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Abstract

Sustainable use and maintenance of agricultural soils are important for maintaining long-term agricultural productivity and environmental quality. These issues are especially important in Cerro Punta, known as the breadbasket of Panama, which is experiencing severe erosion. While current practices and agrochemical usage damage soil health and function over time, application of organic material improves soil physic-chemical properties such as nutrient and total organic carbon (TOC) content. Bokashi, a fermented organic soil amendment with effective microorganisms (EM), is thought to be especially beneficial due to its ability to augment populations of soil microbes, which deliver plant-available nutrients to crops and improve pest resistance. Since bokashi should contribute to the buildup of organic carbon in soils and increase soil microbial biomass, soils with bokashi are expected to be higher in TOC than soils without bokashi. However, little research has been done on the effects of bokashi under field conditions or its use in the tropics, and little is known about its effects in Cerro Punta. The purpose of this study is to compare TOC content in soils with and without bokashi and to examine farmers' perceptions regarding bokashi's effectiveness in terms of soil fertility and pest control in Cerro Punta. Soil samples were collected from fields with and without bokashi and were analyzed for TOC content. Interviews provided background regarding agrochemical and organic matter application history as well as farmers' perceptions of soil fertility and pest control. This study found significantly higher TOC values for soils with bokashi than soils with other common organic amendments. While bokashi users did not describe difficulties with pests or fertility less frequently than other growers, all bokashi users did perceive benefits in terms of fertility and / or pest control. These findings indicate that bokashi application may correspond to greater productivity and increased soil microbe populations, in turn fostering pest control and long-term soil health. Further research regarding the effects of bokashi use in Cerro Punta as well as other intensively farmed areas is recommended.

Abstracto

El uso sostenible y la conservación de suelos agrícolas son importantes para mantener la productividad agrícola y la cualidad del medioambiente. Son especialmente importantes en Cerro Punta, conocido como el granero de Panamá, que está sufriendo erosión serio. Aunque métodos en la practica y uso de agroquímicos dañan la salud de suelos y su función tras de tiempo, la aplicación de materias orgánicas mejora propiedades fisicoquímicas de suelos como contenido de nutrientes y carbón orgánico total. Bokashi, un mejoramiento orgánico del suelo que está fermentado y tiene microorganismos de montaña (MM), está creído a ser especialmente beneficioso debido a su habilidad a aumentar poblaciones de microorganismos del suelo, que reparten nutrientes disponibles a cultivos y también mejoran resistencia a las plagas. Porque bokashi debe contribuir al aumento de carbón orgánico en suelos y también aumentar la biomasa de los microorganismos del suelo, suelos con bokashi están supuesta a ser mas alta en carbón orgánico total que suelos sin bokashi. Sin embargo, pocos investigaciones han hecho sobre los efectos de bokashi bajo condiciones actuales de la finca o su uso en áreas tropicales, y poco está conocido sobre sus efectos en Cerro Punta. El propósito de esta investigación es para comparar el contenido de carbón orgánico total en suelos con y sin bokashi y investigar percepciones de granjeros sobre los efectos de bokashi en fertilidad del suelo y en el control de las plagas en Cerro Punta. Muestras de suelo fueron recolectadas de fincas con y sin bokashi y fueron analizadas para contenido de carbón orgánico total. Entrevistas proveyeron información sobre la historia del uso de agroquímicos y materia orgánica y también información sobre las percepciones que tienen granjeros de la fertilidad del suelo y del control de las plagas. Esta investigación encontró valores de carbón orgánico total sensiblemente más altos en suelos con bokashi que suelos con otros mejoramientos orgánicos comunes. Aunque usadores de bokashi no describieron dificultades con plagas o fertilidad con menos frecuencia que otros granjeros, todos los usadores de bokashi sí percibieron beneficios de fertilidad y / o control de las plagas. Estos resultados indican que la aplicación de bokashi puede corresponder a productividad más alta y poblaciones aumentadas de microorganismos del suelo, así que fomentando el control de las plagas y la salud futura del suelo. Más investigaciones sobre los efectos del uso de bokashi en Cerro Punta y también otras áreas que están cultivadas intensivamente están recomendadas.

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Introduction

Agricultural productivity, upon which human population depends, in turn depends on an array of ecosystem services, including but not limited to water supply, soil fertility, and pest regulation (Zhang et al. 2007). However, many current agricultural practices aimed at increasing productivity threaten the health of agricultural ecosystems, damaging their ability to provide these essential services (Halberg and Muller 2013). This paradox brings about the need for sustainable agriculture, which seeks to maintain healthy ecosystem functioning within agricultural settings and in turn maintain long-term agricultural productivity (Halberg and Muller 2013).

Soils: The foundation of agricultural productivity

Sustainable use and maintenance of agricultural soils are especially important for maintaining long-term agricultural productivity, since soil quality is a determining factor as to where various types of agriculture can take place and how productive they can be (Zhang et al. 2007). Soil quality can be defined as a soil's ability to function within an ecosystem to sustain productivity, environmental quality, and the health of plants and animals (Haynes 2005). Soils consist of a myriad of different components, each of which contributes in distinct ways to a soil's apparent features and quality (Haynes 2005). These components include minerals grains, namely sand, silt, and clay (Plante et al. 2006), as well as soil organic matter (SOM), both particulate and dissolved (Haynes 2005). While SOM usually only constitutes 5 to 10 percent of soil mass, its effects on physical, chemical, and biological properties are highly significant and it is thought to be the most important indicator of productivity (Haynes 2005). Though SOM consists of a wide variety of compounds and elements (Haynes 2005; Govers et al. 2014), soil total organic carbon (TOC) is the most commonly used indicator of SOM concentration (Schumacher 2002, Haynes 2005).

TOC, like SOM, is a broad category and includes many different types of carbon. While elemental carbon forms and inorganic carbon forms are not part of TOC, the organic carbon forms that constitute TOC are numerous and range from recently deposited leaf litter to highly decomposed humus to living soil microbes. These carbon forms can be present dissolved in soil solution or as distinct particles (Schumacher 2002; Haynes 2005; Moscatelli et al. 2005). Particulate organic matter (POM) is enriched in carbon and nutrients, and also aids in aggregate formation, water retention, and thermal properties (Haynes 2005). Dissolved organic matter (DOM) is a primary source of the nutrients Nitrogen, Sulfur, and Phosphorus in plant-available forms, as well as an important substrate and source of energy for soil microbes and fauna (Haynes 2005).

Soil-borne microbes: Drivers of productivity

Soils house a wide variety of above and belowground biota, ranging from earthworms, which aid in soil aggregate formation, to microbes (Birkhofer et al. 2008). Microorganisms are considered to be some of the most important soil organisms, as they are the driving force behind nutrient supplies (Moscatelli et al. 2005). One gram of soil is estimated to contain up to one hundred billion (10^{11}) bacteria and two hundred million (2×10^{8}) fungal hyphae (van der Heijden et al. 2008). Mycorrhizal fungi and nitrogen-fixing bacteria alone are responsible for up to 80 percent of all nitrogen and 75 percent of all phosphorus acquired by plants annually (van der Heijden et al. 2008). These microbes can promote fertility by modifying soil physical structure (Singh et al. 2011) and by improving plant nutrition (Pineda et al. 2010). They improve nutrition by increasing nutrient uptake by plants, by mineralizing nutrients from SOM into plant-available forms, and by fixing atmospheric nitrogen (Pineda et al. 2010; Fatunbi and Ncube 2009). Some soil microbes can even synthesize natural plant hormones that play a role in growth promotion (Pineda et al. 2010).

In addition to promoting soil fertility and plant growth, soil microbes can also contribute to productivity by aiding in pest control (Baoyu et al. 2007; Birkhofer et al. 2008; Pineda et al. 2010; Ndona et al. 2011; Kaschuk et al. 2010). Agricultural pests, such as herbivores and pathogens, can significantly impact productivity and even result in total crop loss (Zhang et al. 2007). While chemical pesticides can be used to control pests, such pesticides are problematic due to their environmental impacts (Shah 2006; Soares et al. 2012; Zhang et al. 2007). They also kill both harmful pests as well as beneficial organisms, including pollinators, predatory insects and soil microbes (Saleh et al. 2013). Soil microorganisms, on the other hand, provide natural, biological control of plant diseases and soil-borne pathogens (Singh et al. 2011, Kaschuk et al. 2010). They do so through the process of induced systematic resistance (ISR), in which non-pathogenic soil-borne microbes enhance plant resistance to a broad range of diseases and detrimental organisms (Pineda et al. 2010).

