RESTORING DEGRADED SOILS WITH ORGANIC MATTER: A CASE STUDY OF THE RESTORATION PROCESS IN MACADAMIA ORCHARDS, LIMPOPO PROVINCE

by

NONYANA THAMBULO AUBREY

STUDENT NUMBER: 11530846

A Thesis submitted to the school of Environmental Sciences, University of Venda, in fulfilment of the academic requirements for the degree of Master of Environmental Sciences (MENVSc)

Supervisor: Mr J.N Steyn

Co-supervisor: Prof. J.E Craford

September 2014

University of Venda
Creating Future Leaders

DECLARATION

I, the undersigned, hereby declare that the work contained in this dissertation is my original work and that I have not previously in its entirety or in part submitted it to any university for a degree. This dissertation does not contain other persons' writing, data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons. Where other written sources have been quoted, then their words have been re-written but the general information attributed to them has been referenced. Where their exact words have been used, then their writing has been placed inside quotation marks, and referenced. This dissertation does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the references sections.

Signature (student)..................................... Date 02/04/15

DEDICATION

I dedicate this work to:

My lovely son, Itani Nonyana and my late mom, Itani Emely Ramukhuvhathi.

ACKNOWLEDGEMENTS

The Almighty God for giving me knowledge, wisdom and understanding to successfully complete my study.

Mr Jacobus Nicolus (Koos)Steyn, my supervisor for his encouragement, support and guidance in finishing this dissertation.

Prof. J.E Craford, my co-supervisor for reading patiently the manuscript of this dissertation.

NRF interns and Welgevonden farm workers for assisting in setting up treatments and collection of data.

University of Venda' Research Publication Committee (RPC) for funding this research.

Laboratories (Bemlab, Central Analytical Labs (CAL) & ZZ2) and Agricultural Research Council-Biometry Unit (ARC) for analysing and providing technical statically reports on soil properties

My family and friends; for believing in me and encouraging me to reach for the top and for always making me feel like a winner. Maria Mabatha, Robby Ramukhuvhathi, Mudau Justice, Elsie Rambau, Khesani Mahlathi, David Sengani, Aluwani Nengovhela, and Roderick M. Baxter for loving me and bringing happiness and love to my life.

ABSTRACT

The main aim of this study was to examine the use of compost as an alternative organic practice to restore or improve soil quality in a macadamia orchard. Two different compost application rates (0,5m^3 and 1m^3 compost per tree) were investigated for the restoration of soil quality in degraded as well as improvement and maintenance of healthy soils of a macadamia orchard. Various biological, physical and chemical soil health indicators were measured to determine the impact of the compost treatments on both the soils of the healthy as well as the degraded soil in a macadamia orchard. Overall 40 % of all soil properties improved in the healthy soil and 53 % of all soil properties that were measured in the degraded soil with the application of compost. The research also found that even the smaller application of compost (0.5m^3) was overall significant to improve soil quality and health of the soils in the study area.

Key words: *Compost, Soil Organic Matter, Soil Quality Indicators*

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

1.1 Background

A fertile soil is the basis for healthy plants, animals and humans. Soil Organic Matter (SOM) has been reported to be the foundation for healthy and productive soils (Magdoff & Van Es, 2000). SOM can be any material that is derived from living organisms, including plants and soil fauna. Organic matter plays a key role to achieve sustainability in agricultural production because it possesses many desirable properties such as a high water holding capacity, cation exchange capacity (CEC), the ability to sequester contaminants (both organic and inorganic) and has beneficial effects on the physical, chemical and biological characteristics of soil (Padmavathiamma *et al*., 2008).

Applications of compost mulches have shown to increase soil microbial activity, assist in weed suppression, suppress diseases, protect against erosion, and to reduce soil temperature variations and thus reducing soil water losses (Abigail, 2004). These variables are important in restoring soil quality and health to the level where the soil has the capacity to carry out ecological functions. In the long term the application of compost mulch will also improve the soil water-holding capacity and increase plant available water. Adding organic compost to orchards has also shown to increase bloom and growth of newly planted trees and fruit yields (Brown & Tworkoski, 2003) and also to maintain SOM.

1.2 Problem Statement

Inorganic fertilizers are known to cause soil acidification, salinization, to increase pest health, to contribute to the depletion of the ozone layer and therefore cause global warming, to cause eutrophication and blue baby syndrome (an illness that begins when large amounts of nitrates in water are ingested by an infant and converted to nitrite by the digestive system) in water as well as being a source of Persistent Organic Pollutants

("POPs") and heavy metal accumulations. Too much inorganic fertilizers can also cause "fertilizer burns" on the crops. Synthetic fertilizers also pollute the environment because of the wasteful applications and the fact that crops use them inefficiently (Altieri & Clara, 2001).

Their productions also require high levels of energy and are not sustainable. It affects the potential amounts of crop residues that can be returned to the soil because it affects the decomposition rates of fresh residues and the integration of residues into SOM. Its use results in a decline of organic matter since the readily available nitrogen leads to rapid microbial decay of SOM in some soils. Microbial biomass is usually lower in soils with long-term inorganic nitrogen applications than soils that have received organic applications (Magdoff & Weil, 2004). Soils with low or degraded SOM normally have low Cation-exchange Capacity (CEC) thereby affecting nutrient supply and are poorly aggregated.

1.3 Research Questions

i. Can compost applications improve SOM and restore soil quality in macadamia orchards agroecosystems?

ii. What are the optimal application rates and techniques for compost applications for the restoration of soil quality in degraded soils?

1.4 Research Objectives

1.4.1 General Objective

To examine the use of compost as an alternative organic practice to restore or improve soil quality in a macadamia orchard.

1.7 Definition of Key Terms

Compost: *the word is derived from the Latin componere- put together. It is the aerobically decomposed remnants of organic materials, and when mature, it is a stable material comprising of humus and humic substances, having a dark brown or black colour and a soil-like, earthy smell.*

Inorganic fertilizers: *are manufactured through chemical processes, also using naturally occurring deposits, while chemically altering them.*

Organic fertilizers: *are mostly mixtures of a number of organic compounds, e.g., the natural organic fertilizers such as manure, crop residues, compost, peat litter, sludge, ash, lime marl, and crude phosphates (Arnold, 1982). These can also refer to 'naturally' occurring compounds, such as peat, manufactured through natural processes (such as composting), or naturally occurring mineral deposits.*

Restoration: *is the process of assisting the recovery of an area that has been degraded, damaged or destroyed (SER, 2004)*

Soil Organic Matter (SOM): *according to Magdoff and Van Es (2000), soil organic matter consists of three distinctly different parts which are living organisms, fresh residues, and well-decomposed residues. In essence, SOM is any material that is derived from living organisms, including plants and soil fauna.*

Soil quality (SQ) : *is usually defined as the capacity of the soil to carry out ecological functions that support terrestrial communities (including agroecosystems and humans), resist erosion, and reduce negative impacts on associated air and water resources (Magdoff & Weil, 2004).*

Soil health: *"Soil health is the capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health." Doran and Zeiss, 2000 (USDA) as highlighted by* Lukas et al., (2001).

Vermicomposting: *also refers to worm composting, it involves making use of red earthworms in a bin to produce castings and consume organic waste.*

1.8 Underlying Assumptions

This research assumed that although there might have been other environmental variables such as climate and soil organisms that may have contributed to changes in the soil additional to the treatments applied, their impacts have been held constant for the purpose of this study.

1.9 Motivation

Unlike manure and other organic amendments, compost is a very stable but not a good source of nutrients. The composting process uses heat and microbial activity to quickly decompose simple compounds like sugars and proteins, leaving behind more stable complex compounds such as lignins and humic acids. The stable products of composting are however an important source of organic matter (Gugino *et al.*, 2009).

Adding compost improves soil texture and aeration, loosens clay and increases the soils' water-holding capacities, improving soil fertility and stimulating healthy root development. The organic matter provided in compost feeds microorganisms that keep soils in a healthy condition, suppressing diseases and pests, naturally producing bio-available nitrogen, potassium and phosphorus, and reduces the need for chemical fertilizers. The increase of SOM in soil continually supplied with composts can result in improvement of soil quality indicators that facilitate nutrient availability and uptake (Magdoff & Weil, 2004).

Significantly, compost can turn agricultural soils into a carbon sink, thus protecting it against climate change. Not only does composting have agricultural benefits, it also combats climate change. When plant wastes are sent to landfills they turn into carbon dioxide and methane, two of the most common greenhouse gases. When those plants are composted, they lock up carbon from the atmosphere for decades and when compost is added to the garden's soil, additional carbon dioxide is sequestered (Environment and natural resources committee, 2010).

Composts contain stable humic and fulvic compounds that can persist in soil for many decades. These compounds also serve to 'hold' unstabilised or labile carbon in the soil for longer. Chemical fertilizers have a carbon footprint caused by its manufacturing process and transportation but composting breaks existing plant materials down into chemical components producing no carbon dioxide emissions. Using compost rather than chemical fertilizer shrinks the carbon footprint and concentrates carbon in soil. Creating carbon sinks increases fertility as well as eliminates excessive carbon emissions.

It is therefore often imperative to switch over to a new approach (compost as organic amendments) for organic farming systems to become more sustainable.

1.10 Conclusion

This research sought to examine the use of compost as an alternative organic practice to restore soil quality and health of macadamia orchard soils. It was important to investigate different application rates and techniques for compost applications for the restoration of soil quality in degraded as well as healthy soils of macadamia orchards. Since SOM is the foundation for healthy and productive soils it was therefore concluded that compost applications can be used to restore and maintain soil quality in macadamia orchards.

CHAPTER 2: LITERATURE REVIEW

2.1 Composting

Composting is the breakdown of any organic material into a crumbly, dark, soil-like product in which none of the original material can be easily identified. Composts are excellent organic amendments for soils (Magdoff & Van Es, 2000). Ekman (2004) defined composting as the conversion of raw organic materials to humus through biological agents. Various organic waste materials produced by farming such as husks, effluent, vegetable waste, and stubble and so on can be used to produce compost. Composts are produced through a controlled aerobic process that biodegrades organic materials to produce stabilized organic products rich in humic and fluvic compounds that last longer in soils than unstable or 'labile' organics from sources such as manures, and crop and pasture residues. The finer particles in compost are mainly humic material, the remnant of cell walls and other slow to degrade materials. Larger particles consist of stable woody organics. Compost products have attributes that some other products such as biochar and humate additives extracted from lignite have, but composts offer additional benefits to the health and fertility of the soil.

Composting is a proven and relatively simple technology, and manufactures products that have broad-spectrum benefits including both long-term and labile carbon, cation exchange, water and nutrient holding benefits, beneficial soil biota, humic and fulvic soil conditioning compounds, and immediate and slow-release nutrients. Other competing products such as fertilizer and manure may provide some of these attributes, but composts can provide them all (Environment and natural resources committee, 2010). There are 3 main types of composting namely; vermicomposting, passive composting, and thermophilic composting.

2.2 Soil Organic Matter

The use of compost is an important strategy to increase the SOM content of soils in especially in agriculture. SOM is considered as a major component of soil quality because it contributes directly or indirectly to many physical, chemical and biological properties of soil. Soil amendments with compost are an agronomically useful practice as well as an attractive waste management strategy. Magdoff & Van Es, (2000) stipulated that soil organisms are positively correlated with organic matter content. As soil organisms decompose organic matter, nutrients are converted into simple inorganic or mineral forms that plants can easily use. This process, called mineralization, provides much of the nitrogen that plants need by converting it from organic forms. For example, proteins are converted to ammonium (NH_4^+) and then to nitrate (NO_3^-).

The mineralization of organic matter is also an important mechanism for supplying plants with such nutrients as phosphorous and sulphur, and most of the micronutrients. According Doran & Zeiss, (2000) as summarised by Lukas, *et al.,* (2001) soil organisms are essential for keeping plants well supplied with nutrients because of the role that they play in breaking down and processing organic matter. Shiralipour (1998) added that an increase in soil organic matter content through compost application can promote root activity, as specific fungi function symbiotically with roots, assisting them in the extraction of nutrients from the soil.

Good soil organic matter management is therefore the foundation for creating a favourable environment for the proper functioning of most ecological processes in the soil. Anything that adds large amounts of organic residues to a soil may increase organic matter (Kimetu *et al.*, 2008). One of the oldest practices in agriculture has been to apply manures, compost or other organic residues generated off the field. A typical agricultural soil has 1 to 6 per cent organic matter which consists of three distinctly different parts: living organisms, fresh residues like compost and well-decomposed residues called humus (Magdoff and Van Es, 2009).

When organic matter is broken down by microorganisms, compounds are formed which help bind together soil particles as aggregates. Soil aggregation stability is a measure of the extent to which soil aggregates resist disintegrating when wetted and hit by rain drops (Gugino *et al.,* 2009). Well aggregated soils till easily, are well aerated and have high water infiltration rates. If soil organisms are absent and inactive, more fertilizers will be needed to supply plant nutrients. These organisms are highly dependent on soil organic matter as source of food. Organic matter, as residue on the soil surface or as a binding agent for aggregates near the surface, also plays an important role in decreasing soil erosion. Organic matter is also the single most important soil property that reduces pesticide leaching as it can change the chemical structure of some pesticides, and other potentially toxic chemicals, rendering them harmless. A supply of active organic matter like compost must therefore be maintained so that humus can continually accumulate (Magdoff & Van Es, 2009).

