

Foreword

This thesis project is the result of a 12-week internship at Finca Loma Linda located in the foothills of the Cordillera de Talamanca mountains of southern Costa Rica. The history of Finca Loma Linda and its colorful array of agroecological endeavors goes back almost fifty years to a time when this region was known as the Southern Frontier and few outsiders dared to traverse through the dense primary forest that dominated the landscape.

In the early 1950's a small group of rugged settlers pioneered this region, and established homesteads throughout the area. The Cole-Christensen family chose to homestead on a site in the hills above an expansive valley that was home to a small outpost called Agua Buena.* The beautiful site of their homestead, characterized by small hills and a flat central area, was given the appropriate title, Loma Linda. At the time the only established colony of any size was the Italian outpost of San Vito, which was several miles away over difficult terrain. Dreams of a subsistence lifestyle were hard fought for the early settlers of this undeveloped land.

Many of the early settlers had high hopes for agricultural prospects in this land of lush forests and "virgin" soils. The families worked long and hard to clear the land in preparation for the production of both subsistence crops, to meet the families immediate needs, and cash crops such as coffee and sugar cane, in an effort to make the farm economically viable. In a rush to begin production on these seemingly fertile soils, the settlers cleared vast tracks of forest, burning the areas that could not be adequately leveled with machetes, unable to foresee the long-term problems associated with

* The majority of the following information was collected from conversations with Darryl Cole-Christensen and from his book *A Place in the Rainforest: Settling the Costa Rican Frontier* (University of Texas Press, Austin: 1997).

exposing the soil to heavy tropical rains. Amidst the fallen forest the farmers began to plant a wide array of crops. After an initial period of success, the soil became less productive as the nutrient base, supplied by the decomposing organic matter from the freshly cut forest, was leached from the soil by heavy rainfall.

The Cole-Christensen family and Finca Loma Linda were subject to the same soil fertility issues that plagued the other farmers in the area. In an effort to overcome this obstacle, farmers began to rely upon a limited number of crops, which were compatible with the soil and climatic patterns in this zone, to provide sustenance for the family. In addition to crops, such as bananas, plantains, corn, ayote and chayote, Loma Linda also introduced livestock to the farm to provide the household with milk, cheese, cream and eggs. Coffee, which is especially well suited for this soil and climate, was also planted in hopes that it would provide the farm with a steady income.

While other crops and money-making ventures would come and go, coffee remained a mainstay of the farm for a period of twenty-five years. For the vast majority of that period Darryl Cole-Christensen, just a teenager upon arriving in Costa Rica, was the primary individual in charge of managing this crop and a variety of other farm projects. From the beginning Darryl had a vision of creating a diverse farm environment: a system that was not reliant upon the success and failure of a single crop from season to season. The farm landscape was, and still remains, a work in progress.

By the late 1960's the value of coffee had dropped so dramatically that other crops soon became more of an asset than they had been previously. During the 1970's Loma Linda turned toward the production and sale of vegetables as its primary source of farm income. Vegetables were harvested on the farm and then trucked down to the port town of Golfito and sold to the families of banana plantation workers.

As other family members moved off the farm to begin businesses in other parts of Costa Rica, Darryl remained and continued to experiment with new techniques in crop

production. The process of trial and error is a key aspect in the success of any farm management system and Loma Linda was no exception. From the earliest days Darryl and his family committed themselves to constant experimentation, testing a vast array of agroecological concepts in an effort to make the farm a healthy yet economically stable environment. Supplemented by his parent's off-farm income, Darryl was able to pursue the process of experimentation and diversification to an even greater extent. This strong commitment to research in agriculture would eventually lead Loma Linda to open its doors to scientists from around the world, studying a vast array of ecological processes.

In the 1980's and early 1990's Loma Linda became the site of numerous studies from both post-doc scientists and Ph.D. students. During this period, the farm was also opened up to a couple of short courses led by the University of California and the Organization of Tropical Studies. These short courses introduced graduate and undergraduate students to the complexities of tropical agriculture through hands-on exercises. The positive feedback from students participating in these short courses eventually led to the formation of a full-fledged internship.

The Loma Linda Internship program began in July of 1998 with one student and has since evolved to include a number of students from universities throughout the United States. The internship itself has been changing over the past couple of years, as student projects have moved from being primarily centered at Loma Linda to involving the farms that are managed by the home-stay families. The role of the internship at the community level has also been changing. The strong connections made between home-stay families and students have led to an outpouring of community support for this program. This support has been translated into a new internship called Programa Pueblos. This program, which is still in the early stages of development, will allow interns the opportunity to become active members of the community, through the exchange of ideas and participation in projects that will benefit local families.

Before my departure for Costa Rica in the fall of 2000, I had been in contact with Darryl regarding ideas for a possible thesis project. Darryl proposed a variety of project possibilities. I was especially drawn to the outline of a project that involved the use of compost leachates as natural fertilizers for vegetable crops. This was the type of project that could incorporate both my agroecological background and my love of gardening. When I arrived in Costa Rica I began the process of preparing a research plan that would keep me busy over the next three months.

This paper presents the results of that research. In addition to this formal analysis, I was able to share the results of my experience in a number of informal ways. Besides the daily progress reports that I would recount to my home-stay family, I was also able to share the results of this project with local vegetable farmers. As my project neared the final stages Darryl invited some local farmers to come view the performance of the test crops, tomatoes and sweet peppers. As we were showing the farmers how the leachate was prepared I began to realize that my internship was coming full circle, no longer was this only a thesis project but now the broader implications of this work was coming to light. It is my hope that these farmers left that day with new ideas about ways that their crops could benefit through the use of on-farm resources. This project is only one small step in the long road towards creating healthy, productive farms free from reliance upon synthetic implements. It is my hope that this line of research will be continued, one day to be incorporated as a regular activity on local farms.

Introduction

In many tropical agricultural production systems organic matter is a key component in the maintenance of healthy, productive soils. Sustainable methods of

fertility enhancement are often employed as an alternative to heavy inputs of synthetic fertilizers. The management of soil organic matter is especially critical for small-scale farmers that do not have ready access to off-farm implements or are financially unable to obtain these resources (Smith et al., 2001; Palm et al., 2001a; Mugendi et al., 1999). Even in areas that have become reliant upon the use of synthetic fertilizers, organic material is often employed to improve soil structure, reduce evapotranspiration rates, supply small amounts of nutrients, and to improve the efficiency of nutrient cycling (Reddy, 1999; Schroth et al., 2001). The application of organic matter can be achieved in a variety of forms including the use of cover crops, the direct application of mulch or compost, and the pruning or natural senescence of leaves from tree species in multistrata agroecosystems.

Limited availability of the major elements, nitrogen and phosphorus, in tropical agroecosystems is often cited as the greatest constraint to crop production (Hedley et al., 1992; Baggie et al., 2000). A number of studies have emerged over the past several years that examine the use of organic matter in ameliorating the availability of these nutrients in tropical soils. Studies have focused upon the incorporation of organic residues in alley cropping systems (Mugendi et al., 1999a; Mugendi et al., 1999b), annual cropping systems (Kettler, 1997a; Baggie et al., 2000), slash/mulch systems (Rosemeyer et al., 2000), fallow systems (Kanmegne et al., 1999), and agroforestry systems (Nichols et al., 2001).

Some studies suggest that the use of organic matter inputs can completely replace the use of synthetic fertilizers in particular systems. Mugendi et al. (1999) found that *ex situ* prunings of the agroforestry tree species *Calliandra calothyrsus* and *Leucaena leucocephala*, applied to a maize cropping system in the subhumid highlands of Kenya, resulted in higher maize grain yield than both the fertilized and non-fertilized controls. Although these results are promising, they only provide one example in which the

application of organic biomass was able to increase crop yields above the yields that were achieved in synthetically fertilized controls. In most cases organic soil amendments need to be supplemented with small amounts of mineral fertilizer in order to obtain sufficient crop yields in tropical agroecosystems (Janssen, 1993; Palm et al., 2001a).

Current literature in this field has focused upon using a few characteristics to systematically quantify the quality of organic residues and hence their value in a particular system (i.e. Palm et al., 2001a; Handayanto et al., 1997). Decomposition and nutrient release patterns are often cited as the most important characteristics for determining the potential of organic inputs in agroecosystems. High quality organic inputs are often characterized by a low ratio of C:N and low lignin and polyphenol concentrations (Handayanto et al., 1997). Plant materials exhibiting these qualities are associated with rapid decomposition and mineralization rates that may satisfy the short-term nutrient element demand of crop plants. Low quality organic inputs are characterized as having high lignin and polyphenol contents resulting in slower decomposition and nutrient release rates (Mellilo et al., 1982). Although most studies have focused upon the use of high quality organic inputs, those of low quality may also prove valuable for use in maintaining soil organic matter levels and providing nutrients in the latter stages of plant development (Kettler, 1997a). Recent studies have begun to examine the mixing of high and low quality organic material in an effort to synchronize nutrient element release and crop nutrient demands (Handayanto et al., 1997; Mafongoya et al., 1997a).