Threats to Healthy Soils & Alternative Management Practices

A wide variety of modern agricultural practices threaten soil health and thus its ability to provide fertility and pest control services (Zhang et al. 2007; Singh et al. 2011). Such practices can damage soil health by reducing the amount of soil present (Govers et al. 2014), by reducing the amount of organic matter and nutrients present (Haynes 2005), and by disturbing soil microbial communities (Zhang et al. 2007). Reductions in soil quantity occur through agricultural erosion, or the accelerated removal of topsoil from agricultural lands via water, tillage, wind, and mass transport from steeply sloped fields (Govers et al. 2014). While highly variable by location, erosion is responsible for average yield reductions of approximately 4 percent per year in intensively farmed areas globally (Govers et al. 2014; Bakker et al. 2004), and is triggered by practices that disturb soil and vegetation such as tilling and mechanical plowing (Zhang et al. 2007). Practices that reduce organic matter content and in turn soil fertility include wide crop spacing, harvesting and removal of crops and organic wastes, tilling, and chemical fertilization (Haynes 2005). Finally, practices that disturb microbial communities, limiting their ability to contribute to fertility and pest control, include chemical fertilizer and pesticide application, mechanical plowing, and tilling (Birkhofer et al. 2008; Zhang et al. 2007; Kaschuk et al. 2010).

There are a number of alternative practices, however, that can be employed in order to conserve soils and sustain their functions. Erosional effects, losses in soil organic matter, and microbial disturbances can be minimized via techniques including conservation tilling, no till-agriculture, crop residue recycling, contour farming, and crop rotation (Singh et al. 2011; Kaschuk et al. 2010). Also, soil amendments such as organic fertilizers, manure, and compost can be applied in order to remediate and enrich soils, combating the effects of soil degradation and loss (Singh et al. 2011; Birkhofer et al. 2008; De Maria et al. 2010). Biofertilizers and biopesticides, such as bokashi, are organic soil amendments containing living microorganisms and are widely applied in order to sustain and improve soil function (Mayer et al. 2008; Boechat et al. 2013).

Bokashi is a Japanese term for fermented organic matter (Boechat et al. 2013). Bokashi consists of an organic waste substrate and Effective Microorganisms (EM), a solution of naturally occurring soil microbes with supposedly beneficial properties, and is fermented before application (Boechat et al. 2013; Mayer et al. 2008; Ndona et al. 2011). Five primary types of both aerobic and anaerobic microbes constitute EM: photosynthetic bacteria (*Rhodopseudomonas palustrus, Rhodobacter spaeroides*), lactic acid bacteria (*Lactobacillus plantarum, L. casei, Streptococcus lactis*), yeasts (*Saccharomyces cerevisiae, Candida utilis*), actinomycetes (*Streptomyces albus, S. griseus*), and fermenting fungi (*Aspergillus oryzae, Mucor* hiemalis) (Ndona et al. 2011; Fatunbi and Ncube 2009). Laboratory analysis of the particular bokashi product studied in this report also confirmed the presence of many other bacterial groups, including *Nitrosomonas multiformis*, which fix nitrogen into plant-available forms, as well as *Trichodermas spp.*, *Bacillus spp,* and *Streptomices spp.*, all of which combat pests (R.C. Agrosupplies, 2014). Purported benefits of bokashi and EM include enhanced soil fertility, increased crop yield, improved plant nutrition, pest and disease control, and improved soil physical characteristics (Cóndor-Golec et al. 2007; Mayer et al. 2008; Pineda et al. 2010). The majority of these benefits are thought to stem from the activity of beneficial soil microbial communities, which bokashi and EM aim to increase (Boechat et al. 2013; Fatunbi and Ncube 2009).

Applications in Cerro Punta, Panamá

Cerro Punta is an agricultural town nestled in the Pacific side of the Talamancan mountain range, within the Bugaba district of Panama's Chiriqui province (Shah 2006). It abuts the *Parque Internacional La Amistad (PILA)*, which spans parts of Panama and Costa Rica, falling within the park buffer zone as well as within the *Chiriquí Viejo* River watershed (Shah 2006). Chiriqui has been described as the breadbasket of Panama (Shah 2006), and produces approximately sixty percent of all food consumed nationally (Conventional Bokashi User 3, pers. comm., 16 Apr 15). Cerro Punta specifically is responsible for producing eighty percent of the vegetables consumed in the country (Soares et al. 2012). The region's dark, rich, volcanic soils and wet, moderate climate allow for this high productivity (Shah 2006; Aguilar and Fernández 2014). Cerro Punta sits at an altitude of 1,600 meters to 1,970 meters above sea level, experiences average temperatures of 14.2 degrees Celsius, and receives an annual rainfall of around 2,000 millimeters (Soares et al. 2012; Shah 2006). Furthermore, water deficits during the dry season are minimal, making intensive production possible all year long (Aguilar and Fernández 2014).

Agricultural production is the most important economic activity in Cerro Punta and the surrounding area, and takes place mostly on medium and small-sized farms and in home gardens (Shah 2006). Market gardens for both vegetables and flowers are the primary source of income for local residents (Shah 2006). The most popular crops include potatoes, onions, lettuce, carrots, broccoli, cabbage, and celery (Aguilar and Fernández 2014); but a wide variety of other fruits and vegetables are also produced in significant volumes (Shah 2006).

While current productivity and profitability levels in Cerro Punta are high, dominant agricultural practices are high input and unsustainable (Shah 2006). Fragile soils on steep slopes are routinely plowed and planted (Aguilar and Fernández 2014), and irrigation and chemical inputs are used heavily. Also, no soil conservation methods or pollution abatement techniques are employed to minimize the effects of such practices (Shah 2006; Soares et al. 2012). These agricultural characteristics have resulted in soil degradation and regional losses of over 200 tons of soil per hectare per year since the 1980s (Aguilar and Fernández 2014), though that number is thought to have increased to between 250 and 300 tons per hectare per year in the past few years (Conventional Bokashi User 3, pers. comm., 16 Apr 15), as well as large amounts of pollution and sedimentation that feed into the *Chiriquí Viejo* River (Shah 2006). This pollution and sedimentation affect downstream users of the river as far as the Gulf of Chiriqui (Aguilar and Fernández 2014), and heavy use of agrochemicals is also associated with negative effects on human health of Cerro Punta residents and on ecosystem health of the nearby parks *PILA* and *Volcán Baru* (Shah 2006; Velez 2013). Furthermore, reductions in productivity due to erosion are expected to become increasingly severe as soils continue to erode (Bakker et al. 2004), negatively impacting national food security and the Panamanian agricultural economy. Assuming an erosion rate of 250 tons of soil per year, the region currently suffers losses of approximately 10% yield per decade (Bakker et al. 2004). For these reasons, Cerro Punta has become one of four designated critical priority areas for combating soil degradation in the Panamanian *Plan de Acción Nacional (PAN-2004)* (Aguilar and Fernández 2014).