2.3 Composting Processes

2.3.1 Vermicomposting (worm composting)

Vermicompost or worm composting, involves making use of some species of earthworms in a container to produce castings and consume organic waste. The waste products that are produced by these worms are then used as a form of compost. Norman *et al.* (2005) assessed the use of commercially processed vermicomposts, on the growth and yields of peppers (*Capsicum annuum*). Compared to the inorganic fertilizer control plots, vermicompost applications increased the growth and yields of peppers significantly; including increased leaf areas, plant shoot biomass, marketable fruit weights and decreased yields of non-marketable fruit.

Application of vermicomposts to soils increased their microbial biomass and dehydrogenase activity. Humic materials and other plant growth-influencing substances, such as plant growth hormones, were produced by microorganisms during vermicomposting, and were produced after increased microbial biomass and activity in soils; these may have been responsible for the increased pepper growth and yields, independent of nutrient availability (Norman *et al.,* 2005).

2.3.2 Passive (or cold) Composting

Passive composting is the slow degradation of plant wastes such as adding mulch to soil (Abigail & Lukas, 2003). It involves simply stacking the materials in piles to decompose over a long time period with little agitation and management. The process has been used for composting of animal wastes (Rynk, 1992) and compost piles, which have taken place since ancient times.

Magdoff and Van Es, (2000) highlighted the benefits of using passive compost or crop residues as mulch in managing soils for high quality. They indicated that these occur routinely in some reduced tillage systems when high residue-yielding crops are grown or when killed cover crops remain on the surface. In some small-scale vegetable and berry farming, mulching is done by applying straw from off-site sources. They further indicated that strawberries grown in the colder northern parts of the country are routinely mulched with straw for protection from winter temperatures.

2.3.3 Thermophilic (or hot) Composting

Thermophilic composting is the rapid breakdown of organic material where the compost pile gets hot and sterilizes weed seeds and pathogens (Abigail and Lukas, 2003). To make thermophilic compost all materials are mixed and a pile is constructed that is at least between 1.5 and 2 metres high and 2 to 3 metres wide. It has to be large enough to generate heat when plant material is broken down. Water is added so that the pile is wet through but not soaked. This type of compost is agitated or turned over regularly. Good quality compost will take about 8 weeks to make; materials that are used for the compost determine the time however and macadamia husks that are composted for example, may take up to 12 weeks to complete the process (Abigail & Lukas, 2003).

Tejada *et al.,* (2009) examined the use of thermophilic compost for its potential for soil restoration. The effect of the organic soil amendments on plant cover, soil physical, chemical, and biological properties and enzymatic activities were determined. All composted plant residues had a positive effect on soil physical properties.

2.4 Soil Health and Agriculture

Lukas, *et al.,* (2001) indicated that soil health is fundamental for agricultural sustainability, but that soils are still undergoing significant degradation in many agricultural systems. It has been discussed that if soil is improved, the whole agricultural system's health is improved. The benefits of having healthy soils are numerous. For example, soil microorganisms produce polysaccharides that act as gums to bind and stabilize soil aggregates, hence influence soil structure as highlighted by Lukas, *et al.,* (2001). Microorganisms and earthworms in healthy soils play a major role in nutrient cycling, making many nutrients available to plants. Healthy soils are also able to buffer against soil-borne diseases and nematodes, thus improving the health of crops.

Agricultural sustainability starts with the soil by seeking to reduce erosion, and to make improvements to soil physical structure, organic matter content, water holding capacity and nutrient balance. Degradation of soil quality can result from increased disruption of macro-aggregates, reductions in microbial biomass, and loss of organic matter due to fire, deforestation, tillage and accelerated erosion (Islam and Weil, 2000) cited by Lukas, *et al.,* (2001). For the macadamia industry, factors most likely to have led to this decline include soil erosion, compaction and landscape modification by machinery. These factors are accentuated by management practices creating bare earth underneath fruit trees in orchards.

2.5 General Uses of Compost in Agriculture

2.5.1 Crop Protection

Application of compost has been advocated by organic farmers for many years as a way to reduce or eliminate the use of pesticides and soil fumigants. This occurs through a phenomenon known as *antagonism* or *amensalism*. Microorganisms that produce substances toxic to competing populations will naturally have a competitive advantage. For example, a species of bacteria commonly found in compost produces antifungal volatiles (Fiddaman and Rossal, 1993). Hoitink *et al.* (1993) showed that wood waste composts were at least as effective as fungicides in controlling *Phytophthora* root rots. In such cases, it appears that composts increase host vigour and their ability to resist infection by pathogens. Thus, compost application can eliminate or reduce the use of pesticides.

Brown and Tworkoski (2003) investigated the effect of compost applications on weeds, fungal and insect pest management in apple orchards. The compost provided weed control for 1 year after application. The growth of the brown rot fungus (*Monilinia fructicola*) was significantly reduced and the compost significantly affected arthropod abundance during two years after application, with more predators and fewer herbivores in the compost treated plots. Populations of spotted tentiform leafminer (*Phyllonorycter blancardella*) and migrating woolly apple aphid (*Eriosoma lanigerum*) nymphs were reduced in the compost plots. This study showed that the use of compost in an orchard ecosystem could be beneficial to management of weed, fungal, and insect pests. The use of compost as a mulch in orchard ecosystems should be encouraged as a sustainable management practice because of a potential to reduce pesticide use.

2.5.2 Carbon Sequestration

Composts contain stable humic and fulvic compounds that can persist in soil for many decades. These compounds also serve to 'hold' labile carbon in the soil. The soil conditioning attributes of composts increase plant growth, and the health soil biota promoted by composts and improved plant growth result in a build up and maintenance of soil carbon in the form of biomass, humic compounds (from both compost and the degradation of biomass in the field) and labile carbon held in the soil (Grant, 2010). Environmental benefits from application of urban composts including the avoided use of chemical fertilizers and pesticides, improved tilth, positive effect on trace minerals (Freibauer *et al.*, 2004).

2.5.3 Water-Holding Capacity

The application of compost products can markedly increase the water-holding capacity of soils. Such an increase is attributed to soil-pore size distribution. Micro-pores called storage pores hold water necessary for growth of plants and microorganisms. Most mineral soils used for agricultural purposes should receive compost rates of 10 to 15 tons/acre to increase water-holding capacity by five to ten percent. When 146 tons/acre of Municipal Soil Waste (MSW) compost was applied on soil, the water-holding capacity increases by 43 percent. When used in a corn crop, compost treatments increased soil water storage by amounts equivalent to two acre-inches of rainfall or irrigation. In sandy soils with low water retention, both the frequency of irrigation in agricultural farms and energy consumption resulting from water pumping should decrease as a result of compost application (Shiralipour, 1998).

2.5.4 Crop Productivity

Mylavarapu and Zinati, (2008) conducted a study with parsley to evaluate the effects of compost applications on yield. Soils treated with compost+fertilizer increased parsley yields from 2.2 tons per hectare from the control plot which received fertilizer only to 3.3 tons in soils that received fertilizer+compost. Significantly higher total soil carbon levels were also recorded in the plots which received compost as compared to the plots which received fertlilizer only. Additions of compost alone reduced soil bulk densities significantly and increased soil moisture retention in simulated drier conditions. Overall, the addition of compost resulted in the improvement of both physical and chemical properties as well as increased parsley yields.

Mays *at al.,* (1973) evaluated heavy applications of compost made from municipal refuse and sewage sludge for the production of forage sorghum, common Bermuda grass and corn. Positive yield responses were observed to annual compost applications at rates of up to 80 metric tons/ha on Bermuda grass, 143 metric tons/ha on sorghum, and 112 metric tons/ha on corn as compared to the controls.

McSorley & Gallaher (1996) determined the effects of yard waste compost on the forage yield of maize (*Zea mays*) in two sites. Forage yield of maize was increased significantly by compost treatments. It was also found that the use of yard waste compost on agricultural sites may not only provide a beneficial amendment for crop production but also a convenient means for disposal of common waste products from urban areas. Ouédraogo *at al.,* (2001) conducted experiments in Burkina Faso and found up to triple increases in sorghum yield with some compost applications and found compost applications mitigated the negative effects of a delay in sowing as well.

2.5.5 Earthworms

Earthworms provide key soil functions that favour many positive ecosystem services (Pelosi *et al*., 2014). According to Shiralipour (1998), the population of earthworms is also increased by the addition of sufficient levels of compost products. He further indicated that the soil movements and tunnelling by the earthworms results in enhanced aeration and water infiltration. Lukas *et al*., (2001) conducted a survey of earthworms in macadamia and other orchards (avocados, coffee, bananas and blueberries). Macadamia orchards were found to support comparatively low populations and biomass of earthworms (Lukas *et al*., 2001). Applications of compost in macadamia orchards should therefore enhance earthworm populations.

2.5.6 Nutrient Enhancement of Soil

Although compost products are known to contain considerable amount of both macroelements and microelements, their nutrients content however is lower than commonly used fertilizers. Hence, nitrogen (N) and phosphorus (P) contents of compost are higher than agricultural soils but their availability is normally low. One reason is that release of nitrogen from an organic source such as compost is in a mineral form that is unavailable to plant roots. Compost nitrogen is a valuable slow released nitrogen source. The rate of microbial mineralization and release of available nitrogen from structural forms in the compost depend on the local climate and soil type (Shiralipour, 1998). Incorporation of compost types with high carbon-to-nitrogen ratios will elevate the carbon-to-nitrogen ratios of soils. A soil carbon-to-nitrogen ratio above 30 causes nitrogen immobilization, or nitrogen-rob, and nitrogen deficiency in plants. Nitrogen occurs when micro-organisms consume the available plant nitrogen in the soil in order to decompose the compost. Application of nitrogen as a mineral fertilizer usually corrects this type of nitrogen deficiency. Alternatively, if cropping can be delayed a few months, the compost will stabilize in the soil, correcting the problem.

Application of compost as a soil amendment also reduces nitrogen leaching from soil. Therefore, utilization of compost as a soil amendment could reduce the amount of commercial nitrogen fertilizer applied and decrease the possibility of nitrate groundwater contamination (Shiralipour *et al.*, 1992b).

2.6 Compost effects on nematode community make-up

As pointed out by Gallaher (1998), the increased nutrient levels and water-holding capacity of soils amended with compost may increase plant tolerance to nematode damage. Gallaher (1998) highlighted that, there is evidence that the addition of certain organic compounds may stimulate fungal parasites of nematodes. However, the most important effect of organic amendments on plant-parasitic nematodes may be the reduction of populations from toxic by-products of decomposition. Ammonia and urea were shown to suppress several nematode species in tests, and the decomposition of some forms of organic nitrogen can release by-products which are toxic to nematodes (Gallaher, 1998). The most effective of these amendments are those with low carbon-to-nitrogen ratios that can release ammonia into the soil (Gallaher, 1998). Regardless of the mechanism involved, the addition of organic amendments may serve to alleviate some of the adverse effects on crop growth caused by plant parasitic nematodes. Of the plant-parasitic nematodes found at some Urban Plant Debris (UPD) Florida field corn research sites, *Paratrichodorus minor* was significantly decreased from application of UPD.

Other nematodes, such as *Meloidogyne incognita,* were not consistently affected by compost applications. Effects of the high carbon-to-nitrogen-ratio compost on these agricultural sites may provide beneficial effects only after several years of UPD application. Transplanted seedlings of squash *(Cucurbita pepo)* and okra *(Hibiscus esculentus)* and the use of conventional tillage incorporated UPD appeared to result in best yields. These results were based on limited data and a limited time for soil properties to be impacted by compost and to translate into crop response. Totally different results may be found between conventional tillage versus no tillage after soil properties have been enhanced from use of UPD. From this same study, it was concluded that the main benefit of UPD against nematodes did not appear to be reduction of nematode populations, but improved growth and tolerance of host plants in nematode-infested sites. Sweet corn yields were equal for UPD treatments both conventional tillage-incorporate and no-tillage-mulch, and both gave yields superior to the conventional tillage control without UPD (Gallaher, 1998).

2.7 Restoration of soil health

Abigail (2004) highlighted that compost can be used to restore and improve soil health, and found that by applying a layer of between 0, 5 and 1 m^3 of compost per tree as a mulch in orchards have been found to improve soils significantly. If remediation of an eroded site is the goal one may need up to $2m^3$ of compost per tree, as this will improve soil health while protecting the underlying ground surface from further erosion during heavy rainfall. Trial applications of compost on working macadamia farms have indicated that management practices including harvesting are not be altered by any of these application rates.

In an Australian vegetable cropping trial which received high inputs of compost, improvements included higher organic carbon content, greater microbial activity and biomass, greater exchangeable nutrient cations, and greater water holding capacity and aggregate stability were observed (Lukas *et al.*, 2001 & Shiralipour, 1998).