The move towards a more predictive understanding of the use of organic inputs has been forwarded by the creation of a database that incorporates numerous studies examining the quality, decomposition and nutrient release patterns of a wide array of plant species (Palm et al., 2001). The organic resource database (ORD) introduced by Palm et al. (2001) contains data collected for almost 300 plant species. In addition to

biomass quality, decomposition rates, and nutrient release patterns, this database also contains information about the type of biomass that was used (leaves, litter, stems, roots or residues), soil type, and climatic conditions. The majority of entries use leaves to quantify the parameters of resource quality.

The value of using leaf biomass from tree species for increasing soil fertility in tropical agroecosystems has been recognized by a number of researchers (e.g. Blum, 1999; Pankurst, 1999). The extensive root network of trees allows them to absorb nutrients in the lower soil horizons that are inaccessible to the shallow rooting systems found in most annual crops. In addition to capturing nutrients that may otherwise be leached down the soil profile (Dhyani et al., 1990), trees in agroecosystems are important for modifying microclimates, reducing wind and water erosion, and providing habitat for beneficial organisms (Gliessman, 1998).

Organic biomass collected from tree species may be incorporated into agroecosystems using a variety of techniques including burning, incorporation into the soil, applying it to the soil surface as mulch, or removing it to another part of the farm to be composted (Lal, 1999). The type of agroecosystem in which the trees are found plays an important role in determining the manner in which their resources will be used. In agroecosystems that employ slash/mulch or alley cropping techniques, organic biomass is often cut from tree species and left in place to regulate soil temperature, provide nutrients, suppress weed growth, and contribute to the formation of soil organic matter (Kettler, 1997b). In other types of tropical agroecosystems, such as annual cropping systems, organic residues may be brought in from other parts of the farm and applied as mulch or incorporated into the soil to provide a nutrient boost, in addition to providing the aforementioned services. The use of tree species in tropical agroecosystems varies greatly from farm to farm, and is often dependent upon the socioeconomic values that are placed upon the species by individual farmers.

In many tropical agroecosystems trees serve a multitude of purposes. The services that they provide include such things as, fodder for animals, a perennial food source for the family, wood for energy or construction materials, and nutrients, in the form of biomass, for other crop species (Nair, 1983). Limited by available land area, small holder tropical farmers are often forced to use creative approaches when trying to incorporate tree species into their systems. In many cases, both cultural and ecological processes are considered when choosing where and which type of tree will be planted. In some agroecosystems trees, are planted along farm boundaries for use as “living fences”, while in other systems, such as multistrata coffee plantations, trees are incorporated directly into the cropping system.

In agroecosystems that do not have an abundance of tree species, farmers are often forced to make critical decisions with regards to where the available resources will be most effectively used. Often times farmers are hesitant to remove biomass from one part of the farm to be used in another part of the system, even if that biomass may promote desirable increases in crop yield (Molina, personal communication). This attitude may be attributed partly to the increased labor involved in the transfer of biomass and, more importantly, the concern that fertility in one part of the system will suffer at the expense of another. In this regard, tropical farmers that have greater amounts of available land, especially land that has been left intact as a natural ecosystem, have distinct advantages over small holder farmers. These farmers, with larger amounts of nutrients available in the form of standing biomass, are able to move resources from one part of the farm to another without significantly altering ecosystem function. Agroecosystems exhibiting higher amounts of biomass, and a less intense focus upon the cultivation of a single crop, may play an important role in the identification of species that can be employed toward improving soil fertility and in the development of new techniques for the incorporation of biomass into cropping systems. The lessons derived from these

systems can then be passed on to other farmers in the community that do not have the available resources to carry out these inquiries. One technique of soil fertility enhancement that may be especially well suited for diverse agroecosystems is the use of compost.

The direct application of tree prunings has been shown to increase crop yield in a number of studies (Mafongoya et al., 1997a&b; Lal, 2000; Kettler, 1997a), yet little attention has been given to the possible benefits associated with composting this material before applying it as mulch (Dreschel and Reck, 1998). In agroecosystems that are stable enough to allow for the short-term removal of organic biomass, composting may provide a low-cost and low technology method of applying a wide variety of on-farm organic resources towards the goal of meeting crop nutrient demands. The composting process is especially well suited for agroecosystems that contain a high degree of plant biomass in some areas of the farm (i.e. multistrata cropping systems or successional forest) and lower amounts of biomass in other areas (i.e. annual crops). Leaf biomass collected in the more diverse areas can be composted with household food wastes, crop residues, and other organic matter, and then incorporated back into the annual cropping system. Compost has an advantage over the direct application of biomass in that the decomposition and humification process has already been started; thus the application of composted materials will promote fertility enhancement at a slightly faster rate than the direct application of uncomposted organic biomass. In addition to the use of compost, compost teas used as liquid fertilizers are another possible innovation that may provide a quick, easy, and sustainable method of nutrient enhancement.

Preliminary studies throughout the United States and abroad have shown that compost teas may be an effective form of supplying nutrients and preventing or suppressing disease in crop plants (Riggle, 1996; Ingham, 1999). The short-term advantage to using a liquid form of compost, as opposed to the compost itself, is that it

can be easily applied through an irrigation system or through backpack sprayers (Ingham, 1999). Compost teas may be especially useful in tropical agroecosystems that are faced with nutrient deficient soils and high incidences of foliar pathogens. The use of compost teas in tropical agroecosystems may provide a holistic approach to increasing the productivity and general health of crops. It has been recognized that the biology of compost teas is not well understood and at this point in time, trial and error appears to be the most valuable method for determining which types of applications will be most useful for a particular system (Riggle, 1996).

This study was initiated with the specific objective of identifying tree species and techniques of preparation that may be used enhance crop growth in a tropical agroecosystem. Compost and compost teas, made from three locally available tree species, were evaluated for their effectiveness as natural fertilizers of locally cultivated vegetable crops.

Materials and Methods

Pot Study

Site Description

This study was conducted at Finca Loma Linda, a 54.8-hectare experimental farm, located in Coto Brus, Puntarenas, Costa Rica. This site, at an elevation of approximately 1200m, receives 3000-3500mm of annual rainfall and the annual mean temperature ranges from 13°C to 25°C (Cole, personal communication). The pot study was conducted on two tables located in a level, open area. The tables were constructed of cinder blocks stacked to a height of approximately 0.5m and covered with corrugated steel roofing. A canopy of clear visquene plastic was then placed over the tables forming a partial

greenhouse, protecting the study crops from inclement weather. The sweet pepper and tomato pot studies were conducted on identical tables facing in a north to south direction, with approximately two meters between the tables. The total surface area of the tables was approximately 5m by 0.75m.

Soil Collection

The soil used in the pot study was collected at the Windmer site on Finca Loma Linda. Soil was collected from a depth of 0-50cm and mixed thoroughly, with all clumps broken up, to ensure homogeneity. One liter of loose soil was added to each one-liter pot and then tapped on a solid surface three times to allow for settling. Pre-experimental soil tests conducted at CATIE (Turrialba, Costa Rica) show a pH (H₂O) of 5.7 and plant available P to be 2.27mg kg⁻¹.

Tree Species

The extracts used in this study were created from compost mixtures of three locally available tree species. *Calliandra calothyrsus*, an N-fixing legume, was introduced to Coto Brus in 1991 and has since been considered as a potential shade crop for coffee. *Senna* spp., a non-N-fixing legume is a native species commonly found in successional forests and has also been considered as a possible shade tree for coffee. The third type of tree used in this study, *Heliocarpus appendiculatus*, is a native non-leguminous species very common in the successional forest and locally recognized as an indicator soil fertility because of the large amounts of biomass produced by its fast growing, broad leaves. The three species are hereafter referred to as *Calliandra*, *Senna*, and *Heliocarpus*.

Experimental Treatments

This study involves the use of leachates made from compost batches of the three aforementioned tree species, as well as a leachate made from a compost that includes a mixture of the three species. This study also incorporates a synthetic fertilizer only treatment and a synthetic fertilizer+mixture compost leachate treatment. All treatments were used in bioassays on two test crops; tomato and pepper. The treatments were as follows:

Control: water

Treatment 1: fertilizer and water

Treatment 2: fertilizer and mixture extract

Treatment 3: *Calliandra* extract

Treatment 4: *Heliocarpus* extract

Treatment 5: *Senna* extract

Treatment 6: mixture extract

Each of the treatments and the control were replicated 6 times for each of the two test crops, for a total of 42 pots with tomatoes and 42 pots with sweet peppers.

