where to rotate or cover-crop.

Nutrient enhancement also took the form of mulching and tillage of weeds, crop residues, and cover crops. Producers cited mulching as an effective way to improve soil fertility, control weeds, and in some cases reduce pest problems all at once, therefore saving labor. Some producers also noted that mulching with weeds and crop residues reduced the amount of outside inputs into the agricultural system. In some cases, mulching can act as both nutrient enhancement (by re-adding nutrients to the soil in the form of decomposing organic matter drawn from the soil) and soil conservation (by covering fertile topsoil, preventing erosion) (Erenstein 2003).

The least-used form of nutrient enhancement by producers was soil amendments. Amendments such as bone meal and fermented coffee grounds bind with essential plant growth nutrients that are already present in soil, making them bioavailable. These amendments are traditional parts of many tropical agricultural systems; however, they are less commonly used since the spread of synthetic fertilizers (Agegnehu and Amede 2017). Multiple producers expressed knowledge of soil amendment techniques, but only two producers (one conventional and one organic) reported making and using soil amendments for fertility management.

Soil conservation practices for preventing erosion and nutrient leeching were used to some extent by all producers. Since most cultivated land in Cerro Punta has a moderate to high slope, the prevention of erosion is particularly important. One producer estimated that, without soil conservation measures, net soil loss is about 300 metric tons per hectare per year and that erosion prevention saves about 100 metric tons of soil per hectare per year (Conventional Producer 2, pers. comm., 9 November 2018).

The most common anti-erosion practices cited by producers were sedimentation boxes, canals to redirect runoff, and terracing crops. Producers who planted perennial trees reported strategic planting to form live barriers at the bottom of tilled areas. Another producer reported the use of myrtle bushes to catch runoff sediment at the bottom of some plots (Conventional Producer 2, pers. comm., 9 November 2018). Most producers who used anti-erosion practices emphasized their importance for managing soil fertility, with one stating that the top 10 to 20 centimeters of soil are by far the most fertile and the most vulnerable to erosion (Organic Producer 1, pers. comm., 12 November 2018).

Aside from differences in the use of synthetic fertilizers to add nutrients, there were few large differences in soil fertility management *Praxis* between organic and conventional producers. Most producers relied on some form of nutrient addition, some form of nutrient enhancement, and a selection of soil conservation practices to maintain and improve their soil fertility. The majority of the interviewed producers could be characterized as using a type of Integrated Soil Fertility Management, selecting the methods that are effective, affordable, and adaptable to what producers understand and believe about the local environment.

Conclusion

When assessing an agricultural system, it is vital to know what producers believe, how they form knowledge, and how those beliefs and forms of knowledge are used to make decisions about key natural resources such as soil. Ethnopedological research methods that elicit producers' cosmovisions (*Kosmos*), bodies of knowledge (*Corpus*), and management practices (*Praxis*) help to form a more complete picture of the interactions between people and the environment in a localized context.

In Cerro Punta, Christian spirituality and land symbolism through anthropomorphism shape producers' evaluation of soil fertility and decision-making about management practices. Additionally, a variety of indicators – mainly qualitative – are used to evaluate and assess soils. Producers' evaluations of soil fertility, as reflected by soil macrofauna surveys, are accurate and reflect observation of changes and variability in soil fertility over time and space.

The religious and symbolic beliefs about soil fertility (*Kosmos*) are combined with observationally formed knowledge (*Corpus*) to inform some practices that improve or maintain soil fertility. The practices that producers use to manage soil fertility, informed by the first two spheres of ethnopedology, form the third sphere of *Praxis*.

Although soil fertility and soil macrofauna density are significantly different between conventional and organic producers, reports of soil management practices do not vary greatly. Most producers use a variety of strategies, guided by their beliefs and knowledge about soil as well as economic and spatial constraints, to manage soil fertility.

Producers' conceptions, knowledge, and practices of soil fertility management in Cerro Punta are complex and reflect the influences of traditional agricultural practice, religion, technology, and ecology. Further research on how producers understand, assess, and manage soil and other important natural resources in a rapidly changing social and ecological context is highly recommended.

Works Cited

Abera, Y. and Belachew, T. (2011). Local perceptions of soil fertility management in southeastern Ethiopia. *International Research Journal of Agricultural Science, 1*(2), 64-69.