2.8 Compost applied as mulching

Carrera *et al.*, (2007) found that when using black polyethylene mulching, tomato yields significantly increased with the addition of compost and manure when compared to inorganic fertilizer, although there was no detectable effect on soil microbial community structure. Above all, applying compost as mulch rather than incorporating it into the soil will greatly improve soil health and is an excellent way to obtain the benefits of compost in an orchard situation where incorporation is not possible (Abigail, 2004). Brown and Tworkoski (2003) also investigated the effect of applying compost as mulch on weed, fungal and insect pest management in apple orchards.

2.9 Macadamia Husks in Compost

Macadamia husks are a by-product readily available on macadamia farms which can be used to make compost with. Lukas *et al.,* (1997) tested compost which included macadamia husks as ingredient in macadamia orchards with degraded soils. Here, 40m^3 of chicken litter was composted with 60m^3 of macadamia husks. The compost was spread in an area that was prone to erosion, and where obvious soil loss had exposed surface roots. The addition of the compost did not affect the farm's standard management practices, as neither sweepers nor nut harvesters were hindered by the presence of the 100mm thick compost layer. Compost addition was beginning to influence microbial activity deeper in the soil profile. The compost layer had a very high level of activity, which is likely to decrease as the organic matter becomes incorporated into the soil. Other plots near the area with no compost addition showed very little variation in the levels of microbial activity at the two sampling times. Another study tested a macadamia husk and chicken litter to further evaluate organic matter addition and improvements in soil health. Some treatments had coconut fibre matting placed on top of them to act as a weed mat, to further reduce the risk of soil erosion. The addition of compost on the commercial macadamia farm gave promising results with improvements in water holding capacity as well as quite dramatic increases in microbial activity.

Cox *et al.,* (2004) investigated how macadamia husk compost can improve soil health in sub-tropical horticulture. The main problem was that the bare soil under mature trees with mechanical harvesting from the orchard floor has resulted in soil loss from erosion. Macadamia husks and poultry manure were composted to provide a surface cover and the effects of compost on soil health assessed. Green waste compost was also included for comparison. Both composts and a compost treatment with a fibre mat on top were applied to three tree plots of macadamias, and soil health indicators were measured for 18 months. Microbial activity increased in the 0-2cm and 2-10cm soil layers under compost over time, and was significantly greater than the bare soil control. The soil pH under the husk compost increased from 4.15 to 5.0 after 18 months in the 0-2cm layer. The green waste compost did not improve these soil properties as much, but was greater than the bare soil. Water holding capacity was only increased by the husk compost. The green waste compost had a much larger particle size and different source material which may explain the differences. By 18 months, the microbial biomass carbon in the 0-2cm layer under the husk compost showed that the population was three times as much than bare soil, while the green waste compost was only 50% greater. The benefits of husk compost under macadamia trees were found substantial as it improved soil fertility and may reduce soil loss in the long term.

2.10 Conclusion

According to Wells *et al.,* (2000) as quoted by Lukas and others in 2001, restoration technologies to improve microbial activity and soil health are not new. These may include the addition of manures, fertilizers, lime and gypsum, and organic materials to soil; and the use of crop rotations, green manures and fallows. In fact, most farmers, both organic and conventional are currently practicing some forms of soil restoration. What is lacking, however, is a thorough understanding of how these processes benefit the soil biology, to promote soil health (Lukas *et al.,* 2001).

CHAPTER 3: MATERIALS AND METHODS

3.1 Research Design

The research was conducted by making use of field experiments to assess the potential of compost applications to improve and maintain high levels of soil organic matter. Because of their high replicability field experiments were considered the most appropriate. An environmental variable such as climate and soil organisms that may influence results was also considered. To meet statistical requirements for adequate representation, all treatments were replicated sufficiently.

3.2 Research Methodology

3.2.1 Soil Quality Experiments

Two compost treatments were applied on experimental plots (degraded soils where the topsoil had been removed) and repeated on other plots (undisturbed soil) in the same orchard. All treatments were replicated seven times each and compared with each other and with the control plots to determine changes in soil quality. The two compost treatments consisted of applications of 2.5 m^3 of compost per trial plot (0.5m^3 of compost per tree in the plot) and treatments of 5 m^3 of compost (1m^3 per tree in the plot) respectively per plot (Figure 1). Compost applications were applied in the form of mulching (Figure 2). Only compost produced by Sandberg at Louis Trichardt, in Limpopo Province was used for this purpose as it is regularly analysed and certified and its contents known and standardized.

A complete block design was used, with each treatment located within a block replicate. Treatments were replicated seven times and selected on plots that were as homogeneous as far as possible representing the treatments and controls. Each plot contained macadamia trees treated with these compost applications. The plots were located in an orchard (Figure 3) consisting of the same macadamia variety (Phahala) in their eighth growing season, planted in rows of 8m x 4m spacing.

16m x16m

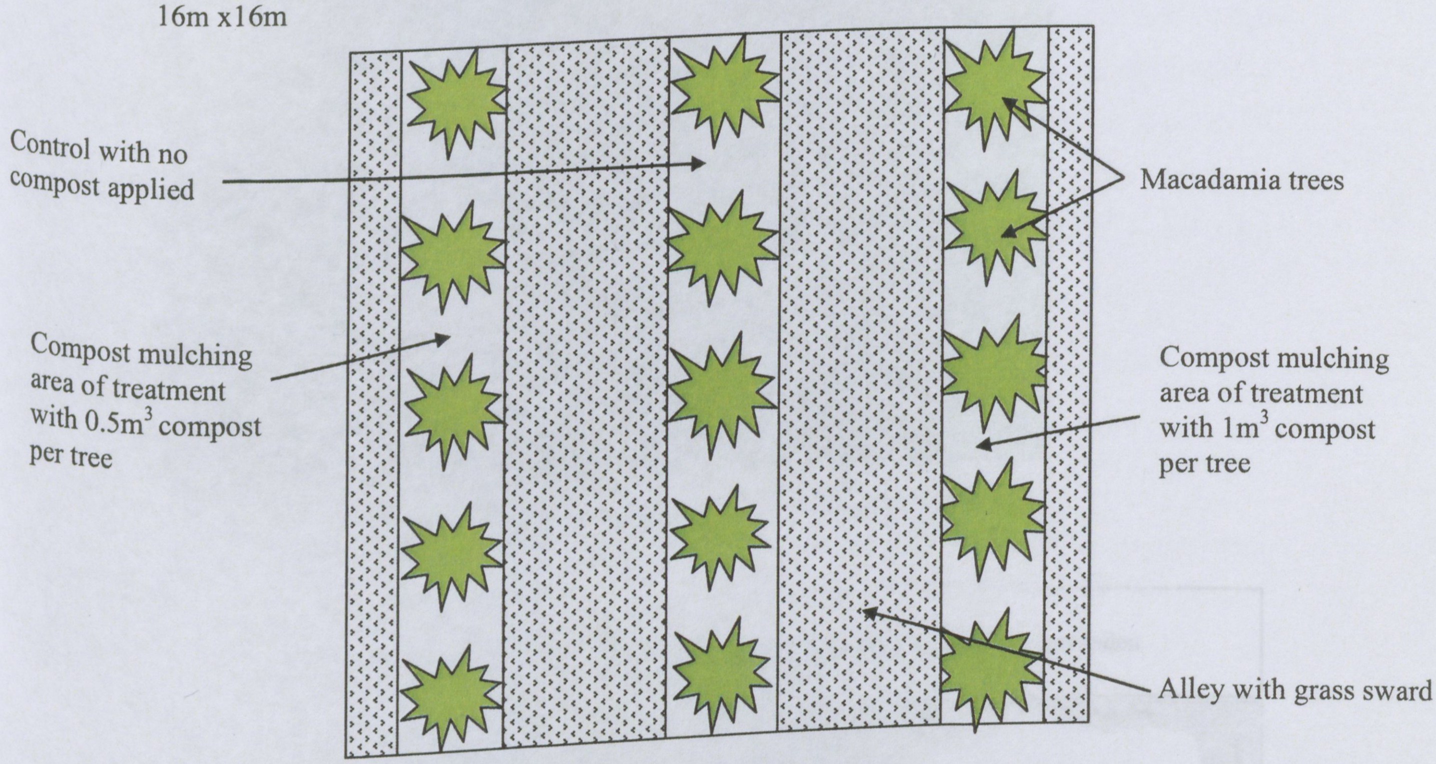

Figure 1: Experimental plot replicate example with treatments and control

Figure 2: Trial plots with compost treatment applications as mulching

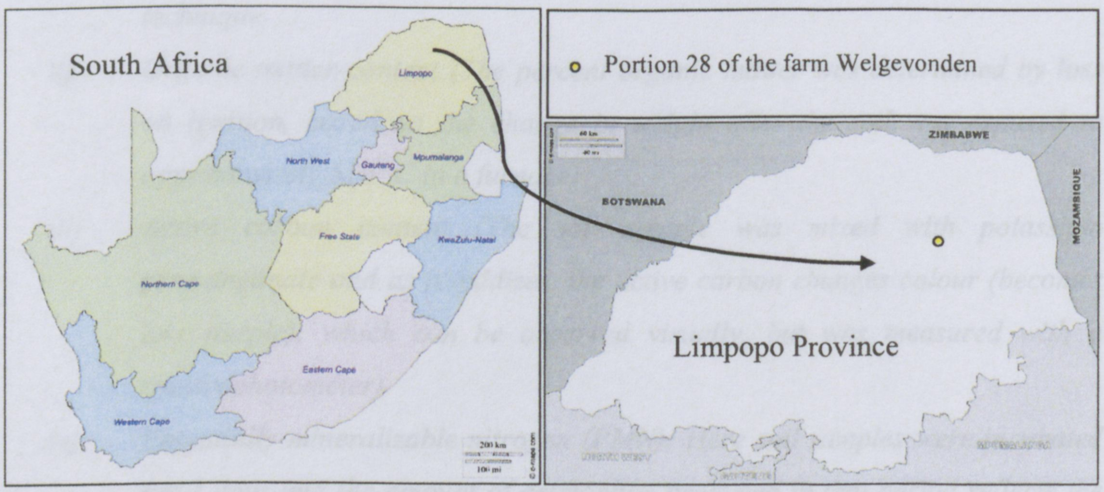

Figure 3: Study area and field trial site within Limpopo Province, South Africa

3.2.1.1 Data Collection on Soil Quality

Sustainability of agricultural management systems has become an issue of wide public concern and international debate. One result is that soil quality indicators have been suggested as a tool for evaluating sustainability of soil and crop management practices (Hussain *et al.*, 1999). To meet specific objectives, data were collected on biological, physical, and chemical indicators of soil quality and health indicators from the trial plots. Soil sampling took place after one year after the treatments had been applied to allow for changes in the soil to take place.

The following soil quality indicators were measured:

a) *Soil Biological Indicators*

i) *Earthworms abundance: Calculated by making use of the formalin expulsion technique*

ii) *Organic matter content (The percent organic matter was determined by loss on ignition, based on the change in weight after the soil was exposed to approximately 510 °C in a furnace)*

iii) *Active carbon content (The soil sample was mixed with potassium permanganate and as it oxidizes, the active carbon changes colour (becomes less purple), which can be observed visually, but was measured with a spectrophotometer)*

iv) *Potentially mineralizable nitrogen (PMN): Here soil samples were incubated for 7 days and the amount of ammonium produced in that period reflects the capacity for nitrogen mineralization (Gugino et al., 2009).*

v) *Nematode community profiling: Community-level physiological profiling method was used to characterize and compare soil microbial communities.*

b) Soil Physical Properties

i) Aggregate stability (The wet sieving method was used with the aid of rainfall simulator (Gugino et al., 2009) to determine the aggregate stability).

ii) Available water capacity (Water was extracted from soil samples under pressure to determine the available water capacity)

iii) Surface and subsurface hardness (Penetration resistance was measured using a penetrometer, an instrument that measures soil resistance to penetration)

iv) Bulk density (The weight of the soil was measured underneath the compost layer by driving a steel ring of known volume, 6cm deep into the soil and calculating the core's dry weight)

c) Soil Chemical Indicators

The following indicators were measured by making use of the services of an accredited laboratory (Bemlab) wherein a standard soil test analysis package was used to measure the following aspects of the soil:

i) Exchangeable macronutrients

ii) Micronutrient concentrations

iii) pH

iv) Electrical conductivity

v) Cation exchange capacity and cation ratios

3.3 Data Analysis

The experiment followed a complete block design analysis of variance executed as follows:

<u>ANOVA Experiment</u>

Source	*Degrees of Freedom*
Blocks	5-1= 4
Treatments	7-1= 6
Error	(7-1) (5-1) =24
Total corrected	7 x 5-1=28

The nematode counts and other soil indicator measurements were transformed to $\log_{10}$(count+1) to stabilize variances before subjected to a random split-split plot analysis (ANOVA) with soil as main effects, the different soil treatments as sub plots and the different species as sub-sub plots. The soil elements data were subjected to a random split plot analysis (ANOVA) with soil as main effects and the different soil treatments as sub plots. The standardized residuals were tested for deviations for normality for both datasets using Shapiro-Wilk's test (Shapiro & Wilk, 1965). In cases where there was strong evidence against normality, due to skewness, outliers were removed until the residuals were symmetric or normal distributed. Therefore the data is considered as reliable. Means of significant effects were compared using Fisher's unprotected t-LSD (least significant difference) at a 5 % level of significance (Snedecor & Cochran, 1980). All data were analysed using SAS, statistical software (SAS, 1999).