Compost Production and Extract Preparation

Biomass of the three tree species was harvested at different sites throughout the farm, with the majority of plant material collected at the edges of disturbed areas (i.e. farm roads). Two hundred liters of plant material were collected for each compost batch. Biomass collected from *Calliandra* and *Senna* included small branches (<1.5cm in diameter), leaves, and fruits, and biomass collected from *Heliocarpus* included only small

branches (<1.5cm in diameter) and leaves. After the biomass was harvested the material was chopped repeatedly with a machete until a relatively uniform mixture was created, with material ranging in size from 2-10 cm.

Individual batches of compost were made for all three species and a mixture compost was created that included a portion of all three species. Once the biomass was harvested and chopped, 200L of plant material were measured out and the fresh weight of the plant material was recorded using a hanging scale. The fresh mass of two hundred liters of plant material for the three tree species and the mixture compost were as follows: 59.18kg for *Calliandra*, 50.25kg for *Heliocarpus*, 38.5kg for *Senna*, and the mixture included 10.85kg *Calliandra*, 13.45kg *Heliocarpus*, and 14.35kg *Senna*. After the mass was recorded the plant material was spread on a concrete floor and five liters of rice bran was spread evenly on the plant material. The material was turned over and mixed several times until the rice bran was evenly spread throughout the mixture. This process was repeated for each of the four compost batches.

After the rice bran had been mixed with the plant material it was immediately transferred to a compost maker. The compost maker consists of a 55-gallon drum that sets horizontally on a metal stand that allows the drum to be rotated. On one side of the drum a small door had been welded on to allow for the placement and retrieval of compost materials. Small holes, approximately 1.5cm in diameter, are present on all sides of the drum to allow for air flow.

Each batch of compost was placed in the compost maker for a period of 7 days. During this period the compost maker was turned three times daily and temperature readings were recorded daily at three different placements within the drum. After the seven day period the composted material was retrieved from the drum and placed within a cinder block compartment resting on a cement floor. The plant material was allowed to

continue composting in these compartments for a period of seven days at which time the extract was prepared.

The extract was prepared by collecting 2.8L of compost from the cinder block compartment and placing it in a bucket filled with 10L of water. The material was agitated by hand for several minutes and then strained through a mesh sieve into another bucket. The compost material collected in the mesh sieve was then placed in cheesecloth and squeezed over the bucket until the majority of the liquid had been removed. This process was repeated twice for each compost batch and yielded approximately 20L of extract. The extracts were then transferred to one-gallon plastic bottles and stored on a cement floor out of direct sunlight. All extracts were made immediately after the 14-day composting process, however the *Calliandra* and *Heliocarpus* composts were created a week before the *Senna* and mixture composts, thus they were a week older when the pot study was initiated.

Germination and Sowing of Test Crops

The tomato (*Lycopersicon esculentum* L. var. Hayslip) and sweet pepper (*Capsicum annuum* var. Agronomico) seeds are common varieties purchased at the local agricultural supply store, and reportedly the most widely used varieties in the area. All pepper and tomato seeds were germinated in paper towels kept moist in a covered area exposed to direct sunlight for a couple of hours a day. The germinated tomato seedlings were planted after 13 days and the pepper seedlings were planted after 21 days. All germinated seeds were planted by making a small indentation in the loose soil in which the roots were placed. The roots were then lightly covered with soil. The cotyledons of all seedlings remained visible above the soil surface. Three seeds of each crop were planted into each pot and watered. After a period of two weeks the most robust seedling was

saved, and the other two were cut at soil level and removed. Throughout the study period all weeds and foreign material were hand picked and removed from the pots.

Leachate and Fertilizer Application

On the third day after planting, the fertilizer treatments (1&2) of both crops were watered with an 80ml solution of Raizal 400™ (9-45-11), with a concentration of 7.5g/L, as prescribed by the manufacturer's label. The fertilizer solution was applied directly to the soil and followed by an additional 50ml of water, to equal the amount of liquid given to the other treatments. The second and final fertilizer application occurred 15 days after the initial application following the same procedure.

At the time of the first fertilizer application, 130ml of water was applied to the soil of the control treatment and 130ml of the appropriate leachate was applied to the soil of treatments 3-6. After the initial application, leachate was applied on a weekly basis to treatments 3-6, with Treatment 2 receiving 130ml of leachate and treatment 1 receiving 130ml of water on days that did not coincide with the two fertilizer applications. The control treatment was given 130ml of water on all leachate application days. All plants in this study were also watered on an as needed basis throughout the study period, with the last application occurring two days before harvest.

Data Collection

Data collection for both the tomato and sweet pepper studies began 15 days after sowing. Measurements of plant height (to the tallest growing apex), leaflet length (from the tip of the longest leaflet to where the basal point of the leaflet meets the petiole), and leaflet count were taken on a weekly basis. Final measurements were taken the day before the experiment was terminated. After a period of 39 days for the tomatoes and 38

days for the peppers, the plants were cut at soil level and their fresh weights were recorded. The roots were extracted from the pots and washed. The collected biomass, above-ground and below-ground, was then dried to a constant weight. The mass of each plant was recorded. All plant material with a mass of less than 0.05g was measured on an analytical balance, while all other masses were recorded using a pan balance. At the time of harvest any visible nutrient deficiencies found in the tomato plants was also noted.

Statistical Analysis

Analysis of variance tests were performed on above- and below-ground biomass, total biomass, number of leaflets, plant height, and longest leaflet for both the tomato and sweet pepper study. A post-hoc test (Tukey-Kramer) was used to compare treatment means. Means were declared significantly different at $P < 0.05$.

Field Study

Site description

The field study was also conducted at Finca Loma Linda (see *Site Description* from pot study), in an area of the farm that had been previously used in agricultural production, yet had been in a fallow state since 1993. Imperial grass (*Axonopus scoparius*) was the dominant species during this fallow period. The site was cleared by hand and the soil was loosened to a depth of 35cm using a fork and spade. The soil was then raked to obtain an even textured surface and all visible roots were removed. Six rows, 5.25m by 0.5m, were created in a north to south orientation. Each of the six rows were divided into seven 0.5m by 0.5m squares, each separated by 20cm of bare soil.

Experimental Design

Each of the treatments used in the field study was the same as those used in the pot study, however in this study the actual compost was used instead of a leachate made from the compost (see *Experimental Treatments* and *Compost Production* from pot study).

Using a randomized block design in which each row was a block, each of the squares was assigned one of the six treatments or a control. This process was repeated in each of the six rows for a total of 6 replicates of each of the six treatments and the control.

In this study, maize (*Zea mays* L. cultivar Hi-bred) was used as the test crop. This crop was chosen because it is commonly cultivated by local farmers for household use and as animal feed. This crop also exhibits greater resistance to pests than other locally cultivated vegetable crops, thus allowing the study to be carried out without the application of pesticides.

Compost and Fertilizer Application

The same compost batches that were used to create the leachates were also used as the mulch in this study. A total of four compost batches were used, however the first two (*Calliandra* and *Heliocarpus*) were made a week earlier than the second two, thus they were stored in the cinder block compartments for an extra week before field application. The treatment mulches were applied 23 days before the planting of the test crop. At this time the *Calliandra* and *Heliocarpus* composts had been out of the compost maker for a period of 23 days and the Mixture and *Senna* composts had been out of the compost maker for a period of 14 days. Each of the mulch treatments received six liters of compost spread evenly within the 0.5m by 0.5m square. The volumetric measurement used for mulch application simulates management practices employed by local farmers.

The average loft of the mulch was 5 cm at the time of application. Afternoon rains watered the mulch in.

In the fertilizer and the fertilizer+mixture compost treatments the fertilizer was applied on the day following the application of mulch. Based upon the recommendations of the local extension agent for the Ministry of Agriculture, triple super phosphate (0-46-0) was applied at a rate of 55.2 grams per treatment. Half of this amount, 22.6g, was placed in each of two holes, 3cm wide and 4cm deep, on either side of where the test crop would be planted.

Sowing of Test Crop

The test crop, *Zea mays*, was pre-germinated for a period of three days in moist paper towels. In each of the treatments two pre-germinated corn seeds were planted to a depth of 1cm and completely covered with soil. In order to protect the seedlings from predation in the early developmental stages, an open-ended PVC pipe (1.8cm diameter, 4cm long) was pressed into the soil surrounding the planted seeds. All seedlings were watered in with 130ml of collected rain water. Approximately two weeks after planting the PVC sleeves were removed and the test crop was thinned to one plant per plot. Throughout the study period weeds were removed from the test plots on a weekly basis.