Despite this designation and the related *Amistad: Conservación y Desarollo (AMISCONDE)* pilot program initiated by the *Autoridad Nacional del Ambiente de Panamá (ANAM)* (Aguilar and Fernández 2014; Queenan 2013; Soares et al. 2012), very few of the alternative practices that could potentially improve the sustainability of the region's agriculture are currently being applied, and those that are in use only affect a small proportion of the region's production (Aguilar and Fernández 2014). It has been estimated that adoption of more sustainable practices could allow increases in economic returns of up to 100,000 U.S. dollars (Aguilar and Fernández 2014). Recommendations for the region include crop rotation, intercropping, contour planting, soil conservation techniques, hydroponics, drip irrigation, agroforestry, and organic cultivation (Aguilar and Fernández 2014; Shah 2006). Of these options, organic cultivation is growing most rapidly in the region, largely through community organizations such as *la Asociación Agro Ecologista La Amistad (ASAELA), el Grupo Orgánico de Agricultores Cerropunteños (GORACE),* and *Amigos del Parque Internacional La Amistad (AMIPILA)* and through organic farmers' associations such as *Asociación Panameña de Agricultura Orgánica (APAO)* and *Asociación para la Producción Orgánica y Comercialización Solidaria (PROCOSOL)* (Aguilar and Fernández 2014; Soares et al. 2012). However, organic fertilizers are expensive and relatively unavailable in the area. Bokashi and gallinaza are the two most common of very few options produced locally and sold at competitive prices (Organic Bokashi User 1, pers. comm., 4 Apr 15). Application of gallinaza, or unprocessed chicken manure, is known to cause a number of environmental and health problems (Pareja and María 2005). So, increased use of bokashi is one of the most feasible routes through which chemical inputs, pollution, and negative effects of soil loss in Cerro Punta can be reduced. If bokashi adoption is also accompanied by a broader transition towards organic cultivation, the region's agriculture can shift more readily towards sustainability.

Literature Review

The Effects of Organic Agriculture on Soils

Organic agriculture limits the technologies available for soil improvement to those free from synthetic chemicals (IFOAM 2014), which could contribute to the well-established productivity gap between organic and non-organic systems (de Ponti et al. 2012). However, organic systems utilizing organic fertilization methods have been associated with indicators of improved soil quality and enhanced physic-chemical properties such as increased soil TOC content, greater diversity of soil fauna, greater soil microbial biomass and activity, and increased nitrogen concentration when compared with conventional systems (Birkhofer et al. 2008; Boechat et al. 2013; De Maria et al. 2010; Fatunbi and Ncube 2009). These improvements contribute to improved productivity in soils to which organic amendments have been applied (Boechat et al. 2013; Fatunbi and Ncube 2009; Khaliq et al. 2006). Long-term organic farming and the application of organic manures and composts have also been associated with improved pest control, fostering predators and thus reducing the abundance of herbivorous pests (Birkhofer et al. 2008). In contrast, mineral fertilizers and chemical herbicides have been shown to both reduce soil TOC levels and negatively affect pest control (Birkhofer et al. 2008). Therefore, organic soil improvement mechanisms will be instrumental in improving soil quality to combat losses in both organic and conventional farming systems. Furthermore, reduced use of chemical fertilizers and pesticides would improve pest control while also fostering healthy soils and long-term productivity. If effective, bokashi's role as both an organic soil amendment and an organic pest control agent could contribute to both objectives.

Bokashi for Fertility and Pest Control

The substrate for bokashi can vary, but the variety studied here included rice husks, charcoal, sawdust, and topsoil (Conventional Bokashi User 3, pers. comm., 16 Apr 15). The EM solution is added to the substrate along with molasses, and the bokashi is then allowed to ferment, either aerobically or anaerobically, before it is ready for application (Boechat et al. 2013; Khaliq et al. 2006). The substrate alone, without the addition of microorganisms, is known to act as an organic fertilizer, improving yields in a variety of crops such as barley, wheat, lucerne, and cotton (Mayer et al. 2008; Khaliq et al. 2006). This could be explained by the presence of a wide variety of nutrients found in the substrate as well as by its contribution to TOC accumulation (Mayer et al. 2008; Birkhofer et al. 2008). Laboratory analyses of the bokashi studied in this report confirmed the presence of Nitrogen, Phosphate, Potassium, Calcium, Magnesium, Manganese, Iron, Zinc, and Copper (IDIAP Laboratorio de Fertilidad de Suelos, 2013; LABSA, 2013). However, bokashi substrate has also been found to have no effect on yield for other crops, such as potatoes (Mayer et al. 2008).

Despite potential benefits of the substrate, bokashi's fame derives more from the microorganisms that it contains. Promotion of EM as an additive for improving pest control, enhancing fertility and productivity, and overcoming problems associated with chemical fertilizer and pesticide application began after its development in the early 1980s (Higa and Wididana 1991; Ndona et al. 2011). The mechanism behind these purported advantages is the accelerated proliferation of soil microbes, which causes rapid decomposition and mineralization of soil nutrient elements into plant-available forms (Fatunbi and Ncube 2009). However, previous findings regarding the actual effectiveness of EM solution have been controversial, and the literature regarding EM spraying varies. EM has been found in some studies to have no significant effects or even negative effects on yield, soil fertility, microbial degradation rates, mineralization rates, or microbial biomass in a number of studies (Mayer et al. 2008; Khaliq et al.

2006; Priyadi et al. 2005; zu Schweinsberg-Mickan and Müller 2009; Javaid 2006; Mayer et al. 2010). On the other hand, EM has also been found to positively affect the same variables (Cóndor-Golec et al. 2007; Ndona et al. 2011; Zydlik and Zydlik 2008). Also, numerous studies have found significant increases in plant growth and yield due to inoculation with specific bacterial species (Singh et al. 2011; Harish et al. 2009; Yazdani et al. 2009; Kavino et al. 2010), suggesting that, especially when tailored to meet the particular needs of a given soil, microorganism additions can indeed be effective in boosting productivity.

There is also varying evidence regarding the results produced by application of the final bokashi product, including both the substrate material and EM. When compared to bokashi substrate alone or sterilized bokashi, bokashi with live EM has been found to produce no significantly different effects on soil fertility or productivity (Mayer et al. 2008; Mayer et al. 2010; zu Schweinsberg-Mickan and Müller 2009). However, bokashi as well as other manures containing EM have also been found to improve soil chemical properties and increase yield when applied alone as well as alongside chemical fertilizer (Ismail 2013; Khaliq et al. 2006; Ndona et al. 2011). Other studies have also found bokashi to significantly increase organic matter content (Cóndor-Golec et al. 2007; Boechat et al. 2013) and rates of organic carbon degradation and nutrient mineralization, especially of recalcitrant fractions of SOM (Fatunbi and Ncube 2009). One study involving application of multiple different substrates both with and without EM found that effectiveness varies with substrate type, and that EM is most effective in increasing soil TOC and crop nitrogen absorption when applied in conjunction with substrates having a low carbon to nitrogen ratio (Boechat et al. 2013). Lastly, another study found improved soil physical characteristics such as aggregation and porosity in soils to which bokashi had been applied compared to soils to which manure alone had been applied (Cóndor-Golec et al. 2007).

In terms of effectiveness in boosting soil microbe populations and activity, microbial biomass has been found to increase with bokashi application (Ndona et al. 2011). Microbial respiration and degradation rates have also been found to increase with bokashi application (Mayer et al. 2008; Boechat et al. 2013; Fatunbi and Ncube 2009; Zydlik and Zydlik 2008; zu Schweinsberg-Mickan and Müller 2009). However, DNA-analysis of the microbial content of EM compared to that of soils with bokashi has shown that many of the bacterial species present in EM may no longer be present in the soils to which bokashi has been added (Cóndor-Golec et al. 2007). The same has been found for manures to which EM has been applied (van Vliet et al. 2006). Therefore, it remains unclear exactly if and how bokashi contributes to soil microbial populations and activity.

Findings on the effectiveness of bokashi in terms of pest suppression, though limited in number, have been more unified. The role of soil microbes in pest suppression has been studied extensively (Pineda et al. 2010), and the effects of EM and bokashi on soil microbe abundance and activity, as discussed above, are also popular subjects of study. However, studies on the direct effects of bokashi and EM on pest suppression are few and far between. Studies have confirmed the presence of various pest-suppressing microbes in EM and in bokashi (Mayer et al. 2008; Mayer et al. 2010; R.C. Agrosupplies, 2014). Improvements in fruit quality due to reduced bacterial and fungal disease have also been found when bokashi is applied. This can be explained by temporary reductions in Nitrogen availability due to enhanced microbial proliferation, which has little effect on plant development but hinders disease development (Ndona et al. 2011). Reductions in parasitic nematode populations have also been found to be associated with bokashi application compared to chemical nematicide application (Cóndor-Golec et al. 2007). Further research regarding the direct effects of bokashi on agricultural pests, however, is absent from the literature. This may be due in part to the qualitative and complex nature of pest monitoring, which makes it difficult to execute controlled, quantitative studies on pest abundance and impacts under multiple treatment regimes.