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Soil Biological Indicators

4.1.1 Nematode Analysis

Nematode populations of the treatments and controls were analysed with the aid of the weighted nematode faunal analysis (Ferris *et al.*, 2009) which measures structure and enrichment of nematode populations. The Structure Index (SI) is a measure of the number of trophic layers within the soil food web along with the potential for regulation by predators (Pattison *et al.,* 2008). A low SI indicates a disturbed or degraded soil ecosystem while a high SI indicates structured or matured conditions (Baniyamuddin *et al.,* 2007). The Enrichment Index (EI) is an indication of the resources available to the soil food web as well as responses by primary decomposers (such as basal nematode communities) (Pattison *et al.,* 2008). According to Baniyamuddin *et al.*, (2007) nutrient enriched soil ecosystems have high EI values while systems which are nutrient depleted have low EI values. A matured nematode community is most ideal for agriculture as only enriched will host too many bacteria and fungi feeders, and have too few omnivores and predators, so a balanced situation between structured and enriched is ideal. Table 1 provides the analyses of each of the 7 repetitions for all treatments in the healthy and degraded soil trial plots as well as the controls.

Table 1. Weighted nematode faunal analysis (*Ferris et al.,* 2009) of the nematodes communities of the compost treatments in healthy and degraded soil.

Soil Category	Treatment	Repetition	Category*	Interpretation (Ferris *et al.*, 2009)
Healthy soil	0.5m3	1	Moderately undesirable	Community is Enriched but unstructured
Healthy soil	0.5m3	2	Moderately undesirable	Community is Enriched but unstructured
Healthy soil	0.5m3	3	Moderately undesirable	No Structure, Highly enriched
Healthy soil	0.5m3	4	Desirable	Enriched and structured
Healthy soil	0.5m3	5	Moderately undesirable	No Structure, Highly enriched
Healthy soil	0.5m3	6	Desirable	Enriched and structured
Healthy soil	0.5m3	7	Moderately undesirable	Community is Enriched but unstructured
Degraded soil	0.5m3	1	Moderately undesirable	No Structure, Highly enriched
Degraded soil	0.5m3	2	Desirable	Enriched and structured
Degraded soil	0.5m3	3	Desirable	Enriched and structured
Degraded soil	0.5m3	4	Desirable	Enriched and structured
Degraded soil	0.5m3	5	Acceptable	Resource limited and structured
Degraded soil	0.5m3	6	Undesirable	Resource Depleted with minimal structure
Degraded soil	0.5m3	7	Moderately undesirable	Community is Enriched but unstructured
Healthy soil	1m3	1	Undesirable	Resource Depleted with minimal structure
Healthy soil	1m3	2	Moderately undesirable	Community is Enriched but unstructured
Healthy soil	1m3	3	Moderately undesirable	Community is Enriched but unstructured
Healthy soil	1m3	4	Moderately undesirable	Community is Enriched but unstructured
Healthy soil	1m3	5	Moderately undesirable	Community is Enriched but unstructured
Healthy soil	1m3	6	Moderately undesirable	No Structure, Highly enriched
Healthy soil	1m3	7	Moderately undesirable	No Structure, Highly enriched
Degraded soil	1m3	1	Undesirable	Resource Depleted with minimal structure
Degraded soil	1m3	2	Undesirable	Resource Depleted with minimal structure
Degraded soil	1m3	3	Desirable	Enriched and structured
Degraded soil	1m3	4	Moderately undesirable	Community is Enriched but unstructured
Degraded soil	1m3	5	Desirable	Enriched and structured
Degraded soil	1m3	6	Desirable	Enriched and structured
Degraded soil	1m3	7	Moderately undesirable	Community is Enriched but unstructured

Healthy soil	Control	1	Undesirable	Resource Depleted with minimal structure
Healthy soil	Control	2	Undesirable	Resource Depleted with minimal structure
Healthy soil	Control	3	Moderately undesirable	Community is Enriched but unstructured
Healthy soil	Control	4	Moderately undesirable	Community is Enriched but unstructured
Healthy soil	Control	5	Moderately undesirable	No Structure, Highly enriched
Healthy soil	Control	6	Moderately undesirable	Community is Enriched but unstructured
Healthy soil	Control	7	Moderately undesirable	Community is Enriched but unstructured
Degraded soil	Control	1	Acceptable	Resource limited and structured
Degraded soil	Control	2	Moderately undesirable	Community is Enriched but unstructured
Degraded soil	Control	3	Acceptable	Resource limited and structured, no enrichment
Degraded soil	Control	4	Undesirable	Resource Depleted with minimal structure
Degraded soil	Control	5	Undesirable	Resource Depleted with minimal structure
Degraded soil	Control	6	Moderately undesirable	No Structure, Highly enriched
Degraded soil	Control	7	Undesirable	Resource Depleted with minimal structure

*Category is the desirability of the population from an agricultural point of view

A further analysis of the contents of Table 1 with the aid of a pivot table (Table 2 & Figure 4) reveals clear trends in desirable and undesirable nematode community make-up categories within the treatments.

Table 2. Pivot table analysis of the content of Table 1.

Count of Quadrat **Column Labels**

Row Labels	**Desirable**	**Acceptable**	**Moderately Undesirable**	**Undesirable**	**Grand Total**
Healthy Soil	**16**	**2**		**3**	**21**
$0.5m^3$	5	2			7
$1m^3$	6			1	7
Control	5			2	7
Degraded Soil	**6**	**6**	**3**	**6**	**21**

$0.5m^3$	2	3	1	1	7
$1m^3$	2	3		2	7
Control	2		2	3	7
Grand Total	**22**	**8**	**3**	**9**	**42**

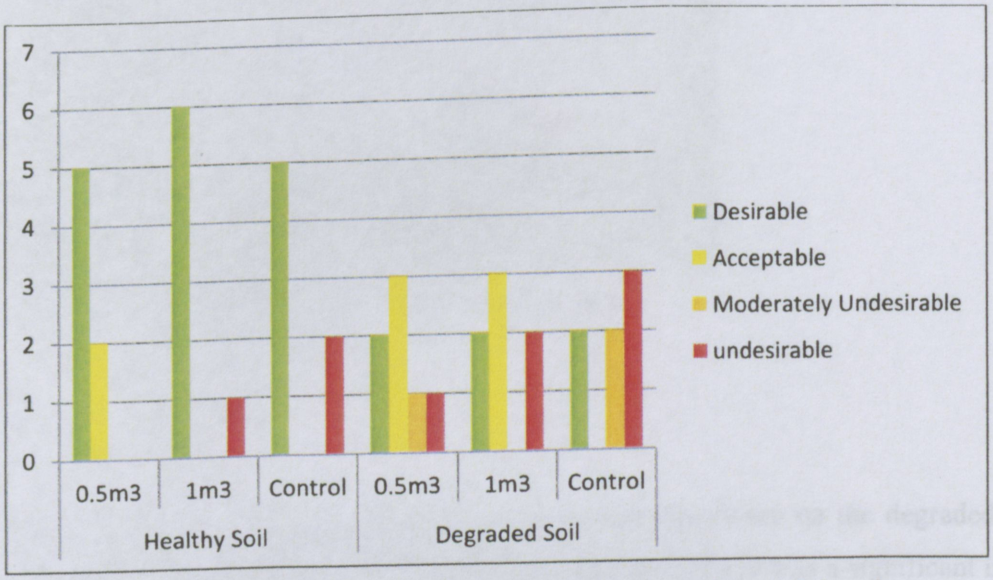

Figure 4: Pivot table analysis of nematode community make-up for various treatments

4.1.1.1 Discussion

Based on the community make-up, the desirable category (highlighted in green) showed significantly higher numbers in the healthy soil as compared to the degraded soil, but not significant increases within the healthy soil as a result of the compost treatments. At the degraded soil the desirable category remained similar within the two treatments and the control, but the undesirable category (highlighted in red) numbers decreased significantly with compost treatments and the higher compost application decreased these numbers the most. The same trend was observed for the undesirable category in the healthy soil except that the highest compost application did not decrease these numbers the most, the lesser compost treatment yielded the best results. The consequence was that compost treatments significantly improved nematode populations in the sense that they contained more beneficial species like predators and less undesired species like the plant parasites.

4.1.2 Earthworm abundance

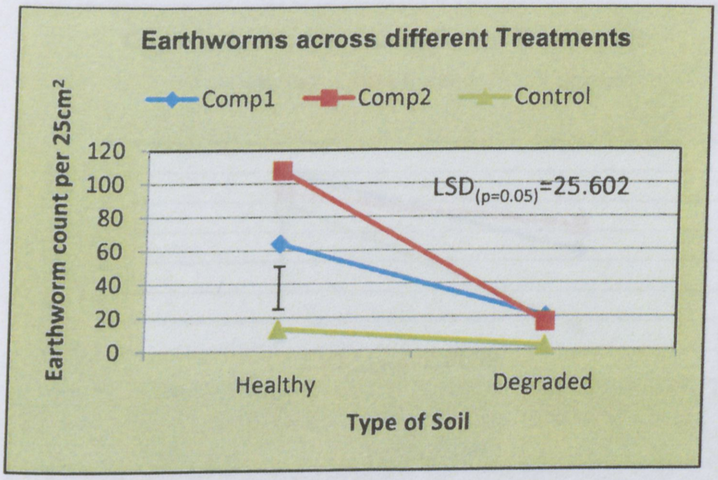

Figure 5: Earthworms across different treatments

4.1.2.1 Discussion

There was no significant difference in earthworm abundance on the degraded soil with compost treatments (Figure 5, Appendix A). However, there was a significant increase in the abundance of earthworms with both compost treatments in the healthy soil. In all treatments however, there was an increase in earthworm abundance. Compost treatments therefore were beneficial to earthworm populations which was an improvement from an agricultural point of view.

4.1.3 Organic matter content

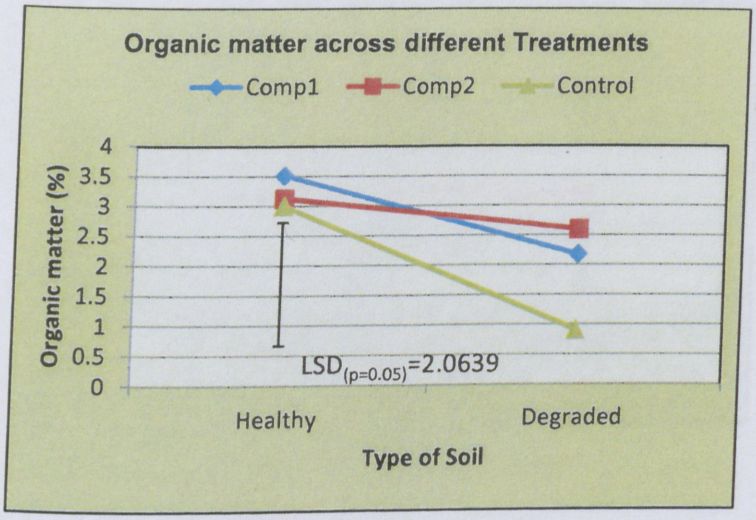

Figure 6: Organic matter across different treatments

4.1.3.1 Discussion

According to Appendix B and Figure 6, there were no significant changes in organic matter content of the healthy soil which was already high in the control. This was not the case in the degraded soil where the organic matter content increased significantly with both treatments as compared to the control. Again all treatments caused increases in organic matter content although not all significantly. From an agricultural point of view the addition of compost improved the situation significantly for especially degraded soil.

4.1.4 Potentially Mineralizable Nitrogen (PMN)

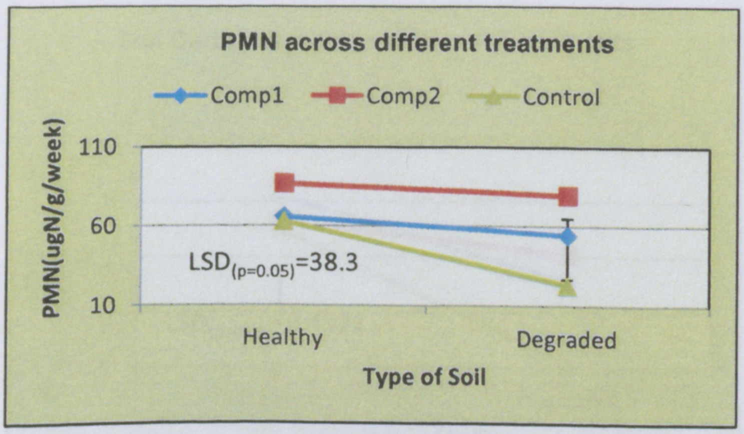

Figure 7: Potentially Mineralizable Nitrogen

4.1.4.1 Discussion

All treatments increased the PMN from the controls but it was already high in the healthy soil whereas it was low in the degraded soil. The first treatment (comp 1 = $0.5m^3$ compost) did not increase the PMN significantly in the degraded soil but the second treatment (comp2 = $1m^3$ compost) increased it significantly. It seems that a lot of compost is needed as a treatment in degraded soil like the type of the study area to significantly improve the PMN levels.