Data Collection

Data collection for the maize mulch study began 17 days after the initial planting. Measurements of plant height (from the soil to the tip of the longest leaf), basal diameter, and leaf count were recorded on a weekly basis. Final measurements occurred 67 days after planting, at which point the maize was cut at soil level and the fresh weight was recorded. The biomass was then dried to a constant weight and the mass was recorded.

Results

Pot Study

For tomatoes grown in the pot study, significant treatment differences were found for total biomass ($F=35.08$, $P<0.0001$), plant height ($F=48.39$, $P<0.0001$), leaflet length ($F=43.84$, $P<0.0001$), and number of leaflets ($F=38.68$, $P<0.0001$). The total biomass of tomato plants grown with fertilizer, fertilizer + mixture leachate, *Senna* leachate, and *Heliocarpus* leachate were significantly greater than the control (Fig. 1). All treatments were found to exhibit significantly greater plant height than the control (Fig. 2). All treatments, with the exception of the *Calliandra* leachate, also exhibited significantly longer leaflets and a significantly greater number of leaflets than the control (Figures 3& 4). A comparison between the two commercial fertilizer treatments, with and without mixture leachate, indicates that total biomass was significantly greater when the mixture leachate was added. Additional comparisons among treatments are reported in Figures 1-4.

For peppers, significant treatment differences were found for total biomass ($F=22.06$, $P<0.0001$), plant height ($F=32.45$, $P<0.0001$), leaflet length ($F=26.27$, $P<0.0001$), and total number of leaflets ($F=28.13$, $P<0.0001$). The total biomass of pepper plants in the fertilizer and fertilizer + mixture leachate treatments were significantly greater than all other treatments, including the control (Fig. 5). These treatments, plus the *Senna* leachate, were also significantly greater than the control for leaflet length and plant height (Figures 6&7). Comparisons among treatments are reported in Figures 5-8.

Field Study

The field mulch study on maize found significant treatment for above-ground biomass ($F=4.64$, $P=0.0016$), height ($F=8.98$, $P<0.0001$) and basal diameter ($F=5.54$, $P=0.0005$). The fertilizer + mixture compost mulch treatment was the only treatment that exhibited significantly greater above-ground biomass and basal diameter than the control (Figures 9&11). The total biomass of the maize grown in the fertilizer + mixture compost treatment was also significantly greater than all other treatments, including the fertilizer only treatment. Both of the fertilizer treatments exhibited significantly greater maize height than the control (Fig. 10). The total biomass of maize grown in the fertilizer + compost mixture treatment was significantly greater than the biomass of the maize grown in the fertilizer only treatment (Fig. 9). Additional comparisons among treatments are reported in Figures 9-11.

Discussion

Pot Study

Crop growth in tropical cropping systems is commonly limited by low soil fertility, especially when deficiencies of nitrogen and/ or phosphorus are present. The low available P found in the soil that was used for our pot study is characteristic of the soil found on many farms in Coto Brus, Costa Rica. The common solution to this mineral deficiency is the addition of high phosphorous fertilizers, such as triplesuperphosphate, in amounts of 15 quintales/hectare or greater (personal communication, Juan Vicente, Ministry of Agriculture extension agent). Based upon this knowledge, it was expected that the two synthetically fertilized treatments, with a guaranteed supply of P, would

promote greater growth of both peppers and tomatoes. This assumption was confirmed in the pot studies, in which the fertilized treatments were significantly greater than the control for all measured parameters, including total biomass, plant height, number of leaflets and leaflet length.

In addition to the two synthetically fertilized treatments, some of the leachate treatments also exhibited stronger growth than the control, in particular the *Senna* and compost mixture extracts, with the most visible differences occurring in the tomato study. The positive growth response of tomatoes to the liquid compost extracts was probably a response to the nutrients contained in these liquid compost extracts. Compost teas can also be associated with the presence of beneficial microorganisms incubated during a steeping period (Brinton, 1996). However, Ingham (2002) suggests that compost extracts prepared with only brief contact between compost and water, as was the case in our study, may effectively capture many of the soluble nutrients found in that compost while amassing only a small portion of the beneficial microorganisms. An in-depth analysis of the composition of our compost extract, including microbial and nutrient content, may provide us with a better understanding of why particular extracts exhibited increased performance while the performance of others did not differ significantly from the control.

Our results indicate that the *Senna* and compost mixture extracts may be the best suited for improving soil fertility, however the duration of leachate storage time may have influenced these findings. Both the *Senna* and compost mixture extracts were created 5 days before the initial application to the tomato plants while the *Calliandra* and *Heliocarpus* extracts were created 12 days before the initial application. Based upon Brinton's (1996) suggestion that compost teas should be used within a week of extraction, the discrepancy between preparation times for the two groups of extracts may have comprised the quality of the *Calliandra* and *Heliocarpus* extracts. Since the same extracts were used throughout the study period, the temporal advantage of the *Senna* and

compost mixture treatments may have disappeared over time. The storage effect may also have played a role in the decreased incidence of treatment differences found in the pepper study, which was initiated 7 days after the tomato study using the same extracts. Future work should include controlled experiments to investigate the temporal dynamics of leachate effectiveness, along with a thorough analysis of chemical composition and microbial activity over time. Such studies would play a key role in setting protocols for the use of liquid compost extracts by local farmers, and would help determine the feasibility of using these extracts on a larger scale.

Although increased growth was observed among some of the compost extract treatments, they did not match the performance of the fertilized treatments. Based upon these observations it appears that these compost leachates may be most effective when supplemented with small amounts of synthetic fertilizer. The added benefit of applying compost extracts to the synthetically fertilized plants was illustrated by the significantly greater total tomato plant biomass achieved in the fertilizer + compost mixture extract treatment when compared to the fertilizer only treatment. Further study in this area should focus upon determining the optimum amount of fertilizer and leachate needed to provide sufficient crop growth.

The nutrient content and microbial activity of the extracts is directly related to the quality of the compost used and the manner in which the extracts were prepared (Bess, 2000; Ingham, 2000). Certain conditions must be obtained to facilitate the conversion of organic matter into compost of high quality. Ideally compost should contain an initial C:N ratio of 25:1 to 30:1, remain aerobic throughout the composting process, reach temperatures of 43-66°C for approximately 3 days, and maintain a moisture content of approximately 50% (Ingham, 2000; Rynk and Richard, 2001). The compost used in our study appears to have met all these criteria, with the exception of the C:N ratio, which we were unable to determine. However, it was assumed that our leguminous composts would

contain a lower C:N than the recommended 25:1. An overabundance of nitrogen in the starting materials would result in some being lost as ammonia gas, yet would have little effect on the overall quality of the compost (Campbell, 1990).

In contrast to the consistency found in recommendations for making compost, numerous forms of extract preparation have been proposed. Research has been conducted using both aerobic and anaerobic extracts with a variety of preparation times and compost to water ratios (Quarles, 2001; Brinton, 1996). Although anaerobic extracts have been successful in past studies (Weltzien, 1991; Brinton, 1995), current research has found that aerobic extracts are more reliable and provide better results (Ingham, 2002; Merrill and McKeon, 2001). The dissolved oxygen in a passive extraction can only maintain microbial metabolism for a period of 48 hours (Merrill and McKeon, 2001), therefore the extraction must be aerated if it is to remain aerobic after this initial period. Although our extraction period was much shorter than the multiple day extraction periods used by other researchers, it may be the most economical form of achieving an aerobic extraction.

This study is only one small part of the initial screening process that needs to be conducted before introducing this technology to tropical farmers. Future studies should examine different combinations of locally available organic material for creating composts that contain an optimal C:N ratio. In addition, researchers should also study other forms of extract preparation, including both aerobic and anaerobic multiple day extractions.

Field Study

Among the non-synthetically fertilized mulch treatments no significant differences were found for any of the measured parameters, including aboveground biomass, plant height, and basal diameter. Similar results have also been reported when uncomposted tree prunings of varying qualities were applied as mulch in a maize

cropping system (Tian et al., 1993; Mulongoy et al., 1993). We also found no significant differences between the mulch treatments and the control when examining maize growth. This result is in contrast to studies performed by Tian et al. (1993) and Mafongoya et al. (1997a), which found significant differences in maize performance between uncomposted mulch treatments and the control. However, these studies were performed on N-deficient soils, whereas in our study phosphorous availability was believed to be the primary factor limiting crop growth. It is generally recognized that the phosphorous contained in organic matter, regardless of composition, is not sufficient to meet crop demands (Palm et al., 1995, Mafongoya et al., 1998). The weak performance of maize grown in the mulch treatments and the control may have been caused by the lack of sufficient quantities of available phosphorous provided by the mulch.