Agegnehu, G. and Amede, T. (2017). Integrated soil fertility and plant nutrient management in tropical agro-ecosystems: A review. *Pedosphere, 27*(4), 662-680.

Altieri, M.A. (2002). Agroecology: The science of natural resource management for poor farmers in marginal environments. *Agriculture, Ecosystems, and Environment, 1971*, 1-24.

Ayuke, F.O., Brussaarda, L., Vanlauwe, B., Six, J., Lelei, D.K., Kibunja, C.N., and Pullemana, M.M. (2011). Soil fertility management: Impacts on soil macrofauna, soil aggregation and soil organic matter allocation. *Applied Soil Ecology, 48,* 53-62.

Barrera-Bassols, N., Zinck, J.A., and van Ranst, E. (2006a). Symbolism, knowledge and management of soil and land resources in indigenous communities: Ethnopedology at global, regional and local scales. *Catena, 65*, 118-137.

Barrera-Bassols, N., Zinck, J.A., and van Ranst, E. (2006b). Local soil classification and comparison of indigenous and technical soil maps in a Mesoamerican community using spatial analysis. *Geoderma, 135*, 140-162.

Bartz, M.L., Pasini, A., and Brown, G.G. (2013). Earthworms as soil quality indicators in Brazilian no-tillage systems. *Applied Soil Ecology, 69*, 39-48.

Bernard, H.R. (2018). *Research methods in anthropology: Qualitative and quantitative approaches*. Lanham, MD: Rowman & Littlefield.

Bhadauria, T. and Saxena, K.G. (2010). Role of earthworms in soil fertility maintenance through the production of biogenic structures. *Applied and Environmental Soil Science, 2010,* 1-7.

Birkhofer, K., Bezemer ,T. M., Bloem, J., Bonkowski, M., Christensen, S., Dubois, D., Ekelund, F., Fliebbach, A., Gunst, L., Hedlund, K., Mäder, P., Mikola, J., Robin, C., Setälä, H.,Tatin-Froux, F., Van der Putten, W. H., and Scheu, S. (2008). Long-term organic farming fosters below and aboveground biota: Implications for soil quality, biological control and productivity. *Soil Biology & Biochemistry, 40*, 2297-2308.

Biswas, S., Ali, M.N., Goswami, R., and Chakraborty, S. (2014). Soil health sustainability and organic farming: A review. *Journal of Food, Agriculture, and Environment, 12*(3), 237-243.

Conventional Producer 1 (9 November 2018). Soil fertility indicators and management, Cerro Punta [personal interview].

Conventional Producer 2 (9 November 2018). Soil fertility indicators and management, Cerro Punta [personal interview].

Conventional Producer 3 (12 November 2018). Soil fertility indicators and management, Cerro Punta [personal interview].

Conventional Producer 4 (14 November 2018). Soil fertility indicators and management, Cerro Punta [personal interview].

Conventional Producer 5 (16 November 2018). Soil fertility indicators and management, Cerro Punta [personal interview].

Conventional Producer 6 (17 November 2018). Soil fertility indicators and management, Cerro Punta [personal interview].

Crittenden, S.J., Eswaramurthy, T., de Goede, R.G., Brussaard, L., and Pulleman, M.M. Effects of tillage on earthworms over short- and medium-term in conventional and organic farming. *Applied Soil Ecology, 83,* 140-148.

Dawoe, E.K., Quashie-Sam, J., Isaac, M.E., and Oppong, S.K. (2012). Exploring farmers' local knowledge and perceptions of soil fertility and management in the Ashanti Region of Ghana. *Geoderma, 129,* 96-103.

Dikinya, O. and Mufwanzala, N. (2010). Chicken manure-enhanced soil fertility and productivity: Effects of application rates. *Journal of Soil Science and Environmental Management, 1*(3), 46-54.

Erenstein, Olaf. (2003). Smallholder conservation farming in the tropics and sub-tropics: A guide to the development and dissemination of mulching with crop residues and cover crops. *Agriculture, Ecosystems, and Environment, 100,* 17-37.