4.1.5 Active Carbon Content Percentage

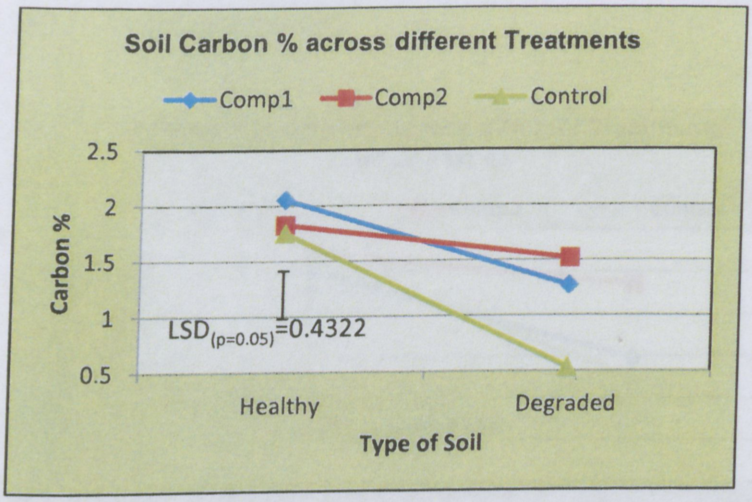

Figure 8: Active carbon content percentage

4.1.5.1 Discussion

Fertilizer Society of South Africa, (2007) norms for ideal carbon levels is 4%. All compost treatments increased the active carbon content but the trend was similar to the organic matter content (Figure 8.) and both the treatment increased the carbon content significantly as compared to the control. This was to be expected as organic matter and carbon content is strongly correlated. High carbon contents are beneficial and desired in healthy soils and compost treatments contributed significantly where carbon content was low as was the case in the degraded soil.

4.2 Soil Physical Properties

4.2.1 Aggregate stability

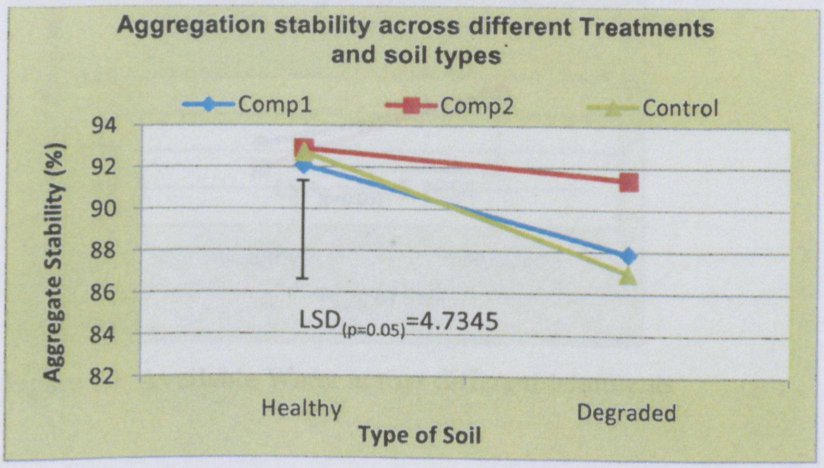

Figure 9: Aggregate stability across different treatment and soil types

4.2.1.1 Discussion

Aggregate stability was very high and the soil had a good strong structure in the healthy soil and compost treatments did not change it significantly (Appendix A, Figure 9). In the degraded soil only the larger quantity of compost as was applied in treatment 2 (comp 2) made a significant change which was an improvement in the stability of the structure of the soil.

4.2.2 Available water holding capacity

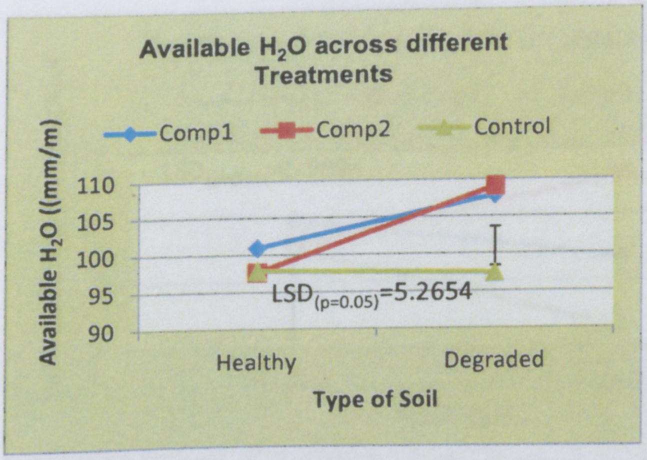

Figure 10: Available Water across different treatments

4.2.2.1 Discussion

Both compost treatments made a significant improvement in the water holding capacity of the degraded soil but had no influence on the healthy soil. Apparently the degraded soil (where the topsoil had been removed) had a higher silt percentage than the topsoil of the healthy soil which explains why the healthy soil had a lower water holding capacity than the degraded soil.

4.2.3 Surface and subsurface hardness (Soil Penetrability)

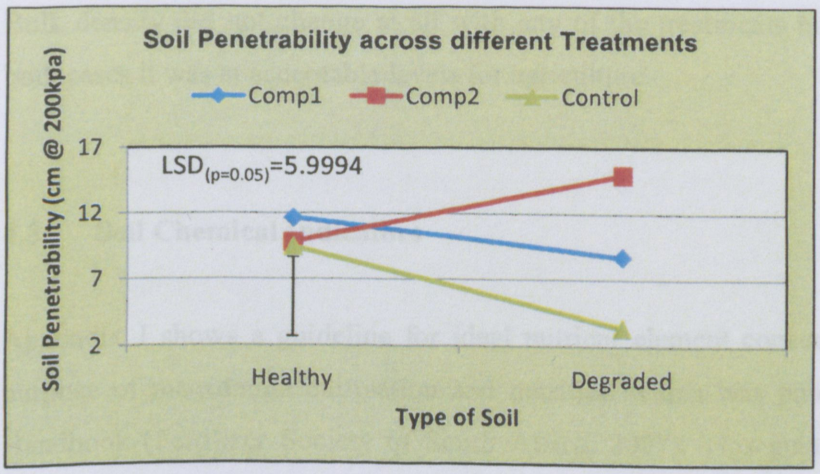

Figure 11: Soil penetrability across different treatments

4.2.3.1 Discussion

With reference to Figure 11 and Appendix B, the penetrability of the healthy soil did not change significantly with the treatments, but significant changes were observed in both treatments in the degraded soil. Compost had a huge impact on soil penetrability in the degraded soil which is significant for plant growth and crop cultivation.

4.2.4. Bulk Density

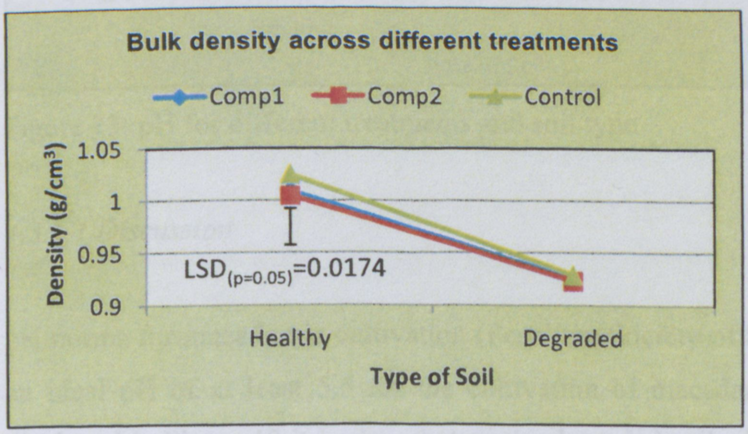

Figure 12: Bulk density

4.2.4.1 Discussion

Bulk density did not change at all with any of the treatments in both the soil types. In both cases it was at acceptable levels for agriculture.

4.3 Soil Chemical Indicators

Appendix J shows a guideline for ideal nutrient element concentrations in soil for the purpose of macadamia cultivation and nutrition which was published in the Fertilizer Handbook (Fertilizer Society of South Africa, 2007). This guideline was also used to assess the chemical changes in the soil which follows in this section.

4.3.1 Soil pH

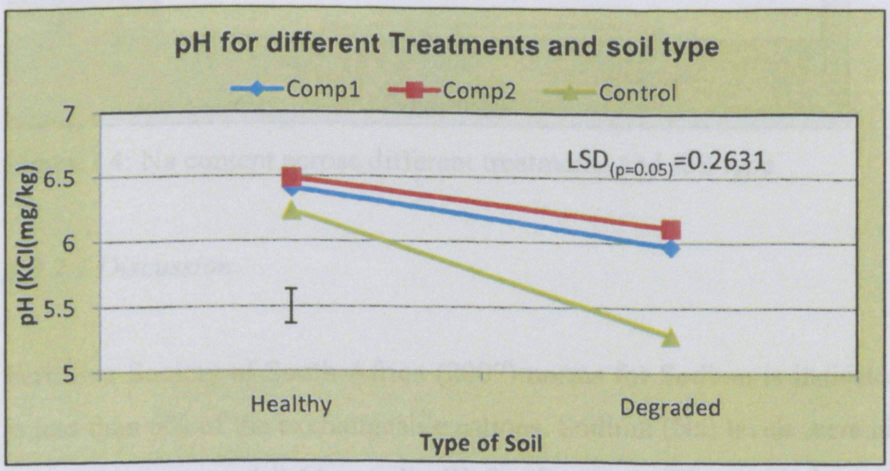

Figure 13: pH for different treatments and soil type

4.3.1.1 Discussion

pH norms for macadamia cultivation (Fertilizer Society of South Africa, 2007) indicated an ideal pH of at least 5.5 for the cultivation of macadamias. From Appendix B and displayed in Figure 13 it is clear that on the degraded soil, pH increased significantly with both compost treatments. However, there was no significant difference in pH between the treatments and the control of the healthy soil. The healthy soil had pH levels which were all higher than the pH of the degraded soil plots. The only difference between the degraded site and the healthy soil sites were that the topsoil had been removed from the degraded site which was the result of careless soil management in the orchard. pH was on the high side in the healthy soil and increased slightly with the treatments, in the degraded soil it was within range for ideal crop production but still a little too alkaline.

4.3.2 Sodium (Na)

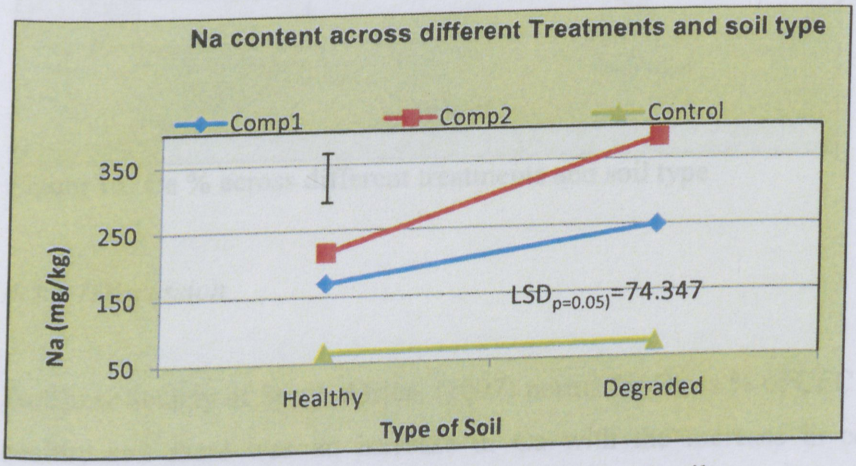

Figure 14: Na content across different treatments and soil type

4.3.2.1 Discussion

Fertilizer Society of South Africa (2007) norms for Sodium is indicated as ideal when it is less than 5% of the exchangeable cations. Sodium (Na) levels were high in all sites and treatments increased it (Appendix B) for the worse. Figure 14 above depicts clearly the increase of Na on both healthy and degraded soil. However, there was no significant increase in Na levels after the treatments on the healthy soil. Significant increases have though been observed on the degraded soil after both compost applications.

4.3.3 Relative Calcium (Ca %)

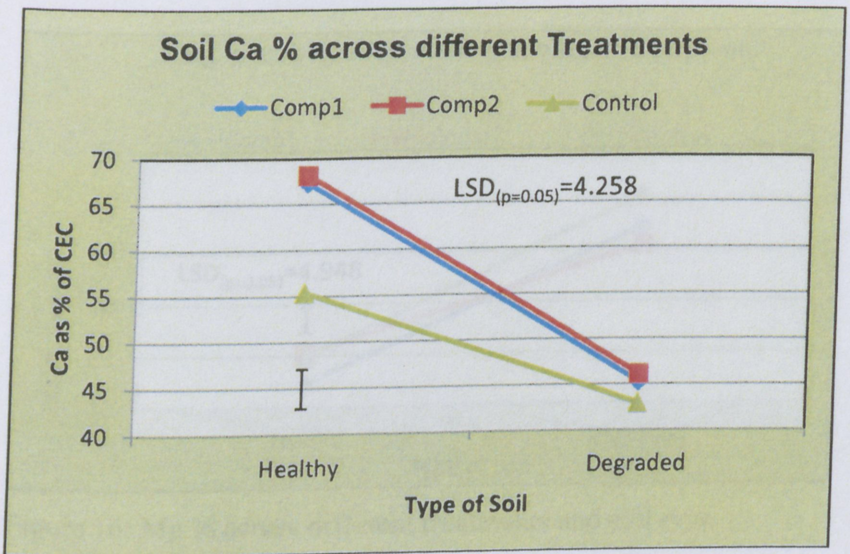

Figure 15: Ca % across different treatments and soil type

4.3.3.1Discussion

Fertilizer Society of South Africa, (2007) norms for Ca as % of CEC is 65 – 70 %. In the healthy soil there was an increase in Ca with the increase in compost application. Compost application therefore affected Ca positively in this case as it was low in the healthy soils before the application. In the degraded soil the compost did not have any significant effect on Calcium levels (Appendix B) but here it was negatively affected by the compost.