Most studies examining the nutrient release patterns of tree prunings have focused solely upon nitrogen, thus there is much less understanding about the dynamics of phosphorus release and immobilization patterns (Palm, 1995). However, a limited number of studies have found that phosphorus uptake by crops can be improved through the use of mulch. For example, Kettler (1997) found that soil bioavailable P and subsequently P-uptake by beans was increased when *Calliandra* prunings were applied to the soil as mulch. An examination of the nutrients contained in our mulch treatments and their subsequent effect on the nutrient uptake of maize would be a valuable supplement to our field study of maize growth.

We found that the fertilizer + compost mixture treatment was the only treatment that exhibited significantly greater aboveground biomass than the control. This treatment also consistently performed better than the fertilizer only treatment for all measured parameters. This result combined with the poor performance observed in the non-fertilized mixture mulch treatment, indicates that the benefits associated with mulching

may only be realized when crop nutrient needs are met by the addition of an inorganic P fertilizer.

Several factors associated with mulching may have played a role in the observed differences in maize growth between the mulched and unmulched fertilizer treatments. The mulch treatment may have increased growth by regulating soil temperature, aiding in the conservation of soil moisture, and improving the availability of nutrients to crops through the manipulation of microclimate and soil faunal activity (Tian et al., 1993, 1995; Palm, 1995).

On the phosphorous deficient soils at our study site the potential of mulches for improving crop yield may be less dependent upon the initial nutrient contents of the plant biomass and more directly correlated to their capacity for improving soil conditions. Based upon the results of our study it appears that value of particular mulches can only be discerned once the crops have been supplied with adequate nutrients. Judicious and informed use of a combination of organic and inorganic resources may help promote high crop yield while relying on a minimum of off-farm resources.

Conclusions

Our study was initiated with the goal of determining nontraditional methods of biomass use that could provide a sustainable approach to increasing crop yield in tropical agroecosystems. The results of our study indicate that the use of composted mulch and compost extracts can provide positive benefits when added to vegetable cropping systems, especially when used in combination with inorganic fertilizers. The targeted use of small amounts of inorganic fertilizers (especially P) combined with organic matter applications may be an important step towards introducing tropical farmers to organic

matter technology. In order to increase the chances of incorporating these methods of organic matter preparation into current management practices, future studies should also focus upon increasing farmer participation in the research process. Increased contact between farmer's and researchers will provide valuable information about which types of organic materials are readily available on local farms and will help determine the general attitude towards the use of compost and compost extracts.

One of the greatest strengths of this study was that the methods of compost and compost extract preparation were simple procedures that could be duplicated in any tropical agroecosystem containing sufficient biomass. Although the pot and field studies employed distinctly different methods of compost application there is potential for the melding of these two procedures into one continuous process. For example, the solid organic matter that remains after the extract has been created could be directly applied as mulch or returned to the compost pile, instead of being discarded as waste. Using this method the benefits of the composted biomass will be optimized both in the extract form, by providing nutrients and beneficial microbes and in the mulch form, by improving soil microclimate and increasing soil organic matter. This type of multi-purpose farm activity may be especially well received by tropical farmers, many of whom want to maximize their use of organic inputs.

This study is only one small piece of the growing knowledge base that is helping tropical farmers make the transition from cropping systems heavily reliant upon the use of off-farm resources to those that incorporate a more ecologically minded approach. This arduous task can only be achieved through continued research and a strong devotion, by all involved parties, towards creating healthy and stable agroecosystems that will be preserved for future generations of farmers.

Afterword

In some cases, the work of extension agents or researchers expounding the virtues of “organic” or “ecological” agriculture is seen as an intrusion by tropical farmers, however the Loma Linda internship is a prime example of how sustainable agriculture can be promoted in a tropical setting using a non-invasive approach. The use of home-stay families creates an environment that is highly conducive to the sharing of knowledge, both scientific and cultural. Many of the students that participate in the Loma Linda internship have a strong background in the environmental sciences and are well versed about the benefits of ecologically sustainable agriculture, yet often lack extensive field training. In contrast, the farmer’s with which they are living have often received little or no formal education and have learned principally through hands-on experience in the field. This convergence of backgrounds provides a prime setting for the development of intern projects that incorporate skills learned by students in a university setting with those gained by farmers through years of practical experience.

The resource base provided by Loma Linda allows farmers and interns to carry out inquiries that would normally be limited by time or available resources, including labor and capital. Students work closely with local farmers to determine research priorities and develop projects that appeal to both parties. These projects provide the perfect atmosphere for students to learn about the difficulties inherent to tropical agriculture while allowing them the opportunity to test some of the concepts that they have learned at the university. The devotion of students to exploring sustainable methods of crop production has strongly influenced the communities surrounding Loma Linda.

Increased awareness among local farmers of the importance of ecological stewardship in tropical agroecosystems has been one of the great successes of the Loma

Linda internship. This approach to agricultural extension work may also prove valuable in other areas, especially where research and extension efforts have been hindered by lack of farmer enthusiasm and participation. This internship relies heavily upon farmer participation in the research process, allowing them the opportunity to direct research priorities and carry out experiments alongside interns. This grass-roots approach to promoting sustainable agriculture has received positive acclaim from both farmers and interns. The positive outlook among local farmers has been maintained through the constant stream of new interns, each one bringing a unique approach to solving existing problems. Although individual interns may come and go, collectively they have left a legacy that will forever continue to shape the communities in which they lived.