There is still much to be learned about bokashi and its usefulness in terms of soil fertility, microbial activity, and pest suppression in different parts of the world (van der Heijden et al. 2008; Cóndor-Golec et al. 2007; Fatunbi and Ncube 2009). There are notable gaps in the literature regarding bokashi use in the tropics (Cóndor-Golec et al. 2007), as well as few studies regarding the interactions between bokashi and non-organic agrochemicals when applied together (Khaliq et al. 2006), which is often the case in Cerro Punta. Furthermore, there is little knowledge regarding the extent to which bokashi is presently being used in Cerro Punta or in Panama in general. This study aims to contribute to the body of knowledge regarding how bokashi is currently being used in Cerro Punta, and whether such usage is effective. By doing so, this research also aims to help inform local farmers' decisions regarding if and how to utilize bokashi. Specifically, this study asks: What are the effects of bokashi application on total organic carbon content of agricultural soils and on farmers' perceptions regarding soil fertility and pests in Cerro Punta, Panama?

Methods

Participant selection

Participants were recruited through a non-random, voluntary process termed purposeful sampling based on their ability to meet the study specifications (DiCicco-Bloom and Crabtree 2006; Queenan 2013). In order to qualify, participants must have owned and be actively farming a farm, field, or garden plot within Cerro Punta or Guadalupe, a small town within walking distance of Cerro Punta. Enough participants were recruited to sample 20 fields and plots, of which bokashi had been applied to ten. If a participant had multiple available fields or plots, each was sampled and discussed during the interview. Some interviews corresponded to multiple samples, and some interviews did not correspond to any samples. However, no samples were taken which did not correspond to at least one interview.

Potential participants were identified through community networking. For some participants, such as those located further from the research base and those operating on a larger scale, this involved gathering contact information through local organizations including *AMIPILA* and *GORACE,* then calling the potential participant in order to set up an initial meeting. During that initial meeting, the potential participant was provided with basic information regarding the goals of the project (DiCicco-Bloom and Crabtree 2006). If the potential participant agreed to participate in an interview and / or the sampling process, he or she was then presented with a participation consent form to be signed by both the participant and the researcher (DiCicco-Bloom and Crabtree 2006). Then, depending on the availability of the participant, the interview and sampling processes were conducted immediately after signing or an additional meeting time was scheduled.

Other potential participants, namely those located very close to the research base and operating on smaller scales, were initially contacted through a casual introduction at their homes or in their fields. These potential participants were also provided with basic information regarding the study as well as a consent form during this interaction. If consent was obtained, as with the previous group, the researcher either proceeded to the interviewing and sampling procedures or scheduled an additional meeting time, according to participant preferences.

Personal interviewing

Personal interviews took place with each grower prior to soil sample collection. Interviews followed the style of semi-structured individual in-depth interviews, consisting largely of a previously defined sequence of questions, but at times straying from or delving further into each topic as the conversation allowed (DiCicco-Bloom and Crabtree 2006; Mason 2004). During each interview, the participant was asked a series of open-ended questions regarding the following themes: the participant's use of bokashi, if applicable; the participant's use of other agricultural products, both chemical and otherwise; the participant's experiences with agricultural pests; and the participant's perceptions of soil fertility. Through these questions, the researcher sought to first obtain an approximate application schedule for all agricultural products used by the participant in the field(s) or plot(s) of interest. Then, if the participant used bokashi, the researcher asked questions about the participant's perceptions of pests and soil fertility before employing bokashi compared to after beginning use, and / or in areas without bokashi compared to areas with bokashi. If, on the other hand, the participant did not use bokashi, he or she was asked about their perceptions regarding pests and soil fertility in general, as well as what products, if any, he or she felt significantly improved their experiences with either.

As is customary in anthropological research, the researcher took brief notes during the course of the interview rather than recording the conversation, and later returned to the research base in order to transcribe the interview more fully (DiCicco-Bloom and Crabtree 2006). Interviews lasted between approximately 15 to 40 minutes, depending on the participant. Once all relevant information had been gathered through the interviewing process, the participant was asked if and when he or she would be available to supervise sampling in the field(s) or plot(s) discussed during the interview, if applicable. If the participant was unwilling or unable to permit sampling, or if information from the interview revealed that sampling would not be beneficial for the purposes of this study, the interview concluded the interaction.

Sample collection

Either immediately following completion of the interview or at a later date, depending on participant preference, the participant accompanied the researcher to the field(s) or plot(s) discussed during the interview. Within each field or plot, 3 points were selected for sampling. This repetition was done in order to increase the number of samples taken over the given space, and thus better represent the soil characteristics of the entire plot or field (Jones and Willett 2006). Points were selected by first establishing the approximate location of the field or plot center. Points 1, 2, and 3 were then established by measuring either 5 or 10 meters from the center in three distinct directions, forming a triangle of points around the center (M. Garcia, pers. comm., 6 Apr 2015). Distance from the center was determined according to field or plot size: a distance of 10 meters was used in larger fields, while a distance of 5 meters was used in smaller garden plots.

From each point, a shallow scoop of soil was taken using a 100 milliliter plastic sample cup and filling it to the brim, penetrating no more than 10 centimeters below the soil surface (Mayer et al. 2008). The 3 scoops, 1 from each point, were then poured into a plastic Tupperware container and mixed thoroughly with a dull knife for a period of 2 minutes in order to insure homogeneity (Boechat et al. 2013). A portion of the mixed sample was then transferred back into one of the sample cups, filling the cup as completely as possible without packing the soil. The lid was then sealed and labeled, and the cup was placed inside of a plastic Ziploc bag in order to avoid oxygen exposure and / or water leakage. The bag was then kept on ice at approximately 4 degrees Celsius for a period of 3 to 7 days, depending on the date taken. The samples were then delivered to a government Instituto de Investigación Agropecuaria de Panamá (IDIAP) soil analysis lab, where they were dried and prepared for analysis. This storage and preparation method was designed in order to prevent significant losses of organic carbon due to microbial degradation, since storage at or below 4 degrees Celsius greatly reduces microbial activity (Schumacher 2002). Furthermore, immediate sealing of the samples should have prevented significant organic carbon losses due to volatilization (Schumacher 2002; Jones and Willett 2006).

Sample analysis

Upon delivery to the soil laboratory, samples were air-dried (Schumacher 2002; Fatunbi and Ncube 2009) in the sun for a minimum of 12 daylight hours and then stored in an oven at 38 degrees Celsius until testing (IDIAP Employee, pers. comm., 27 Apr 15). Testing for TOC followed the standard Walkley-Black procedure for dichromate oxidation, involving complete oxidation with sulfuric acid and dichromate (Walkley and Black 1934; Schumacher 2002; Fatunbi and Ncube 2009). According to the procedure, 0.1g and 0.5g of each dried soil sample were weighed and poured into separate Erlenmeyer flasks, to each of which 20mL of Potassium dichromate and 10mL of Sulfuric acid concentrate was added (Sato et al. 2014). After a period of 2 hours, each flask was filled with tap water to the 100mL line and then allowed to rest for another hour (IDIAP Employee, pers. comm., 27 Apr 15). At that time, solution from each flask was transferred into a cuvette and read in a spectrophotometer at 645 nm (Fatunbi and Ncube 2009). Known conversion factors were then used in order to convert the reading first to percent organic mater and then to total organic carbon (Fatunbi and Ncube 2009).

Data analysis

After completion of soil sample analysis, TOC content results were compiled in Excel. The samples were grouped into two categories, defined by either presence or absence of bokashi, and the TOC values from each group were compared using t-tests. This process included both a two-tailed t-test, in order to test for a significant difference between the two categories, as well as a one-tailed t-test, in order to test specifically for higher TOC values in the category with bokashi present (Harmon 2011). Similarly, soils to which bokashi had been applied were compared with those to which specifically either gallinaza or caballaza had been applied, excluding from analysis those to which no organic materials had been applied.