4.3.4 Relative Magnesium (Mg %)

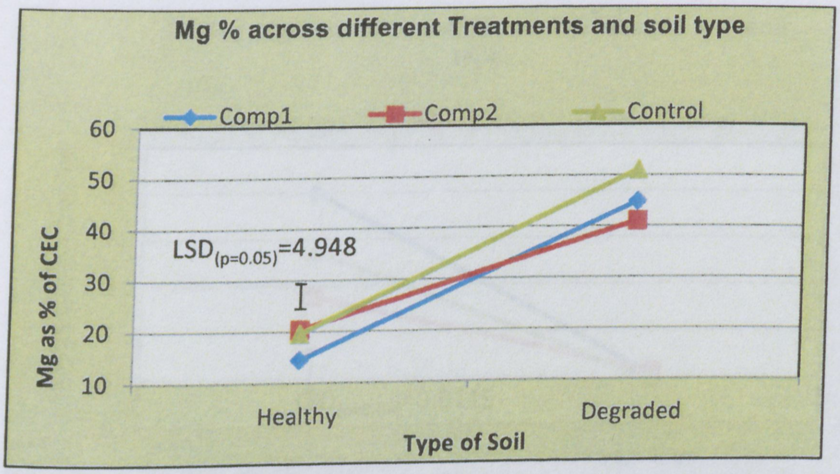

Figure 16: Mg % across different treatments and soil type

4.3.4.1 Discussion

Fertilizer Society of South Africa, (2007) norms for Mg is 20 – 25 % of CEC. According to Appendix B and Figure 16 above there was no significant difference on Mg levels after compost treatments on the healthy soil. There was also not a significant change in Mg levels on the degraded soil with any of the treatments, here the soil Mg levels were within range but on the high side.

4.3.5 Ca:Mg relationship

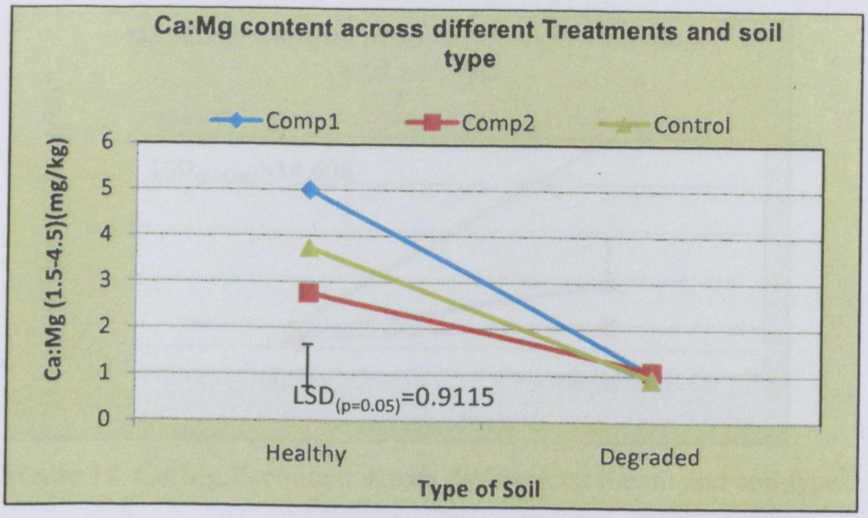

Figure 17: Ca:Mg content across different treatments and soil type

4.3.5.1 Discussion

On the degraded soil the Figure 16 shows that there was no significant difference in the Ca: Mg relationship that compost application made and Mg levels were too high in all the treatments and control whereas it was ideal in the healthy soil and the Mg:K relationship was also ideal in the healthy soil. Agriculturally, Ca:Mg relationship was poor on the degraded soil despite compost amendment.

4.3.6 Ca:Mg:K relationship

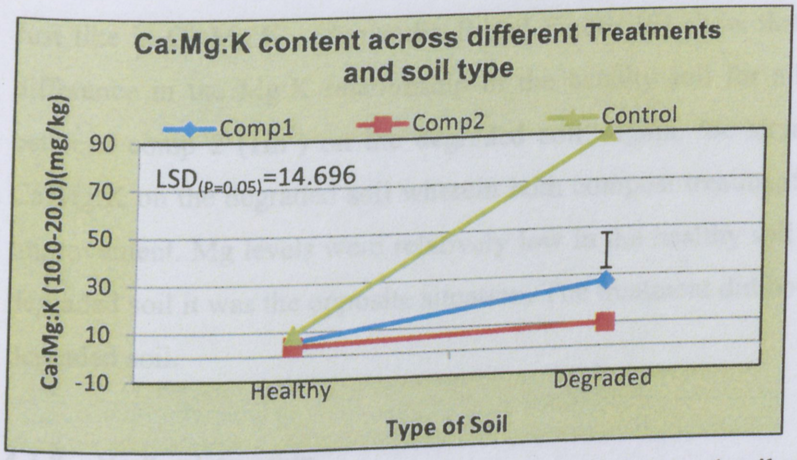

Figure 18: Ca:Mg:K content across different treatment and soil type

4.3.6.1 Discussion

Appendix B and Figure 18 above shows that there was no significant difference in the relationship between Ca:Mg:K in the healthy soil for all treatments and the control. However, there was a significant difference in the relationship between Ca:Mg:K of both the compost treatments and control of the degraded soil. Compost improved the Ca:Mg:K relationship significantly in degraded soil in this case.

4.3.7 Mg:K relationship

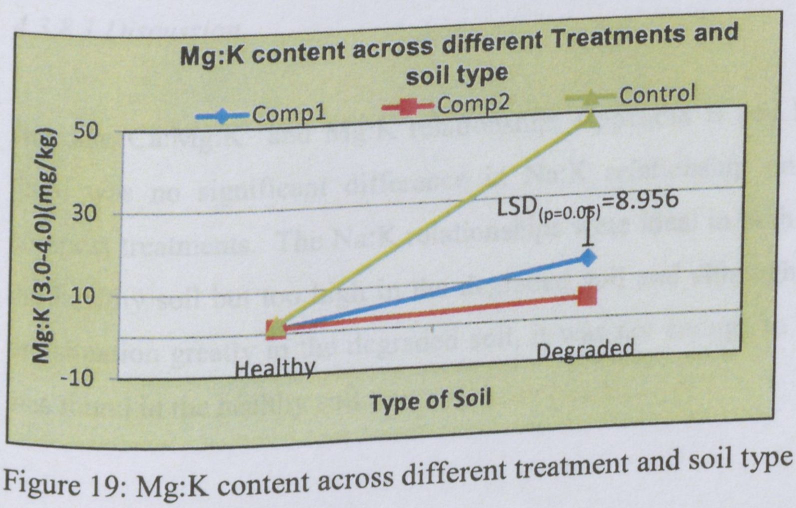

Figure 19: Mg:K content across different treatment and soil type

4.3.7.1 Discussion

Just like in Ca:Mg:K , (Appendix B and Figure 19) show that there was no significant difference in the Mg:K relationship in the healthy soil for all compost treatments and between comp 2 ($1m^3$) on the degraded soil. Again, the situation was the same as in Ca:Mg:K on the degraded soil wherein both compost treatments resulted in a significant improvement. Mg levels were relatively low in the healthy soil and K levels high, in the degraded soil it was the opposite situation. The treatment did however improve this in the degraded soil.

4.3.8 Na:K relationship

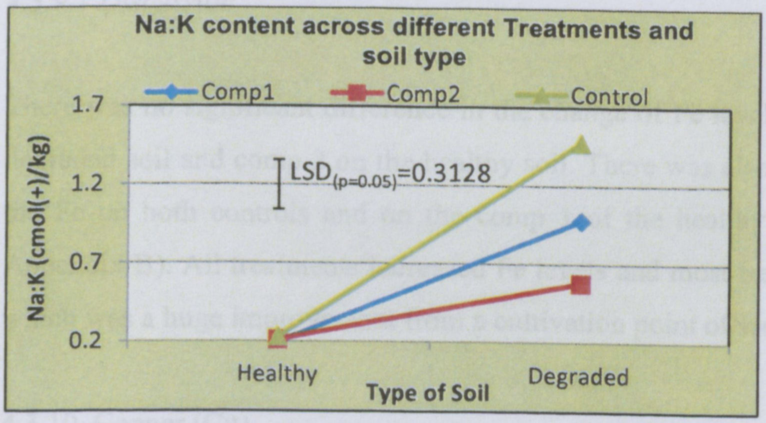

Figure 20: Na:K content across different treatment and soil type

4.3.8.1 Discussion

Just like Ca:Mg:K and Mg:K relationship, Appendix B and Figure 20 both show that there was no significant difference in Na:K relationship on the healthy soil for all compost treatments. The Na:K relationships were ideal in both treatments and control in the healthy soil but too high in the degraded soil and although the treatments improved the situation greatly in the degraded soil, it was not enough to bring it to ideal levels as was found in the healthy soil.

4.3.9 Iron (Fe)

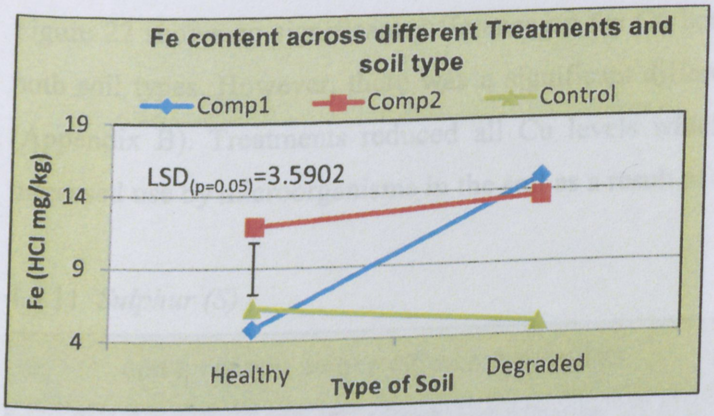

Figure 21: Fe content across different treatments and soil type

4.3.9.1 Discussion

There was no significant difference in the change of Fe levels between comp 1 and 2 on degraded soil and comp 2 on the healthy soil. There was also no significant difference in the Fe on both controls and on the comp 1 of the healthy soil (Figure 21 above and Appendix B). All treatments increased Fe levels and most treatments did so significantly which was a huge improvement from a cultivation point of view.

4.3.10 Copper (Cu)

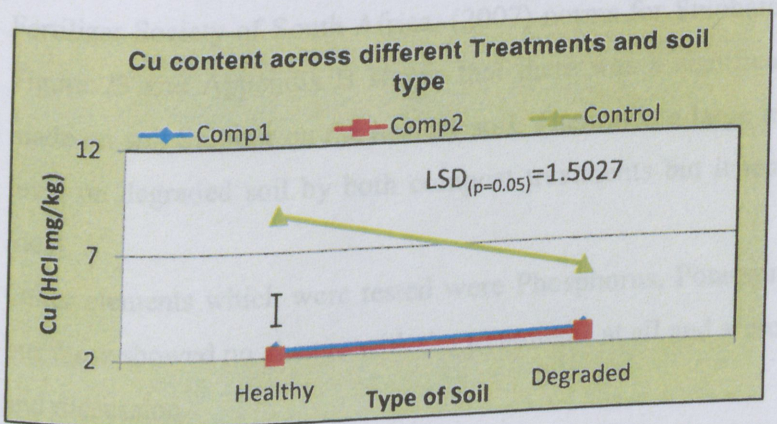

Figure 22: Cu content across different treatment and soil type

4.3.10.1 Discussion

Figure 22 shows no significant difference on the Cu between all compost treatments on both soil types. However, there was a significant difference in their respective controls (Appendix B). Treatments reduced all Cu levels which were probably as a result of increased use by microorganisms in the soil as a result of the compost treatments.