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Appendix

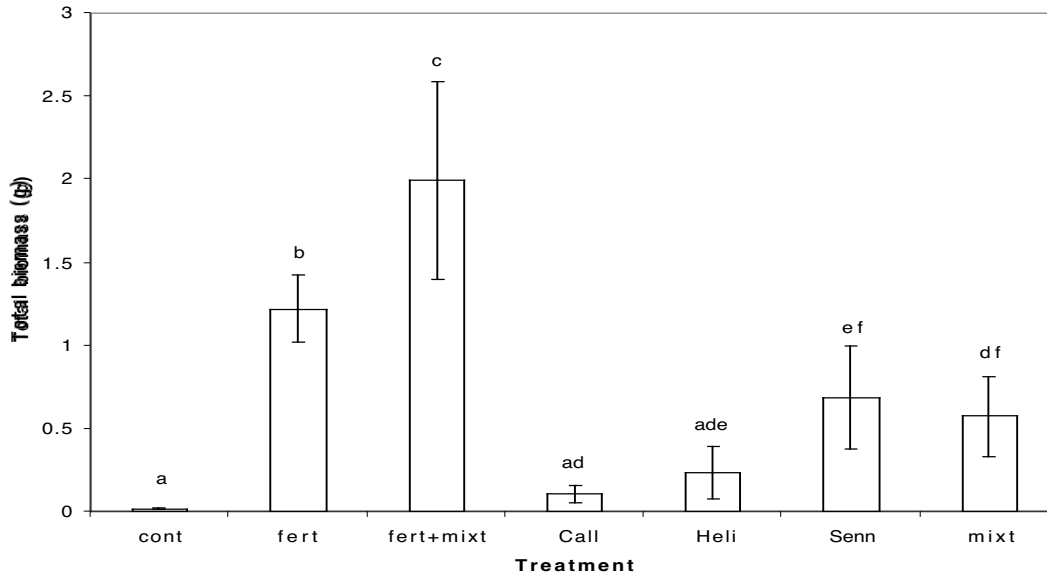
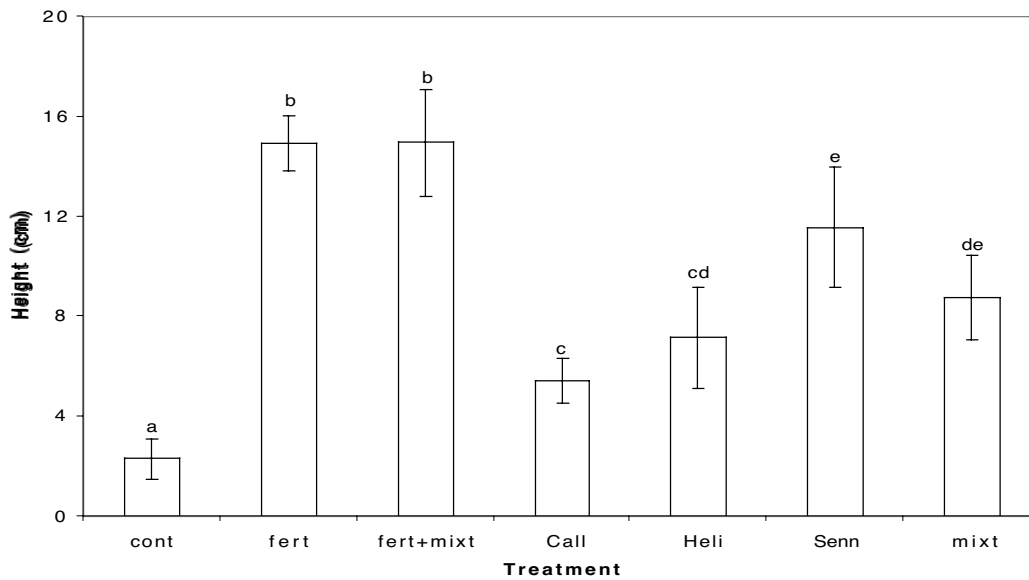
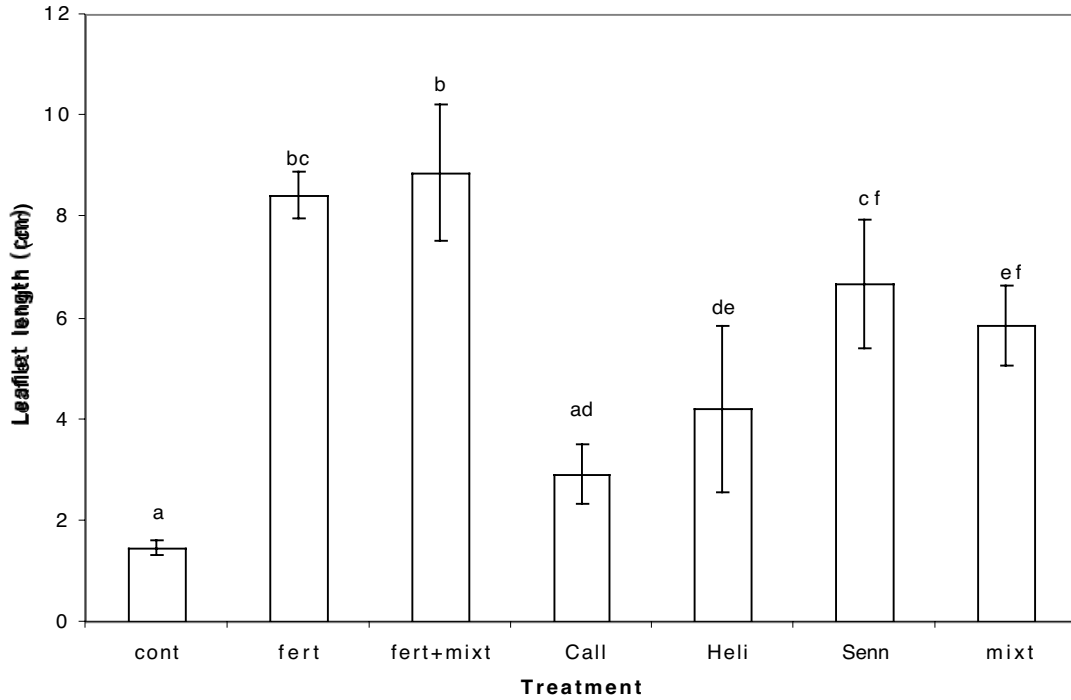


Figure 1: Mean total biomass of tomato plants harvested after 39 days of growth. The treatments are abbreviated as follows: cont: control, fert: fertilizer treatment, fert+mixt: fertilizer + compost mixture extract, Call: *Calliandra* extract, Heli: *Heliocarpus* extract, Senn: *Senna* extract, mixt: compost mixture extract. Error bars indicate +/-1 standard deviation. Treatments exhibiting the



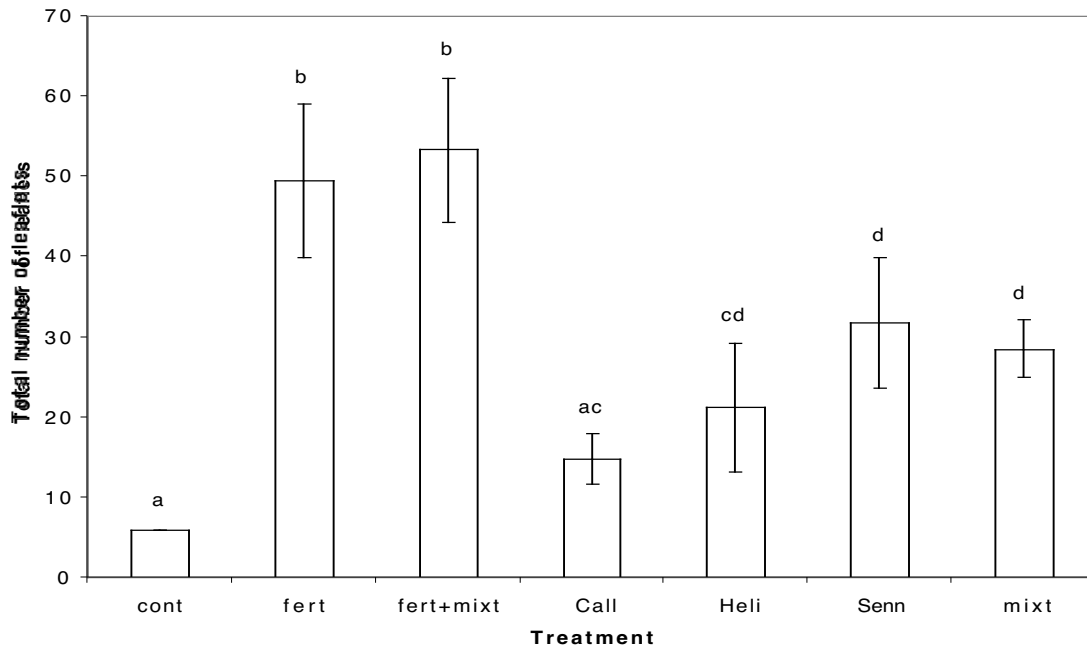
same letter are not significantly different ($P>0.05$).

Figure 2: Mean height of tomato plants after 38 days of growth. See Figure 1 for treatment abbreviations. Error bars indicate +/- 1 standard deviation. Treatments exhibiting the same letter



are not significantly different ($P>0.05$).

Figure 3: Mean length of the longest tomato leaflets after 38 days of growth. See Figure 1 for



treatment abbreviations. Error bars indicate +/-1 standard deviation. Means followed by the same letter are not significantly different ($P>0.05$).

Figure 4: Mean number of leaflets of tomato plants after 38 days of growth. See Figure 1 for treatment abbreviations. Error bars indicate +/-1 standard deviation. Means followed by the same letter are not significantly different ($P>0.05$).