Interactions with potential confounding variables, including time, agrochemical use, and topographical location were also analyzed (Mehio-Sibai et al. 2005). In order to test the effect of time since last application of organic material (bokashi, gallinaza, or caballaza) on soil TOC, TOC levels were plotted against time since last application in Excel and linear regression analysis was performed (Modeling for prediction). This was done with all samples together, as well as with only bokashi samples and only gallinaza or caballaza samples, since different organic soil amendments evolve differently over time (Ndona et al. 2011). Information regarding time of last application derived from information in the interview(s) corresponding with each sample. Linear regression analysis was also employed to test for a relationship between sample holding time, or the span of time between when the sample was taken to when sample drying was completed, and TOC level. Then, in order to assess the potential significance of agrochemical use, organic soils were compared to conventional soils using the previously described t-test method. This process was completed for the entire soil sample collection, as well as within the categories of soils to which bokashi had been applied and soils to which either gallinaza or caballaza had been applied. Finally, in order to test the effect of topographical location on TOC levels, sample locations were ranked along a topographical scale of 1 to 4, described in Figure 1 below, and a one-way analysis of variance (ANOVA) test was performed in order to test for a significant effect of topographical ranking on mean TOC levels (Hammer 2015).

Figure 1: Sample Topographical Scale

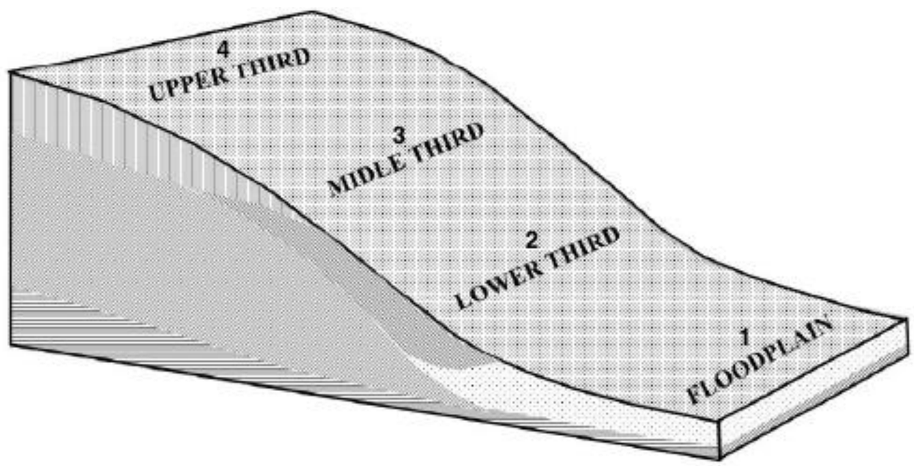


Figure adapted from Aquino et al. 2013

Qualitative information collected though personal interviews was also grouped in order to allow for categorical analysis (DeCuir-Gunby et al. 2011; Queenan 2013). Responses from participants using bokashi were grouped into the following categories: 1) Those describing only minimal to manageable problems with both pests and fertility, 2) Those describing significant difficulties with pests but only minimal to manageable problems with fertility, 3) Those describing only minimal to manageable problems with pests but significant difficulties with fertility, and 4) Those describing significant difficulties with both pests and fertility. Responses from participants not using bokashi were then grouped into the same categories, and the frequencies of bokashi users versus non-bokashi users within each category were compared. Frequencies were calculated by dividing the number of bokashi user responses in each category by the total number of participants using bokashi, and likewise for non-bokashi users (Queenan 2013). It is important to note that participants were only asked open-ended questions regarding their experiences with both pests and soil fertility in order to avoid researcher influence, and were not presented with the terminology “minimal to manageable problems” versus “significant difficulties” (DiCicco-Bloom and Crabtree 2006). Therefore, grouping into the above categories was done at the researcher’s discretion, through interpretation of participant responses (DeCuir-Gunby et al. 2011). Using the in-depth personal interviews to complement the quantitative soil data (DiCicco-Bloom and Crabtree 2006), any differences found in frequencies between bokashi users and non-bokashi users were then compared with differences found in soil organic carbon content in order to draw connections between soil composition and farmer perceptions.

Responses from bokashi users were also compared to one another in order to assess user perceptions about bokashi's effectiveness in terms of pest suppression and fertility enhancement. To do so, bokashi user responses were grouped into the following additional categories: 5) Those describing reduced problems with pests and improved soil fertility with bokashi, 6) Those describing reduced problems with pests but no significant changes in fertility with bokashi, 7) Those describing no significant changes in problems with pests but improved soil fertility with bokashi, and 8) Those describing no significant changes regarding pests or fertility with bokashi. Since no participants expressed negative effects of bokashi on pest suppression or soil fertility, additional categories including such responses were unnecessary. Frequencies for responses in each of these categories were calculated in the same way, and then compared.

Results

Due to ownership of multiple qualifying fields or plots as well as the inability of 4 interview participants to allow for sampling, a total of 13 participants were recruited. From that number, 8 interviews with bokashi users (4 organic and 4 conventional), 5 interviews with non-bokashi users (all conventional), 10 samples from bokashi users (4 organic and 6 conventional), and 10 samples from non-bokashi users (all conventional) were obtained. Of the 5 interviews with non-bokashi users, 2 participants also identified as former bokashi users. The most notable limitation and possible source of error for all results of this study is the small size of all sample groups. Also, since sample sizes were small and participants were not chosen randomly, it cannot be confirmed that the distributions of TOC values and interview responses accurately represent the study population. The results of this study are also limited due to the fact that a number of variables, such as agrochemical use and site topographical location, could not be controlled for. However, each potentially confounding variable was considered and no significant relationships were detected.

Soils

When the set of soil samples to which bokashi had been added was compared to the set including all samples lacking bokashi, the set lacking bokashi appeared to have a higher mean TOC content, although the difference was not statistically significant. As shown in Table 1, the average TOC for soils with bokashi was 2.12%, as compared to 2.36% for soils without bokashi. This was also the case when soils with bokashi were compared to only those to which gallinaza or caballaza had been added instead, for which the average TOC was 2.37%. However, one sample, to which caballaza had been applied within thirty days prior to sampling and was still visually dominant within the sample, had an abnormally high TOC value of 6.22% and was determined to be an outlier. When this outlier was excluded from statistical analysis, the average TOC for soils with bokashi surpassed that of soils lacking bokashi, although the difference was still statistically insignificant. When soils with bokashi were compared to soils with either gallinaza or caballaza while again excluding the outlier, the mean TOC of soils with bokashi was found to be significantly greater than that of soils with either manure type (1.89%) with a confidence interval of 90% ($P \leq 0.1$). Finally, when soils with bokashi were compared exclusively with those with gallinaza instead, the mean TOC of soils with bokashi was found to be significantly greater than that of soils with gallinaza (1.85%) with a confidence interval of 95% ($P \leq 0.05$).

Table 1: Mean TOC comparisons by type of soil amendment

Comparison	Mean TOC under Condition 1 (with bokashi)	Mean TOC under Condition 2	P-value from 1-tailed t-test
Soils with bokashi v. soils without bokashi	2.12	without bokashi: 2.36	0.30
Soils with bokashi v. soils without bokashi *excluding outlier		without bokashi*: 1.93	0.12
Soils with bokashi v. soils with either gallinaza or caballaza		with gallinaza or caballaza: 2.37	0.12
Soils with bokashi v. soils with either gallinaza or caballaza *excluding outlier		with gallinaza or caballaza*: 1.89	0.07
Soils with bokashi v. soils with gallinaza		with gallinaza: 1.85	0.05

As shown in Table 2, all t-tests regarding the effects of agrochemical application versus organic practices failed to reveal significant inequalities. When organic soils with bokashi were compared to conventional soils with bokashi, the mean TOC value for organic soils (2.14%) was greater than that for conventional soils (2.11%), but not significantly so. Similarly, if the aforementioned outlier remains excluded from analysis, the mean TOC value of 1.68% for soils with either gallinaza or caballaza (all of which were conventional) was lower than that for organic soils with bokashi, but not significantly so. This was also the case for the mean TOC value of 1.85% for soils with gallinaza. When conventional soils with bokashi were compared to conventional soils with either gallinaza or caballaza, thus excluding any potential differences due to organic practices, the mean TOC for those with bokashi was still greater than that for those with other manures (1.89%), though not significantly so. However, the mean TOC for conventional soils with bokashi was found to be significantly greater than that of conventional soils with gallinaza (1.85%) with a degree of 90% confidence ($P \leq 0.1$).