4.3.11 *Sulphur (S)*

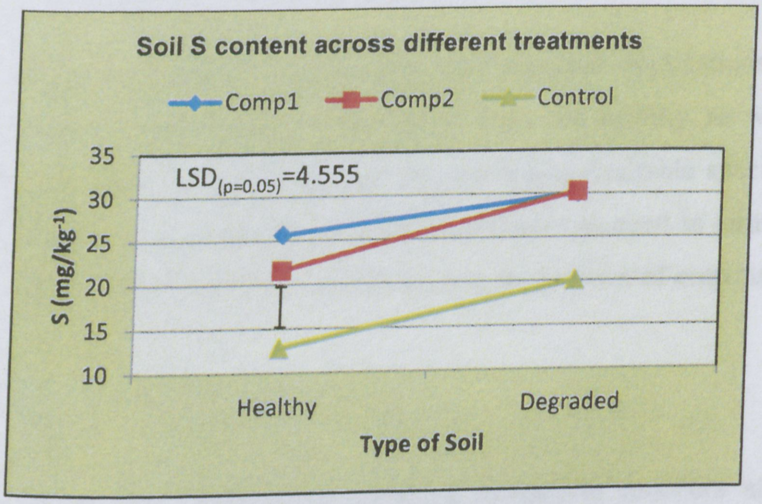

Figure 23: Soil Sulphur across difference treatments

4.3.11.1 Discussion

Fertilizer Society of South Africa, (2007) norms for Sulphate Sulphur is 20 mg per kg^{-1} Figure 23 and Appendix B shows that there was a significant difference that compost made on soil Sulphur on the healthy soil. There was a large increase also on the Sulphur level on degraded soil by both compost treatments but it resulted in levels higher than ideal.

Other elements which were tested were Phosphorus, Potassium, Manganese and Boron, but these showed no change with the treatments at all and were not included in the graphs and discussion.

CHAPTER 5: SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

5.1.1 Soil Biological Indicators

5.1.1.1 Nematode Analysis

From the results it was clear that compost applications significantly improved the nematode community make-up in both the healthy as well as the degraded soil by decreasing unwanted species and increasing desirable species. The final composition of nematode species and numbers were more balanced in terms of nematode predators and plant parasites which is conducive for the practice of crop cultivation.

5.1.1.2 Earthworm Abundance

All compost treatments increased earthworm numbers although not significantly in degraded soil. More compost would probably improve the situation in degraded soils.

5.1.1.3 Organic Matter Content (OM)

OM was already high in the healthy soil and treatments did not bring any change but in the degraded soil significant increases of OM were observed with both treatments.

5.1.1.4 Potentially Mineralizable Nitrogen (PMN)

PMN was already high in the healthy soil and treatments did not bring any change but the higher compost treatment increased the PMN in the degraded soil significantly.

5.1.1.5 Active Carbon Content Percentage

Active carbon content was again already high in the healthy soil, low in the degraded soil and increased significantly with both treatments in the degraded soil but no significant change in the healthy soil.

5.1.2 Soil Physical Properties

5.1.2.1 Aggregate Stability

Aggregate stability was high in the healthy soils and compost treatments did not change it much, but it was low in degraded soils and only the higher compost treatment had a significant improvement on soil structure in this case.

5.1.2.2 Available Water Holding Capacity

Compost treatments improved the water holding capacity of the degraded soil only, in the healthy soil there were no significant changes.

5.12.3 Surface and Subsurface Hardness (Soil Penetrability)

Soil penetrability was already high in the healthy soils and compost did not improve it significantly but in the degraded soil both the treatments improved it significantly.

5.1.2.4 Bulk Density

Bulk density did not change with any of the treatments in either healthy or degraded soils.

5.1.3 Soil Chemical Indicators

5.1.3.1 Soil pH

pH did not change significantly with treatments in the healthy soil, but here the pH was already very high, higher than the ideal levels. Compost increased the pH levels of the degraded soil which was not desired but the final range was still acceptable for crop production.

5.1.3.2 Sodium (Na)

Compost increased Na levels in all cases which was not an improvement because these levels were all too high, but the increases were only significant in the degraded soils.

5.1.3.3 Relative Calcium (Ca %)

Compost treatments decreased the Ca levels significantly for the healthy soil but had no significant effect on the degraded soil. This was an improvement for the healthy soil as Ca levels were too high in the control. All levels were acceptable in the degraded soil.

5.1.3.4 Relative Magnesium (Mg %)

Compost did not change magnesium levels in the healthy soil but greatly improved levels in the degraded soil.

5.1.3.5 Ca:Mg relationship

Ca:Mg relationships were optimal in the healthy soil and worsened in degraded soil after compost applications.

5.1.3.6 Ca:Mg:K relationship

Ca:Mg:K relationships were poor in the healthy soil but improved in degraded soil after compost applications. Compost therefore have good Ca:Mg:K relationship which is important to rehabilitate the degraded soil.

5.1.3.7 Mg:K relationship

Mg:K relationship was not ideal in the healthy soil and the compost treatments did not improve it but a significant improvement was observed in the degraded soil.

5.1.3.8 Na:K relationship

Na:K relationships were good in the healthy soil and compost treatments did not change it. It was however poor in the degraded soil but treatments improved it significantly though not enough to ideal relationships.

5.1.3.9 Iron (Fe)

Iron levels were significantly improved by compost on both soil types although only the higher application improved Fe levels in the healthy soil.

5.1.3.10 Copper (Cu)

In case of Copper, compost treatments decreased its levels significantly in both the soil types.

5.1.3.11 Sulphur (S)

Only the higher compost applications increased Sulphur levels significantly in both soil types. This was a good improvement in both cases.

5.2 Conclusion and Recommendations

Compost treatments improved soil conditions in most cases. Where $0.5m^3$ compost was applied to the healthy soil, it significantly improved five (nematode, earthworm, organic matter content, PMN, and active carbon content percentage) out of five of the biological properties measured, three (aggregate stability, available water holding capacity and soil penetrability) out of four of the physical properties and two (Iron and Sulphur) out of eleven of the chemical properties measured in this research exercise. With $1m^3$ compost applied, three out of five of the biological properties were significantly improved, one out of four of the physical and two out of eleven of the chemical properties also improved significantly. Only six of these soil properties did not change significantly with the application of compost. Similarly where $0.5m^3$ compost was applied to the degraded soil, it significantly improved three out of four of the biological properties, two out of four of the physical properties and five out of eleven of the chemical properties. With $1m^3$ compost applied here, three out of five of the biological properties were significantly improved, three out of four of the physical and five out of eleven of the chemical properties also improved significantly. Only six of these soil properties did not change significantly with the application of compost. Overall 40 % of all soil properties improved in the healthy soil and 53 % of all soil properties that were measured in the degraded soil with the application of compost. Only two properties of the chemical indicators (calcium and copper) of all the indicators measured showed a decline in condition when compost were added to the soil.

It is concluded that soil organic matter and soil health can be improved and maintained by making use of compost with the aim of restoring quality and health of both healthy and degraded soils in macadamia orchards. The research showed that even the smaller application of compost ($0.5m^3$) was overall significant to improve soil quality and health of the soils in the study area. The implication is that fertilizer applications can be reduced with improved soil conditions and nutrient uptake becomes more efficient in healthy soils than in degraded soils. Applying the compost as mulch also proved effective, these applications however have to be repeated annually to maintain good soil conditions.

References

Abigail, J. & Lukas, V. Z. (2003). How to compost on farm. *Soil sense*. NSW Agriculture, Wollongbar.

Abigail, J. (2004). Using compost in macadamia orchards. *Soil sense*. NSW Agriculture, Wollongbar.

Altieri, M. A., & Clara I. N. (2001). "Ecological impacts of modern agriculture in the United States and Latin America." *globalization and the rural environment*: 121-135.

Arnold, F. (1982). *Fertilizers and fertilization: Introduction and practical guide to crop fertilization*. Weinheim; Deerfield Beach, Florida; Basel: Verlag Chemie.

Baniyamuddin, M. & Ahmad, W. (2007). Some new and known species of Dorylaimoidea (Dorylaimida: Nematoda) from Natural forest of Arunachal Pradesh, India. *Journal of Nematode Morphology and Systematics*, Vol 10, No 1

Brown, M.W. & Tworkoski, T., (2003). Pest management benefits of compost mulch in apple orchards. *Agriculture, Ecosystems and Environment.* 103 (2004) 465–472.

Cox, J. *et al.*, (2004). *Macadamia Husk Compost Improves Soil Health in Sub-Tropical Horticulture.* 3rd Australian New Zealand Soils Conference, 5 – 9 December 2004, University of Sydney, Australia. Published on CDROM.
Website www.regional.org.au/au/asssi/

Carrera, L.M. *et al.*, (2007). Effects of cover crops, compost, and manure amendments on soil microbial community structure in tomato production systems. *Applied Ecology*. 37 (2007)247-255.

Doran, J.W & Zeiss, M.R. (2000). Soil health and sustainability: managing the biotic component of soil quality. *Applied Soil Ecology*. 15 : 3–11

Ekman, J. (2004). Organic Materials in Horticulture – their safe use. NSW Agriculture. Wollongbar.

Environment and Natural Resources Committee (2010). *Soil carbon sequestration in Victoria*. Submission no. 23. Victoria. Submission by Compost Victoria.

Fertilizer Society of South Africa (2007). FSSA Fertilizer Handbook. Edition 6: 292.

Freibauer *et al.*, (2004) Carbon sequestration in the agricultural soils of Europe. Geoderma 122 (2004) 1 –23.

Gallaher, R.N. (1998). Growing field crops with compost. department of agronomy. university of Florida. Gainesville, Florida

Gugino, B. K. *et al.*, (2009). 2nd ed. *Cornell soil health assessment training manual*, Cornell university, Geneva, New York.

Islam, K.R. & Weil, R.R. (2000). Soil quality indicatory properties in mid-Atlantic soils as influenced by conservation management. *Journal for Soil Water Conservation, 55, 69-78.*

Kimetu, J. M. *et al.*, (2008). Reversibility of soil productivity decline with organic matter of differing quality along a degradation gradient. *ecosystems*. 11: 726-739.

Lukas, V.Z. *et al.*, (2001). Healthy soils in macadamia orchards. NSW Agriculture, bruxner highway, Wollongbar NSW 2477.

Magdoff, F. & Van Es, H. (2000). Building soils for better crops. 2nd ed. *Sustainable Agriculture Network Handbook Series*; Book 4, University of Vermont, Burlington: sustainable agriculture publications.

Magdoff, F & Weil, R.R. (2004). *Soil organic matter in sustainable agriculture*. CRC Press LLC, US.

Mays, D. A., Terman, G. L. & Duggan, J. C., (1973). Municipal compost: effects on crop yields and soil properties. *Journal of environmental quality.* Vol. 2 No. 1, p. 89-92.

McSorley, R. & Gallaher, R.N. (1996). Effect of yard waste compost on nematode densities and maize yield. *Supplement to Journal of Nematology*. 28(4): 655-660.

Mylavarapu, R.S & Zinati, G.M. (2009). Improvement of Soil Properties using Uompost for Optimum Parsley Production in Sandy Soils. *Scientia Horticulturae.* 120 (2009) 426–430.

Norman Q.A. *et al.*, (2005). Effects of vermicomposts produced from cattle manure, food waste and paper waste on the growth and yield of peppers in the field. Soil ecology laboratory, The Ohio State university, Columbus, OH 43201, USA.

Ouédraogo, E., Mando, A. & Zombré, N.P., (2001). Use of compost to improve soil properties and crop productivity under low input agricultural system in West Africa. *Agriculture, ecosystems and environment.* 84 (2001) 259–266.

Pelosi, C.S. *et al.*, (2014). Pesticides and earthworms. A review. *Agronomy for sustainable development.* 34: 199-228.

Padmavathiamma, P.K. *et al.*, (2008). An experimental study of vermi-biowaste composting for agricultural soil improvement. *Bioresource technology.* 99 (2008) 16721681.

Rynk, R. (1992). On-farm composting. natural resource, agriculture, and engineering service, cooperative extension, Ithaka, New York.

SAS Institute, Inc. (1999), SAS/STAT User's guide, Version 9.1, Volume 2. SAS Institute Inc, SAS Campus Drive, Cary, North Carolina 27513.

Shapiro, S. S. & Wilk, M. B. (1965). An analysis of variance test for normality (completesamples), Biometrika, 52: 591-611. (Non-Normality test)

Shiralipour, A. (1998). The effects of compost on soil. Center for biomass programs,university of Florida, Gainesville, Florida.

Snedecor, G.W. & Cochran, W.G. (1967) Statistical methods, sixth edition, The Iowa state university press, AMES, IOWA USA. Chapter 4: 11-12

Tejada, M., Hernandez, M.T. & Garcia, C., (2009). Soil restoration using composted plant residues: Effects on soil properties. *Soil & tillage research.* 102: 109–117.

USA, Society for Ecological Restoration International (SER). (2004). Ecological restoration – a Means of conserving biodiversity and sustaining livelihoods. ***A call to action by the ecological restoration joint working group of SER international and the IUCN commission on ecosystem management.*** USA.