Guiterrez-Guiterrez, A. and Muñoz, J. (2009). Interacción genotipo por ambiente de siete variedades de papa en la zona papera de Chiriquí, Panama. *Revista Latina de la Papa, 15*(1), 12-19.

Kome, G.K., Enang, R.K., and Kfuban Yerima, B.P. (2018). Knowledge and management of soil fertility by farmers in Western Cameroon. *Geoderma Regional, 13,* 43-51.

Laekemariam, F., Kibret, K., and Mamo, T. (2017). Farmers' soil knowledge, fertility management logic and its linkage with scientifically analyzed soil properties in southern Ethiopia. *Agriculture and Food Security, 6*(57), 1-12.

Lal, R. (1988). Effects of macrofauna on soil properties in tropical ecosystems. *Agriculture, Ecosystems, and Environment, 24*, 101-116.

Lavelle, P., Brussaard, L., and Hendrix, P. (1995). *Earthworm management in tropical agroecosystems*. New York, NY: CABI Publishing.

Mader, P., Fliebbach, A., Dubois, D., Gunst, L., Fried, P., and Niggli, U. (2002). Soil fertility and biodiversity in organic farming. *Science, 296*, 1694-1697.

Medeiros M.F.T., da Silva T.C., da Silva Sousa R., and Silva R.R.V. (2014) Oral History in Ethnobiology and Ethnoecology. In: Albuquerque U., Cruz da Cunha L., de Lucena R., Alves R. (eds) *Methods and Techniques in Ethnobiology and Ethnoecology*. Springer Protocols Handbooks. Humana Press, New York, NY

Nazarea, V., Rhoades, R., Bontoyan, E., and Flora, G. (1998). Defining indicators which make sense to local people: Intra-cultural variation in perceptions of natural resources. *Human Organization*, *57*(92), 159-170.

Organic Producer 1 (12 November 2018). Soil fertility indicators and management, Cerro Punta [personal interview].

Organic Producer 2 (15 November 2018). Soil fertility indicators and management, Cerro Punta [personal interview].

Palinkas, L.A. (2013). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Administration and Policy in Mental Health and Mental Health Services Research, 42*(5), 1-13.

Pareja, E. and María, M. (2005). Manejo y procesamiento de la gallinaza. *Revista LASALLISTA de Investigación, 2*(1), 43-48.

Pauli, N., Barrios, E., Conacher, A.J., and Oberthur, T. (2012). Farmer knowledge of the relationships among soil macrofauna, soil quality and tree species in a smallholder agroforestry system of western Honduras. *Geoderma, 189*, 186-198.

Pauli, N., Abbott, L.K., Negrete-Yankelevich, S., and Andres, P. (2016). Farmers' knowledge and use of soil fauna in agriculture: A worldwide review. *Ecology and Society*, *21*(3), 1-22.

Pérès, G., Vandenbulcke, F., Guernion, M., Hedde, M., Beguiristain, T., Douay, F. Houot, S., Piron, D., Richard, A., Bispo, A., Grand, C., Galsomies, L., and Cluzeau, D. (2011). Earthworm indicators as tools for soil monitoring, characterization and risk assessment: An example from the national Bioindicator programme (France). *Pedobiologia, 54,* 77-87.

Radford, B.J., Key, A.J., Robertson, L.N., and Thomas, G.A. (1995). Conservation tillage increases in soil water storage, soil animal populations, grain yield, and response to fertiliser in the semi-arid subtropics. *Australian Journal of Experimental Agriculture, 35*(2), 223-232.

Raymond, C.M., Fazey, I., Reed, M.S., Stringer, L.C., Robinson, G.M., and Evely, A.C. (2010). Integrating local and scientific knowledge for environmental management. *Journal of Environmental Management, 91*, 1766-1777.

Schon, N.L, Mackay, A.D., Gray, R.A., van Koten, C., and Dodd, M.B. (2017). Influence of earthworm abundance and diversity on soil structure and the implications for soil services throughout the season. *Pedobiologia, 62*, 41-47.

Scopel, E., Triomphe, B., Affholder, F., Macena Da Silva, F.A., Corbeels, M., Valadares Xavier, J.H., Lahmar, R., Recous, S., Bernoux, M., Blanchart, E., de Carvalho, I., and de Tourdonnet, M.S. (2013). Conservation agriculture cropping systems in temperate and tropical conditions, performances and impacts: A review. *Agronomy for Sustainable Development, 33*(1), 113-130,

Shah, A. (2006). Conservation through sustainable agriculture: The case of the Cerro Punta watershed, Panama. *Journal of Sustainable Forestry, 22*(1), 143-156.