As shown in Figure 2, plotting sample TOC content versus time since the last application of organic material revealed a slight trend towards lower TOC content corresponding to greater periods of time since the last application of organic material. However, regardless of whether the outlier was included or excluded from analysis, this trend was highly insignificant, with R-squared values of 0.016 and 0.004, respectively. Similarly, as shown in Figure 3, plotting TOC content versus sample holding time revealed no significant trends. With the outlier included, a slight negative trend was observed with an R-squared value of 0.023, but with the outlier excluded, a slight positive trend was observed with an R-squared value of 0.096. Lastly, as shown in Figure 4, an observable effect of topographic ranking on TOC content was found, but ANOVA tests both including and excluding the outlier found no significant difference between the topographical groups, with P-values of 0.886 and 0.708, respectively.

Table 2: Mean TOC comparisons by organic attribute

Comparison	**Mean TOC under Condition 1 (Organic with bokashi)**	**Mean TOC under Condition 2**	**P-value from 1-tailed t-test**
Organic soils with bokashi v. conventional soils with bokashi	2.14	conventional with bokashi: 2.11	0.46
Organic soils with bokashi v. conventional soils with either gallinaza or caballaza		conventional with gallinaza or caballaza: 2.37	0.34
Organic soils with bokashi v. conventional soils with either gallinaza or caballaza *excluding outlier		conventional with gallinaza or caballaza*: 1.68	0.17
Organic soils with bokashi v. conventional soils with gallinaza		conventional with gallinaza: 1.85	0.14

Figure 2: Sample TOC content v. time since last OM application

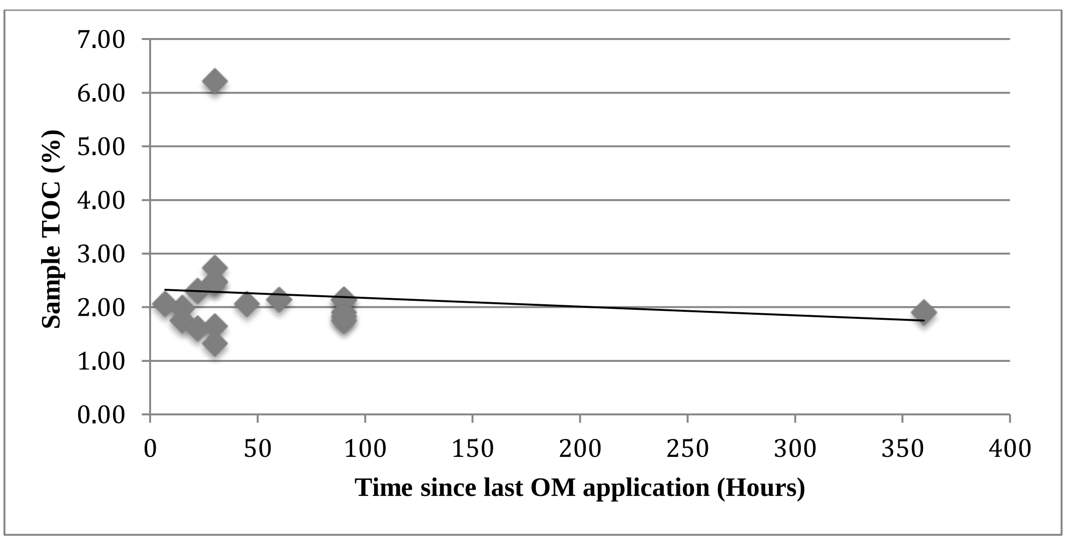


Figure 3: Sample TOC v. sample holding time

(a) Including outlier (b) Excluding outlier

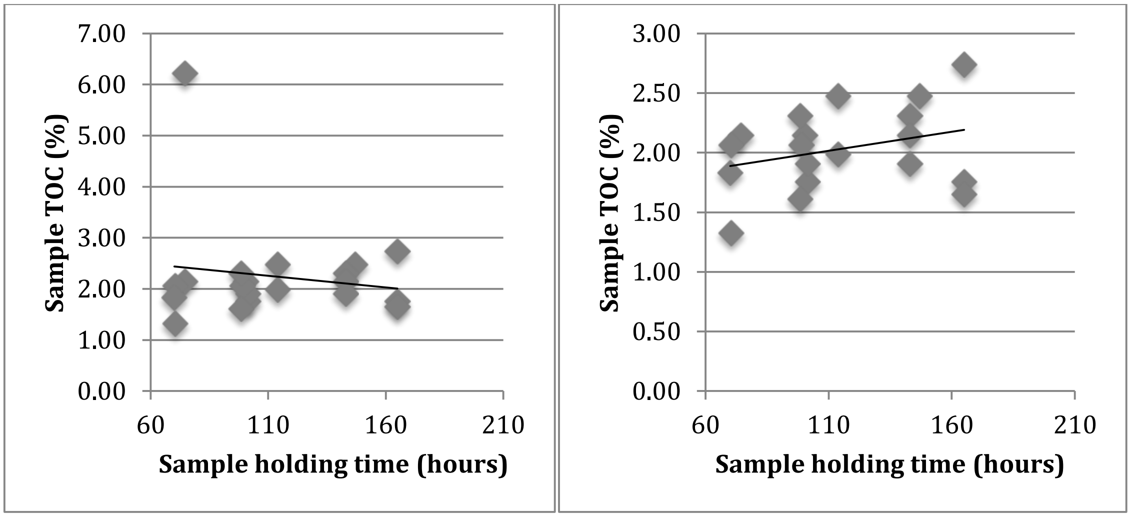
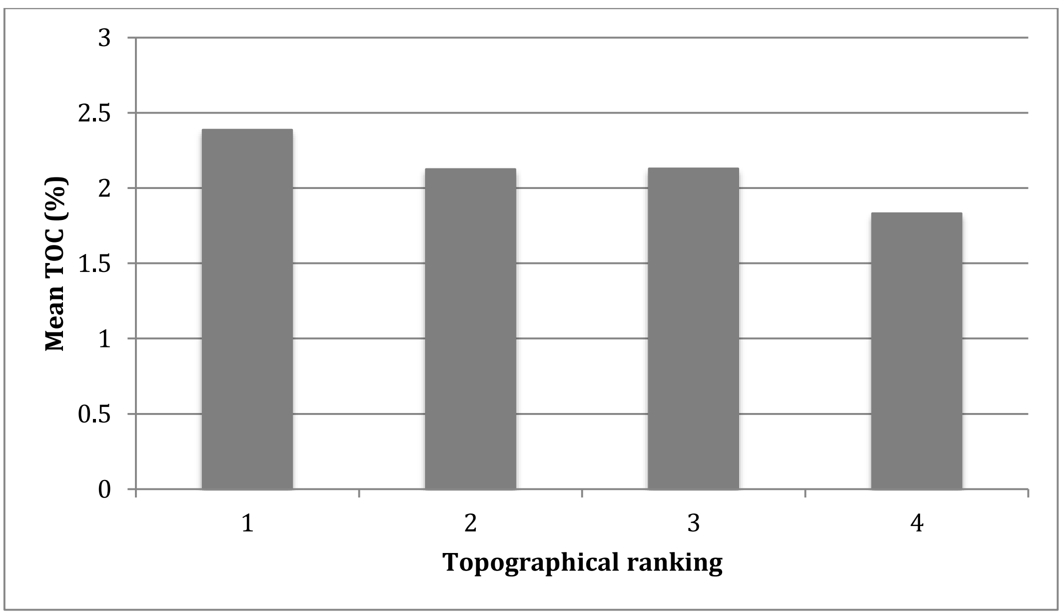


Figure 4: Mean TOC Content by topographical ranking



Interviews

Categorization of all interviewees according to their experiences with pests and fertility revealed that participants only described significant problems with pests, if any, and never with fertility. Of participants who used bokashi, 75% described minimal problems with both pests and fertility, and 25% described minimal problems with fertility but significant problems with pests. These figures were identical for organic bokashi users and for non-organic bokashi users. Of participants who did not use bokashi, however, 60% described minimal problems with both pests and fertility, and 40% described minimal problems with fertility but significant problems with pests. These results are summarized in Table 3.