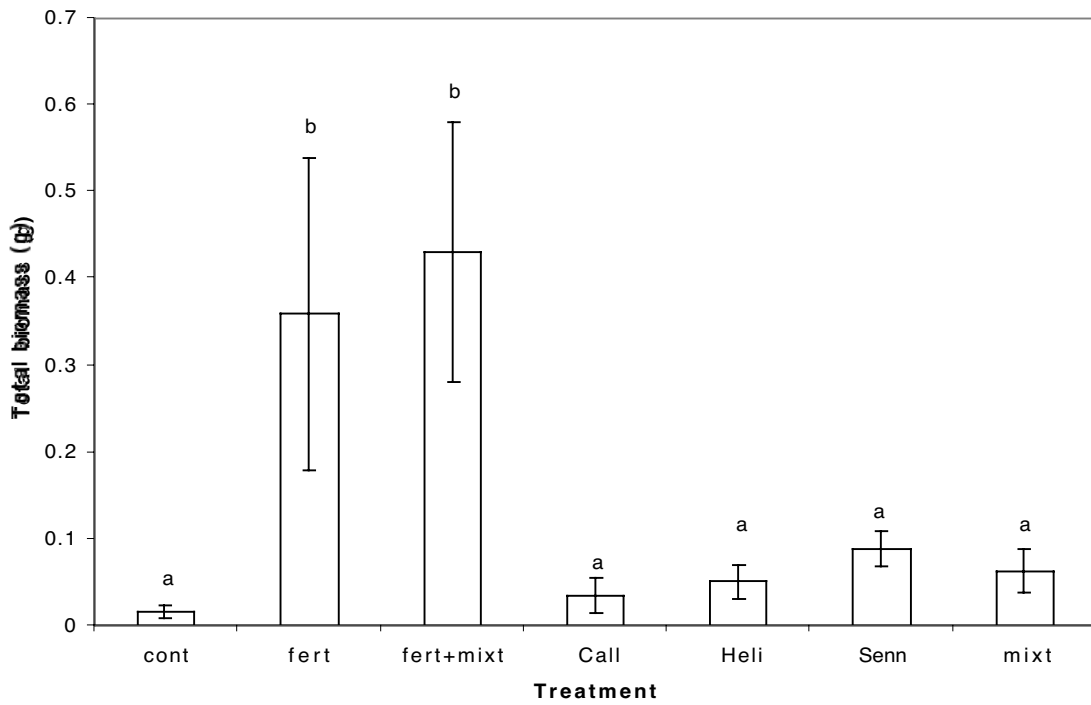
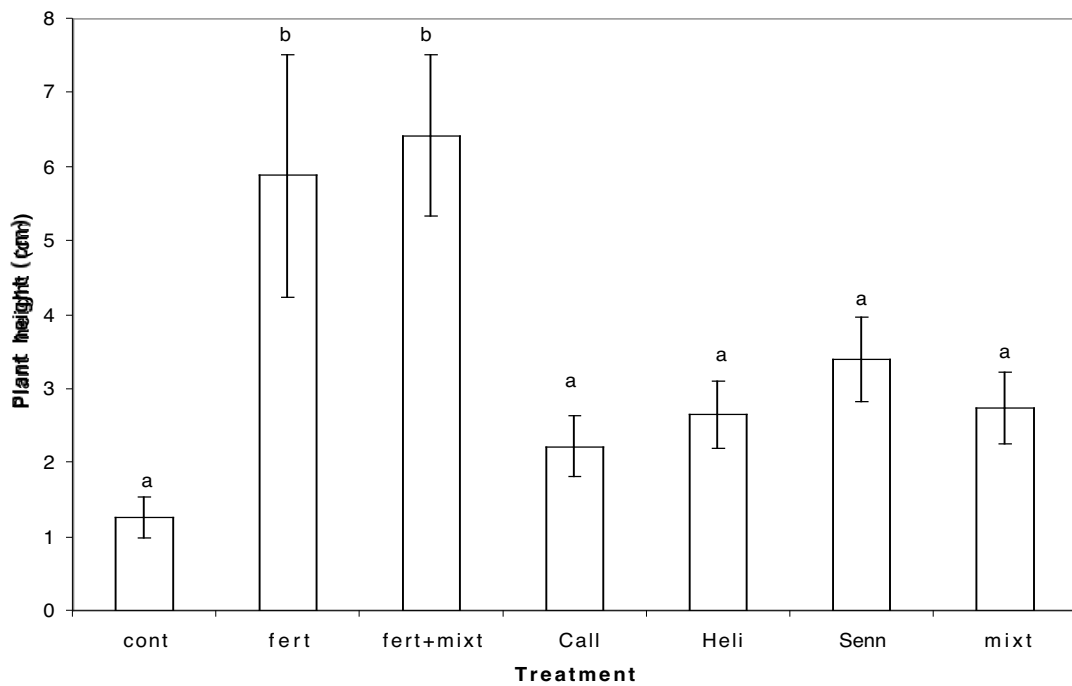


Figure 5: Mean total biomass of pepper plants after 38 days of growth. See Figure 1 for treatment



abbreviations. Error bars indicate +/- 1 standard deviation. Bars exhibiting the same letter are not significantly different ($P>0.05$).

Figure 6: Mean height of pepper plants after 38 days of growth. See Figure 1 for treatment abbreviations. Error bars indicate +/- 1 standard deviation. Bars exhibiting the same letter are not significantly different ($P>0.05$).

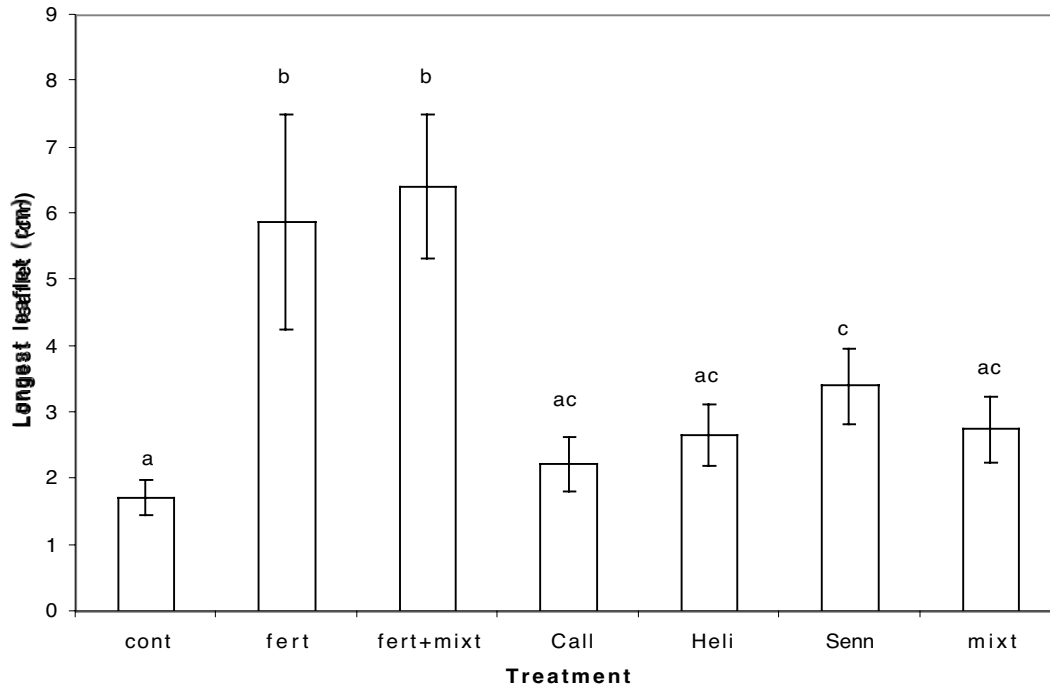
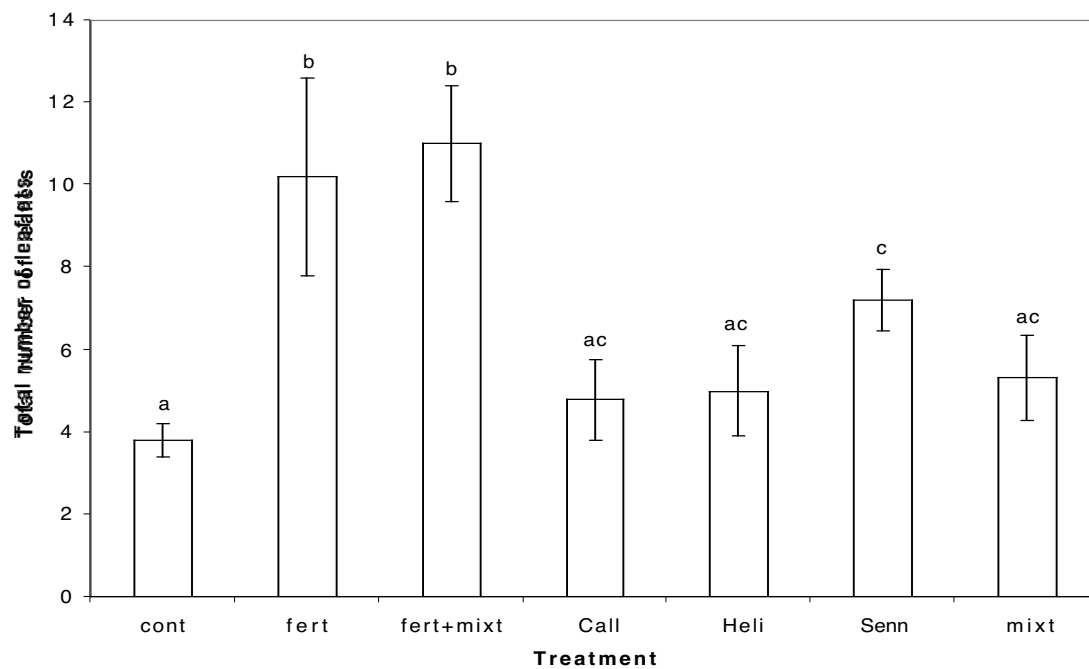
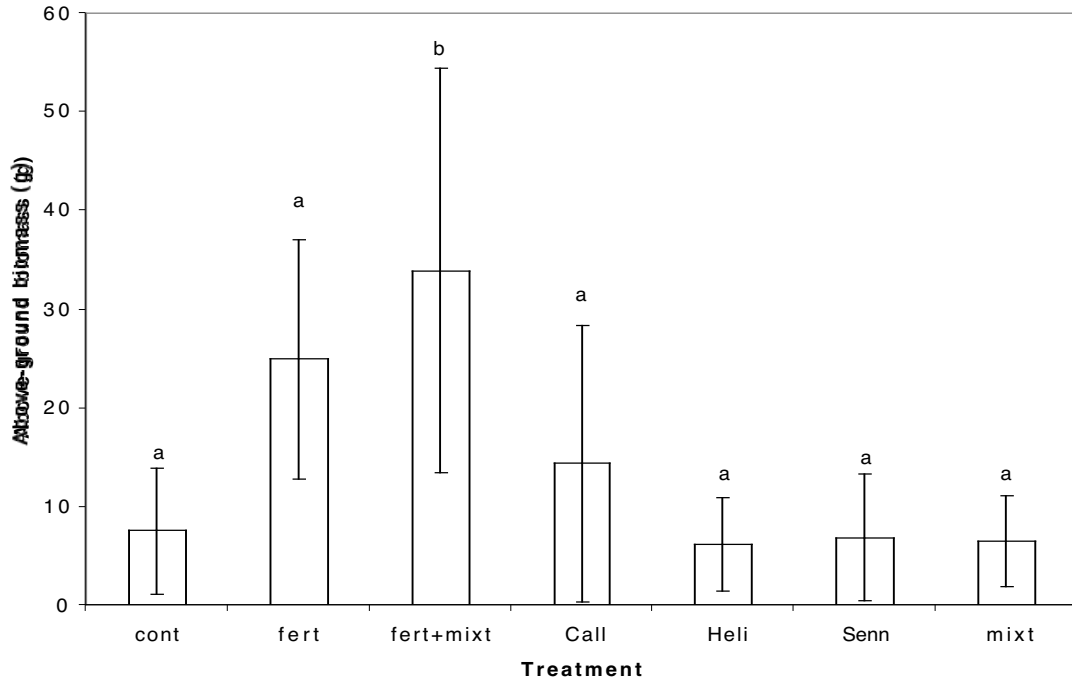