Singh, S., Singh, J., and Pal Vig, A. (2016). Effect of abiotic factors on the distribution of earthworms in different land use patterns. *Journal of Basic & Applied Zoology, 74*, 41-50.

Stockdale, E.A., Shepherd, M.A., Fortune, S., and Cuttle, S.P. (2002). Soil fertility in organic farming systems – fundamentally different? *Soil Use and Management, 18*, 301-308.

Tittonell, P., Vanlauwe, B., Leffelaar, P.A., Rowe, E.C., and Giller, K.E. (2005). Exploring diversity in soil fertility management of smallholder farms in western Kenya: I. Heterogeneity at region and farm scale. *Agriculture, Ecosystems & Environment, 110*, 149-165.

Van Beek, C., Herold, N., Kessler, A., and Vonk, R. (2017). The quest for improving soil fertility: Why an integrated approach is needed. *Outlook on Agriculture, 46*(4), 289-294.

Wambeke, A. (1992). *Soils of the tropics: Properties and appraisal*. New York, NY: McGraw Hill.

Watson, C.A., Atkinson, D., Gosling, P., Jackson, L.R., and Rayns, F.W. (2002). Managing soil fertility in organic farming systems. *Soil Use and Management, 18*, 239-247.

Weiss, S. A. (2015). Sustainability of cover crop rotations in tropical low-external-input smallholder organic cropping systems (Doctoral dissertation, University of Florida). Retrieved from ProQuest Dissertations & Theses Global.

WinklerPrins, A.M. and Barrera-Bassols, N. (2004). Latin American ethnopedology: A vision of its past, present, and future. *Agriculture and Human Values, 21*, 139-156.

Appendix I: Interview Guide for Producers

English

How many years have you been farming? How long have you owned or farmed on the land you currently use?

What vegetable crops do you grow? When and where do you grow them? Do you grow perennial crops as well?

What tillage methods do you use, if any? How often do you till your land?

Do you use any fertilizer, soil amendments, or treatments? If so, which ones? How much do you apply and when? What are the purposes of these amendments?

Do you use pesticides or herbicides? If so, which ones? How much do you apply and when?

Do you use any soil conservation practices? If so, which ones? How often?

What is soil fertility? Is soil fertility important to you? If yes, why?

What indicators, if any, do you use to evaluate soil fertility? How often and when do you use these indicators? How do you use these indicators when making soil management decisions?

On a scale of 1 (least fertile) to 5 (most fertile), how fertile is your soil?

What animals live in your soils? How do these animals affect your soil?

Español

¿Por cuantos años ha sido productor Ud.? ¿Por cuánto tiempo ha trabajado Ud. las tierras que usa ahora?

¿Qué cultivos siembra Ud.? ¿Cuándo y en qué cantidad? ¿Cultiva Ud. árboles frutales?

¿Cuándo va a sembrar, como rompe Ud. la tierra? ¿Con que frecuencia hace Ud. esto?

¿Usa Ud. algunos abonos o insumos? ¿Si los usa, cuáles usa? ¿Con que frecuencia, cuantos y cuándo? ¿Para que los usa?

¿Usa Ud. algunos pesticidas o herbicidas? ¿Si los usa, cuáles? ¿Con que frecuencia, cuantos y cuándo?

¿Tiene Ud. un plan para la conservación de los suelos? ¿Si tiene uno, que es? ¿Qué métodos usas? ¿Con que frecuencia?

¿Qué es la fertilidad de los suelos? ¿Para Ud., es importante la fertilidad de los suelos? ¿Por qué?

¿Cómo evalúa Ud. la fertilidad de los suelos?

¿En una escala de 1 (menos fértil) a 5 (más fértil), que es el nivel de fertilidad en sus suelos?

¿Cómo toma Ud. decisiones sobre la finca? ¿Y sobre el manejo de los suelos?

¿Qué tipos de animales hay en sus suelos? ¿Cómo afectan ellos a los suelos?