Categorization of interviewees who used bokashi revealed that 62% of participants who used bokashi felt that it improved their experiences with both pests and fertility. Another 25% felt that bokashi had improved their experiences with fertility but not with pests, and lastly 12.5% felt that bokashi had improved their experiences with pests but not with fertility. No participants who were actively using bokashi felt that it had not improved either pests or fertility, nor did either of the two participants who had previously used bokashi but were no longer using it at the time.

Table 3: Percentages of participant responses by category

Category	1: Minimal problems with pests and fertility	2: Minimal problems with pests; sig. problems with fertility	3: Sig. problems with pests; minimal problems with fertility	4: Significant problems with pests and fertility
Percentage of bokashi users	**75%**	**0**	**25%**	**0**
Percentage of non-bokashi users	**60%**	**0**	**40%**	**0**
Percentage of organic bokashi users	**75%**	**0**	**25%**	**0**
Percentage of conventional bokashi users	**75%**	**0**	**25%**	**0**

Discussion

Effects of bokashi on soil TOC

Once the outlier was excluded from analysis, results consistently showed higher TOC levels in soils to which bokashi had been applied than in those to which it had not, as well as than in those to which other manures had been applied instead. Exclusion of this sample was supported by its status as a statistical outlier as well as by the visual dominance of caballaza in the sample, indicating that the sample composition more closely represented that of pure caballaza than that of amended topsoil. Although statistical significance was only found when soils with bokashi were compared specifically to those with either gallinaza or caballaza and those with exclusively gallinaza and never with a confidence interval of greater than 95%, this may be explained by the small sample sizes represented in this study. Since there are fewer than 10 samples representing each category, even the slight differences observed may be of both biological significance as well as statistical significance if assessed through a larger study (Harmon 2011).

These findings are in agreement with the majority of the literature regarding bokashi's effect on soil TOC content. Several studies have found increased SOM, to which TOC is directly proportional, in response to application of various organic materials with EM (Ismail 2013; Birkhofer et al. 2008). Others have also found significant increases in SOM specifically associated with bokashi application (Cóndor-Golec et al. 2007). The results of this study therefore provide additional support for the conclusion that bokashi is effective in boosting soil TOC content.

Findings of greater TOC content in organic soils groups versus conventional soils groups, though statistically insignificant, are also in agreement with the literature. Soil organic carbon has been found to be significantly higher in organic systems than in conventional systems (Birkhofer et al. 2008; Kaschuk et al. 2010). Other authors have explained this as resulting from the long-term application of mineral fertilizers and pesticides in conventional systems, which are thought to counteract the build-up of soil carbon by providing an excess of available Nitrogen, in turn allowing rapid microbial proliferation and consumption of organic carbon supplies (Birkhofer et al. 2008). While bokashi also increases microbial populations, effects of increased degradation rates due to bokashi application may be balanced by the substrate's contribution to SOM buildup over time (Boechat et al. 2013). This is especially likely in organic systems, in which microbial populations tend to be Nitrogen-limited (Boechat et al. 2013). Statistical insignificance in this study could again be explained by insufficient sample sizes and thus does not necessarily imply a lack of biological significance.

Similarly, while this study failed to detect significant changes in soil TOC due to topographic location, a slight trend toward lower TOC content at higher, more steeply sloped locations was observed. This trend, which is expected and well documented in the literature (Yoo et al. 2006), may nonetheless be of biological significance and might also prove to be statistically significant had more samples been taken from sites within each topographical category (Harmon 2011). Therefore, potential interference of topographic location on TOC results cannot be eliminated from interpretation of this study.

Results from analysis of time since last application of organic material as a potentially confounding variable is not, however, in agreement with expectations according to the literature. While this study found little to no relationship between soil TOC and time since last application of organic material, it is understood that bokashi's effects on carbon mineralization rates vary over time (Ndona et al. 2011). Theoretically, there should be a period of delay during which no changes are observed, followed by a period of accelerated decomposition and mineralization resulting in temporary decreases in TOC, followed by a return to normal and a period of very gradual accumulation (Ndona et al. 2011). Failure to detect such changes may also be due to sample size as well as to the low degree of variation in time since last application observed. Most growers in Cerro Punta follow similar planting and fertilization schedules, planting new crops roughly every three months and applying organic material once or twice per season (Conventional Bokashi User 2, pers. comm., 16 Apr 15; Conventional Bokashi User 3, pers. comm., 16 Apr 15; Organic Bokashi User 3, pers. comm., 16 Apr 15). Therefore, it is unlikely that time since last application of organic material played an interfering role in this study. Finally, this study's finding of no relationship between sample holding time and soil TOC is expected, since all samples were stored on ice and retained for no more than 7 days. Under these conditions, soil samples can be kept for a period of up to 28 days without significantly affecting TOC results (Schumacher 2002). It is therefore safe to assume that sample holding time did not interfere with TOC results in this study.

Effects of bokashi on farmer perceptions

The increased soil TOC levels in soils with bokashi found in this study are indicators of increased SOM and soil fertility in soils with bokashi (Haynes 2005). Therefore, one would expect to find that study participants who used bokashi had more positive perceptions of soil fertility than those who did not use bokashi. However, this was not the case. Rather, all study participants described only minimal to manageable problems with fertility. At the same time, the vast majority (87.5%) of participants who did use bokashi indicated that bokashi improved their soil fertility. Participants described these improvements as resulting from bokashi's more complete blend of soil nutrients and well as its effects on soil permeability, which reduces topsoil erosion (Organic Bokashi User 1, pers. comm., 14 Apr 15; Gallinaza User 1, pers. comm., 15 Apr 15). This discrepancy may be explained by the already high background fertility of the region's volcanic soils (Shah 2006). Therefore, rather than assuming no difference in farmer perceptions regarding fertility, the results can be interpreted as indicating the following: While most users of bokashi in Cerro Punta do perceive positive effects on soil fertility, soils in the area are still productive enough to prevent any strong differences in perceptions of fertility between growers who use bokashi and growers who do not. In this way, interview results can be seen as in agreement with TOC findings. More refined categories presented in survey formats might be more successful in distinguishing differences in perceptions of soil fertility.

The finding that the majority of study participants who used bokashi (75%) also perceived improvements in pest control associated with bokashi use provides further insight regarding how bokashi might be affecting microbial populations within Cerro Punta soils. Increases in microbial mass and activity are expected to coincide with increases in TOC (Birkhofer et al. 2008; Moscatelli et al. 2005), however, laboratory analysis for more specific microbial indicators such as carbon dioxide evolution or microbial carbon content would be necessary in order to draw definite conclusions regarding such increases, since the ratio of microbial biomass to TOC varies from soil to soil (Moscatelli et al. 2005). Since financial limitations prevented inclusion of such analyses in this study, associated farmer perceptions can instead be used in order to form hypotheses regarding the effects of bokashi on microbial populations in Cerro Punta (DiCicco-Bloom and Crabtree 2006). Specifically, the perception of enhanced pest control with bokashi leads to the hypothesis that bokashi is boosting beneficial soil microbe populations, which are in turn providing natural pest control. As one participant explained, the bacteria in the bokashi may be controlling other bacteria as well as nematodes and fungi that would otherwise damage crops (Organic bokashi user 1, pers. comm., 14 Apr 15). On the other hand, gallinaza augments pest problems as it carries dangerous bacteria in addition to fungi and herbivorous larvae (Pareja and María 2005; Gallinaza User 1, pers. comm., 15 Apr 15; Conventional Bokashi User 2, pers. comm., 16 Apr 15; Organic Bokashi User 3, pers. comm., 16 Apr 15). Agrochemical application also magnifies pest problems over time (Birkhofer et al. 2008), which, according to study participants, is because they kill both beneficial and damaging microbes as well as both herbivores and their natural predators, thus upsetting the natural balance of the soil ecosystem (Organic Bokashi User 1, pers. comm., 14 Apr 15; Organic Bokashi User 4, pers. comm., 18 Apr 15). So, by relating these qualitative interview results back to the literature regarding bokashi, soil microbes, and pest control, we can hypothesize that the increased TOC with bokashi application observed in this study likely includes increased microbial populations (Birkhofer et al. 2008; Moscatelli et al. 2005). Those enhanced microbial populations might in turn be improving plant resistance and controlling populations of above and belowground pests (Pineda et al. 2010).