Figure 7: Mean length of the longest leaflet for peppers after 38 days of growth. See Figure 1 for treatment abbreviations. Error bars indicate +/- 1 standard deviation. Bars exhibiting the same



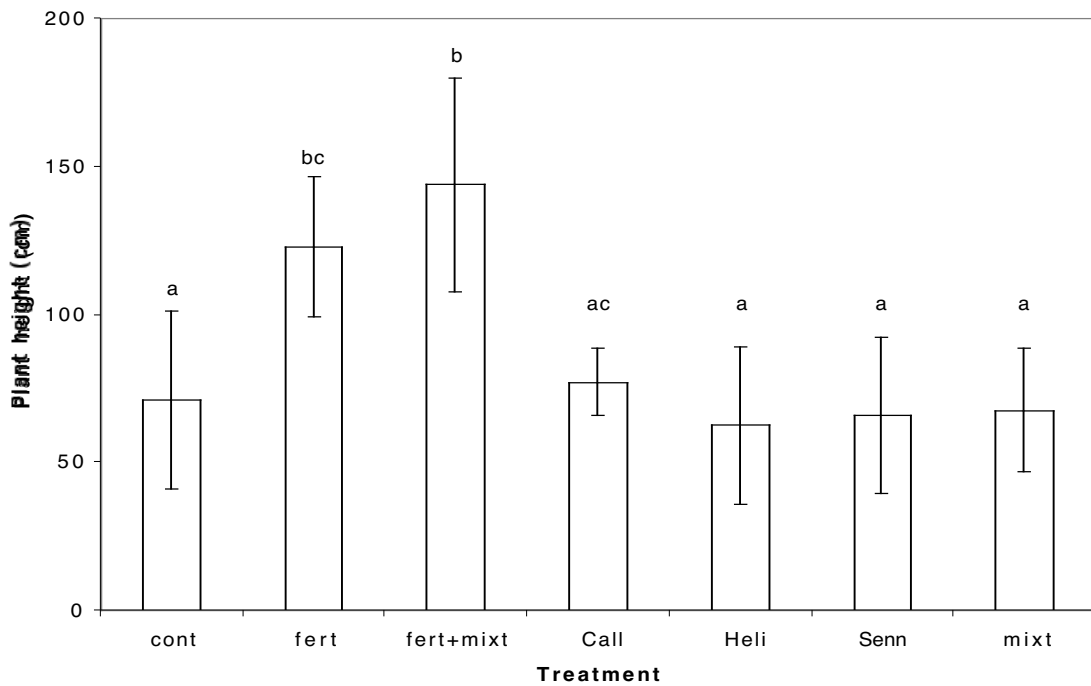
letter are not significantly different ($P>0.05$).

Figure 8: Mean number of leaflets of pepper plants after 38 days of growth. See Figure 1 for



treatment abbreviations. Error bars indicate +/- 1 standard deviation. Bars exhibiting the same letter are not significantly different ($P>0.05$).

Figure 9: Mean above-ground biomass of maize in a field mulch study. Treatments are abbreviated as follows: cont: control, fert: fertilizer treatment, fert+mixt: fertilizer + compost



mixture mulch, Call: *Calliandra* mulch, Heli: *Heliocarpus* mulch, Senn: *Senna* mulch, mixt: compost mixture mulch. Error bars indicate +/- 1 standard deviation. Bars exhibiting the same letter are not significantly different ($P>0.05$).

Figure 10: Mean plant height of maize grown in a field mulch study. See Figure 9 for treatment abbreviations. Error bars indicate +/- 1 standard deviation. Bars exhibiting the same letter are not significantly different ($P>0.05$).

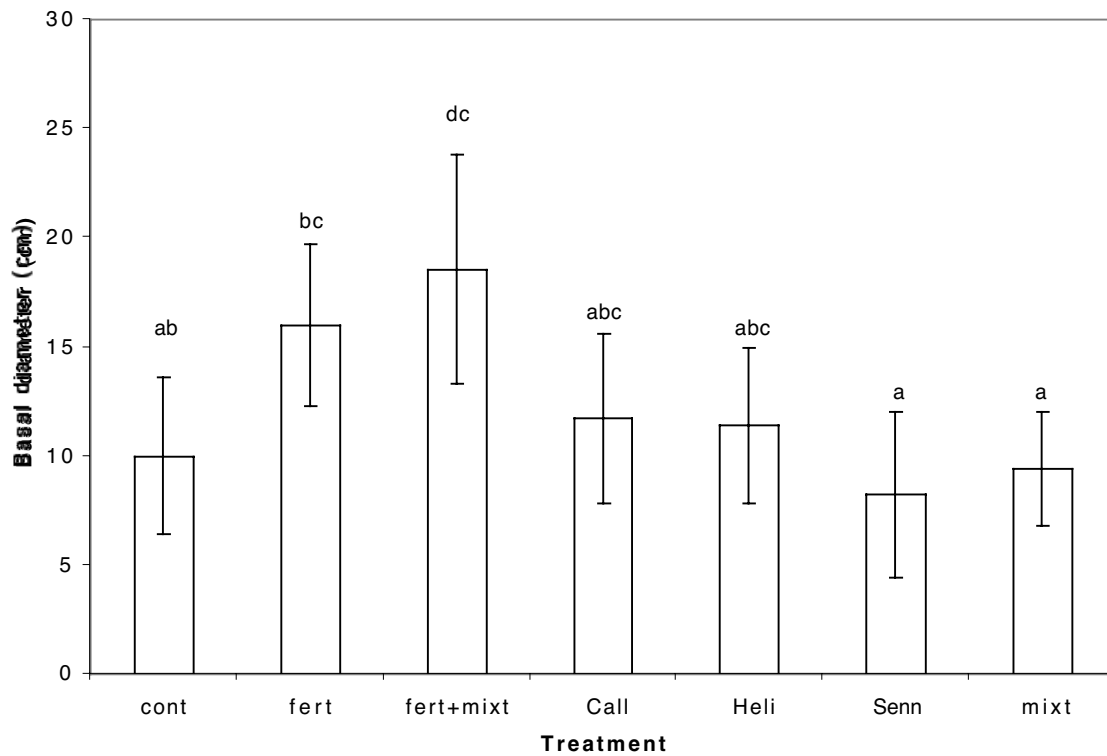


Figure 11: Mean basal diameter of maize grown in a field mulch study. See Figure 9 for treatment abbreviations. Error bars indicate +/- 1 standard deviation. Bars exhibiting the same letter are not significantly different ($P>0.05$).