It is important to note that participants in this study described other benefits of bokashi use in addition to enhanced fertility and improvements in pest control, as well as location-specific challenges associated with production in Cerro Punta, both organic and otherwise. This information helps to provide a more complete picture of how bokashi is and is not working in Cerro Punta, and what environmental, social, and political changes might amplify its usage in the future. In terms of additional draws to bokashi, participants mentioned improved worker health, reduced overall production costs, and increased profits due to bokashi use in place of gallinaza (Organic Bokashi User 3, pers. comm., 16 Apr 15; Organic Bokashi User 1, pers. comm. 14 Apr 15; Organic Bokashi User 2, pers. comm., 14 Apr 15; Conventional Bokashi User 3, pers. comm., 16 Apr 15; Conventional Bokashi User 4, pers. comm., 17 Apr 15; Conventional Bokashi User 1, pers. comm., 14 Apr 15). Perceptions regarding the costs of bokashi varied, and some compared costs of bokashi directly to those of gallinaza (Gallinaza User 1, pers. comm., 15 Apr 15). In this comparison, bokashi is more expensive. The majority, however, compared overall costs, including agrochemical expenses, when using bokashi versus gallinaza. In this comparison, both organic and conventional growers agreed that bokashi reduces the cost of production by limiting or completely eliminating the need for chemical fertilizers and pesticides (Organic Bokashi User 1, pers. comm., 14 Apr 15; Conventional Bokashi User 3, pers. comm., 16 Apr 15; Conventional Bokashi User 4, pers. comm., 16 Apr 15). Some described savings of up to 50% or even 70% after switching to bokashi (Organic Bokashi User 1, pers. comm., 16 Apr 15; Conventional Bokashi User 3, pers. comm., 16 Apr 15).

In terms of challenges associated with adoption of bokashi and organic practices in general, participants also mentioned the current high cost and low demand for organic food in Panama, the initial additional labor and increased expenses associated with the transition towards organic production, and the effects that neighboring farms can have when they are not also producing organically or are continuing to use gallinaza (Gallinaza User 1, pers. comm., 15 Apr 15; Organic Bokashi User 3, pers. comm., 16 Apr 15; Organic Bokashi User 4, pers. comm., 18 Apr 15). Participants also mentioned the limited supply of both bokashi and other organic options in the area, as well as the fact that bokashi is very difficult to produce by hand (Conventional Bokashi User 2, pers. comm., 16 Apr 15). One participant also described climate changes currently taking place in Cerro Punta, involving more rain during the rainy season as well as a shorter dry season. This participant described increased erosion and problems with fungus due to these changes (Gallinaza User 1, pers. comm., 15 Apr 15). Finally, one participant pointed out the need for a soil laboratory closer than the nearest government lab in Divisa, which would enable growers to test their soils more frequently and more rapidly, in turn enabling them to make more educated decisions about which products to apply and when (Conventional Bokashi User 2, pers. comm., 16 Apr 15).

Conclusion

The expectation of this study was to find increased TOC levels in soils with bokashi compared to those without bokashi, whether they had been amended with gallinaza or caballaza, or had not been amended with any organic matter. Although the observed increase in TOC was not always statistically significant, the results do consistently support this conclusion. As this study is lacking specific data regarding microbial respiration rates or microbial carbon mass, this finding could indicate one of several things regarding soil composition and microbial communities. TOC levels in soils with bokashi could be elevated due to enhanced organic carbon buildup over time, resulting from repeated additions of organic carbon-rich bokashi substrate. Increased TOC levels in soils with bokashi could also be attributed to increased microbial biomass, resulting from the addition of beneficial microbes deriving from the EM component of bokashi. However, if microbial degradation rates were also increased along with microbial biomass, carbon losses as carbon dioxide would also be increased and the quantity of TOC present in soils with bokashi would be reduced. According to the existing literature, increased TOC levels in soils with bokashi are most likely a result of both SOM buildup and increased microbial biomass, with increases in both materials outweighing any potential decreases in TOC due to accelerated degradation of SOM (Birkhofer et al. 2008; Moscatelli et al. 2005; Pineda 2010).

This study also found increased TOC levels in organic soils than in conventional soils, though again results were largely significantly insignificant. Since sample sizes were small, this finding should not be discarded, but rather viewed as potentially biologically significant though inconclusive. This finding is in agreement with the existing literature (Birkhofer et al. 2008), and can be explained by the fact that carbon buildup can be enhanced in organic systems due to Nitrogen limitation of microbial degradation, as chemical nitrogenous fertilizers are not applied in organic systems (Boechat et al. 2013).

Personal interviews were used in this study to not only provide essential information regarding agricultural practices to complement each sample, but also to provide information regarding farmers' perceptions on bokashi's effectiveness in Cerro Punta. Such information was then used to complement soil data and understand more fully in what ways bokashi is seen as beneficial or unhelpful in the area. It was discovered that, while bokashi users and non-bokashi users alike perceive roughly the same degree of difficulty with pests and fertility, the vast majority of bokashi users perceived improvements in soil fertility and pest control associated with bokashi application. This reveals two important concepts. The first and most apparent conclusion is that most growers interviewed who are using bokashi have perceived improvements regarding both pests and fertility and, since a large proportion of bokashi users in the area were interviewed, it is reasonable to assume that this is true for the population of Cerro Punta.

The second and subtler conclusion stems from the first. If most bokashi users perceive benefits regarding fertility and pests, then actual changes in soil composition affecting both fertility and pests may be taking place. Increased soil TOC content would positively affect fertility, and this change is confirmed by the soil data. Increased microbial populations would positively affect pest control, and increased microbial carbon mass could be contributing to the observed increases in TOC, although this is uncertain without further testing. So, in this way, the interview results from this study lead to the hypothesis that increased TOC associated with bokashi application in Cerro Punta might be a result of increased microbial populations in addition to increased organic carbon buildup. If so, then bokashi application is contributing to both increased productivity in the area as well as improved soil ecosystem health, which will help to foster and protect that productivity in the long-term.

Recommendations for further research

Further research is necessary in order to confirm the results regarding increased TOC levels in both bokashi systems and organic systems in Cerro Punta. Larger sample sizes would provide a better opportunity for statistical significance and, if taken randomly, would also help to confirm that findings are representative of the population. Also, larger sample sizes would help to either better understand or eliminate potential complicating or interfering variables such as time since last application, agrochemical use, and topographic location. Alternatively, a study that controlled for such variables might also be better able to capture the effects of bokashi alone and arrive at more conclusive results.

Further research regarding specific microbial parameters and their responses to bokashi application will also be necessary in order to test the hypotheses established through this study and in order to better understand the precise soil biological changes associated with bokashi application in Cerro Punta. Additionally, similar research should be done in other agricultural areas in the tropics and around the world, since different soils in different climates may respond to bokashi application in distinct ways. Location-specific findings would then enable farmers in various regions to make more educated decisions regarding fertilizer and soil amendment usage. Where bokashi is found to improve fertility and / or pest control, such as in Cerro Punta as suggested by this study, farmers might be able to reduce or even eliminate their use of chemical fertilizers and pesticides by incorporating bokashi into their production methods. Such reductions would have profound impacts on the environment, on long-term soil health and productivity, on human health, and on costs of production.

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