APPENDICES

Appendix A.1 - ANOVA table for the different soil elements

Source	DF	pH MS	pH P	P_ MS	P_ P	K MS	K P	Na MS	Na P	Ca MS	Ca P
Soil	1	3.21	<.0001	53168	0.0020	2922621	<.0001	86740	0.0003	195145	0.4402
Rep(Soil)	12	0.07		5887		181235		5541		663195	
Tmt	2	0.96	<.0001	107905	<.0001	4731001	<.0001	175030	<.0001	5838077	<.0001
Soil*Tmt	2	0.30	0.0122	7894	0.1856	148212	0.3152	22460	0.0209	1042815	0.0551
Error	23	0.06		4353		122041		4885		316326	
Total Corrected	40	7.78		455540		17662817		660554		29190776	
Shapiro-Wilk (P>W)			0.668		0.004		0.595		0.828		0.108
Kurtosis			-0.296		3.931		-0.804		-0.445		0.538

Source	DF	Mg MS	Mg P	CaPERS MS	CaPERS P	MgPERS MS	MgPERS P	KPERS MS	KPERS P	NaPERS MS	NaPERS P
Soil	1	11707949	<.0001	3675.7	<.0001	7594.8	<.0001	814.1	<.0001	4.026	0.1050
Rep(Soil)	12	213756		41.3		45.6		20.2		1.494	
Tmt	2	286565	0.0119	272.8	<.0001	106.3	0.0115	304.3	<.0001	29.669	<.0001
Soil*Tmt	2	69958	0.2864	104.4	0.0037	120.2	0.0072	0.3	0.9696	2.756	0.1651
Error	23	52967		14.4		19.5		8.9		1.413	
Total Corrected	40	16204309		5257.2		9043.9		1869.8		119.303	
Shapiro-Wilk (P>W)			0.118		0.592		0.098		0.134		0.071
Kurtosis			0.901		0.510		-0.356		-0.617		1.773

Source	DF	CaMg MS	CaMg Mean	CaMg_K MS	CaMg_K P	MgK MS	MgK P	S MS	S P	NaK MS	NaK P
Soil	1	80.664	<.0001	11590.0	<.0001	4057.8	<.0001	517.6	<.0001	6.161	<.0001
Rep(Soil)	12	1.083		776.8		264.2		46.3		0.339	
Tmt	2	4.345	0.0055	5475.9	<.0001	1477.1	<.0001	492.2	<.0001	0.558	0.0038
Soil*Tmt	2	4.543	0.0046	4891.1	<.0001	1549.6	<.0001	17.0	0.3739	0.571	0.0034
Error	23	0.661		171.9		63.8		16.5		0.078	
Total Corrected	40	126.640		45599.5		14749.3		2471.4		14.273	
Shapiro-Wilk (P>W)			0.035		<0.0001		<0.0001		0.061		0.030
Kurtosis			0.311		3.670		3.649		2.587		1.797

Source	DF	SAmAc MS	SAmAc P	Fe MS	Fe P	Mn_HCl MS	Mn_HCl P	Cu_HCl MS	Cu_HCl P	T MS	T P
Soil	1	1491.94	0.14	148.1	0.0009	1683.9	0.0011	7.01	0.06	517.64	<.0001
Rep(Soil)	12	517.13		9.4		129.0		5.25		46.31	
Tmt	2	7848.07	0.00	147.5	<.0001	2528.4	<.0001	102.09	<.0001	492.17	<.0001
Soil*Tmt	2	168.31	0.78	110.7	0.0005	63.0	0.6036	14.18	0.003	16.96	0.3739
Error	23	653.74		10.3		122.0		1.80		16.51	
Total Corrected	40	38766.34		1012.9		11220.0		343.83		2471.36	
Shapiro-Wilk (P>W)			<0.0001		0.187		0.658		0.130		0.061
Kurtosis			7.598		-1.053		0.287		0.145		2.587

Appendix A.2

Soil	Tmt	N	MgK Mean	MgK Group	NaK Mean	NaK Group	Fe Mean	Fe Group	Cu_HCl Mean	Cu_HCl Group	SplitPERS Mean	SplitPERS Group	SoilPERS Mean	SoilPERS Group
D	comp1	7	14.35	b	0.979	b	14.90	a	2.741	c	16.1	b	8.71	bc
D	comp2	7	4.94	c	0.577	c	13.62	a	2.549	c	17.0	b	14.93	a
D	control	6	48.23	a	1.470	a	4.84	b	5.720	b	24.3	a	3.33	c
H	comp1	7	0.97	c	0.194	d	4.79	b	2.347	c	13.9	bc	11.64	ab
H	comp2	7	1.05	c	0.209	d	11.87	a	2.093	c	11.0	c	9.79	ab
H	control	7	1.93	c	0.227	d	6.23	b	8.744	a	13.9	bc	9.43	ab
LSD$_{(p=0.05)}$			8.956		0.312		3.59		1.5027		4.113		5.9994	

Source	DF	SandPERS		Den		SoilPen		AvailH2O		Aggr	
		MS	P	MS	P	MS	P	MS	P	MS	P
Soil	1	155.2	0.0596	0.078	**<.0001**	10.46	0.5515	372.62	**0.00**	152.8	**0.008**
Rep(Soil)	12	66.5		0.001		14.05		30.30		14.4	
Tmt	2	247.3	**0.0068**	0.001	0.4434	104.36	**0.0422**	187.10	**0.00**	23.3	0.300
Soil*Tmt	2	27.1	0.5134	0.000	0.8976	109.24	**0.0371**	125.50	**0.01**	16.4	0.425
Error	23	39.5		0.001		28.64		22.78		18.4	
Total Corrected	40	2411.6		0.116		1264.99		1908.18		847.0	
Shapiro-Wilk (P>W)			0.003		0.695		0.026		0.633		0.488
Kurtosis			2.249		-0.500		1.352		0.092		0.037

Source	DF	CarbonPERS		PMN	
		MS	P	MS	P
Soil	1	5.628	**<.0001**	3340.0	0.105
Rep(Soil)	12	0.119		1427.9	
Tmt	2	1.191	**0.0023**	6113.3	**0.014**
Soil*Tmt	2	0.765	**0.0142**	1631.1	0.269
Error	23	0.149		1172.8	
Total Corrected	40	14.384		62939.3	
Shapiro-Wilk (P>W)			0.097		0.103
Kurtosis			1.603		0.362

Source	DF	Orgmatter		Earthworm	
		MS	P	MS	P
Soil	1	18.26	**<.0001**	24868.7	**<.0001**
Rep(Soil)	12	0.39		738.7	
Tmt	2	3.78	**0.001**	10606.7	**<.0001**
Soil*Tmt	2	2.14	**0.015**	5737.5	**0.0005**
Error	24	0.42		538.6	
Total Corrected	41	44.95		79347.6	
Shapiro-Wilk (P>W)			0.063		0.555
Kurtosis			1.861		0.345

Appendix B– Means and t-groupings for the different soil types and treatments for the different soil elements

			pH		Na		CaPERS		MgPERS		CaMg		CaMg_K	
Soil	Tmt	N	Mean	Group	Mean	Group	Mean	Group	Mean	Group	Mean	Group	Mean	Group
D	comp1	7	5.97	b	249.4	b	45.27	c	44.851	b	1.049	d	27.289	b
D	comp2	7	6.11	b	381.4	a	42.89	c	40.999	d	1.086	d	9.723	c
D	control	6	5.28	c	72.0	d	46.07	c	50.982	a	0.915	d	89.667	a
H	comp1	7	6.41	a	170.0	c	67.34	a	14.469	c	4.994	a	5.889	c
H	comp2	7	6.48	a	216.1	bc	55.37	b	20.330	c	2.753	c	3.869	c
H	control	7	6.23	ab	65.0	d	68.15	a	19.541	c	3.736	b	8.896	c
LSD$_{(p=0.05)}$			0.263		74.35		4.258		4.9487		0.912		14.696	

			MgK		NaK		Fe		Cu_HCl		SplitPERS		SoilPen	
Soil	Tmt	N	Mean	Group	Mean	Group	Mean	Group	Mean	Group	Mean	Group	Mean	Group
D	comp1	7	14.35	b	0.979	b	14.90	a	2.741	c	16.1	b	8.71	bc
D	comp2	7	4.94	c	0.577	c	13.62	a	2.549	c	17.0	b	14.93	a
D	control	6	48.23	a	1.470	a	4.84	b	5.720	b	24.3	a	3.33	c
H	comp1	7	0.97	c	0.194	d	4.79	b	2.347	c	13.9	bc	11.64	ab
H	comp2	7	1.05	c	0.209	d	11.87	a	2.093	c	11.0	c	9.79	ab
H	control	7	1.93	c	0.227	d	6.23	b	8.744	a	13.9	bc	9.43	ab
LSD$_{(p=0.05)}$			8.956		0.312		3.59		1.5027		4.113		5.9994	

			AvailH2O		Orgmatter		Earthworm	
Soil	Tmt	N	Mean	Group	Mean	Group	Mean	Group
D	comp1	7	107.9	a	2.17	c	20.0	c
D	comp2	7	109.0	a	2.59	bc	16.4	c
D	control	6	97.4	b	0.90	d	2.3	c
H	comp1	7	101.0	b	3.51	a	64.0	b
H	comp2	7	97.6	b	3.12	ab	107.7	a
H	control	7	97.8	b	2.99	ab	13.0	c
LSD$_{(p=0.05)}$			5.265		2.064		25.6	

Appendix C.1– Means and t-groupings for the different treatments for the different soil elements

		P_		K		Mg		KPERS	
Tmt	N	Mean	Group	Mean	Group	Mean	Group	Mean	Group
comp1	14	117.9	b	1077	b	1050.3	a	10.70	b
comp2	14	195.1	a	1460	a	1024.1	a	15.29	a
control	13	16.2	c	310	c	740.1	b	6.08	c
$LSD_{(p=0.05)}$		52.25		276.62		182.24		2.357	

		NaPERS		S		T		SAmAc	
Tmt	N	Mean	Group	Mean	Group	Mean	Group	Mean	Group
comp1	14	3.334	b	27.83	a	27.83	a	32.17	a
comp2	14	4.916	a	25.88	a	25.88	a	58.72	b
control	13	1.914	c	16.1	b	16.1	b	10.62	c
$LSD_{(p=0.05)}$		0.941		3.218		3.218		20.246	

		Mn_HCl		Zn_HCl		B		ClayPERS	
Tmt	N	Mean	Group	Mean	Group	Mean	Group	Mean	Group
comp1	14	32.08	b	20.34	b	0.229	a	39.43	ab
comp2	14	44.46	a	35.2	a	0.246	a	38.14	b
control	13	17.37	c	6.818	c	0.058	b	42.38	a
$LSD_{(p=0.05)}$		8.7456		7.478		0.0613		2.967	

	P_		K		Mg		KPERS	
Tmt	Mean	Group	Mean	Group	Mean	Group	Mean	Group
comp1	117.9	b	1077	b	1050.3	a	10.70	b
comp2	195.1	a	1460	a	1024.1	a	15.29	a
control	16.2	c	310	c	740.1	b	6.08	c
52.25		276.62		182.24		2.357		

Appendix C.2

Tmt	NaPERS Mean	NaPERS Group	S Mean	S Group	T Mean	T Group	SAmAc Mean	SAmAc Group
comp1	3.334	b	27.83	a	27.83	a	32.17	a
comp2	4.916	a	25.88	a	25.88	a	58.72	b
control	1.914	c	16.1	b	16.1	b	10.62	c
0.941		3.218		3.218		20.246		

Tmt	Mn_HCl Mean	Mn_HCl Group	Zn_HCl Mean	Zn_HCl Group	B Mean	B Group	ClayPERS Mean	ClayPERS Group
comp1	32.08	b	20.34	b	0.229	a	39.43	ab
comp2	44.46	a	35.2	a	0.246	a	38.14	b
control	17.37	c	6.818	c	0.058	b	42.38	a
8.7456		7.478		0.0613		2.967		

Tmt	N	SandPERS Mean	SandPERS Group	PMP Mean	PMP Group
comp1	14	45.57	a	60.18	ab
comp2	14	47.86	a	83.09	a
control	13	38.92	b	44.28	b
$LSD_{(p=0.05)}$		4.978		27.12	

Appendix D: ZZ2 Lab results on PMN

Sample Type: Soil

Lab number	Sample description	PMN (ugN/g/week)	Lab number	Sample description	PMN
18154	GS A	(i) 48.4	18175	PS A	(i) 49.0
18155	GS A	(ii) 50.0	18176	PS A	(ii) 7.9
18156	GS A	(iii) 70.1	18177	PS A	(iii) 11.9
18157	GS A	(iv) 63.4	18178	PS A	(iv) 12.9
18158	GS A	(v) 22.8	18179	PS A	(v) 139.4
18159	GS A	(vi) 127.2	18180	PS A	(vi) 126.7
18160	GS A	(vii) 79.1	18181	PS A	(vii) 33.7
18161	GS B	(i) 71.8	18182	PS B	(i) 75.2
18162	GS B	(ii) 52.9	18183	PS B	(ii) 30.6
18163	GS B	(iii) 87.7	18184	PS B	(iii) 25.8
18164	GS B	(iv) 66.6	18185	PS B	(iv) 148.7
18165	GS B	(v) 106.7	18186	PS B	(v) 71.3
18166	GS B	(vi) 67.5	18187	PS B	(vi) 124.6
18167	GS B	(vii) 153.7	18188	PS B	(vii) 80.1
18168	GS C	(i) 71.1	18189	PS C	(i) 40.1
18169	GS C	(ii) 43.7	18190	PS C	(ii) 22.8
18170	GS C	(iii) 100.3	18191	PS C	(iii) 9.4
18171	GS C	(iv) 60.8	18192	PS C	(iv) 11.1
18172	GS C	(v) 58.1	18193	PS C	(v) 27.7
18173	GS C	(vi) 49.5	18194	PS C	(vi) 20.5
18174	GS C	(vii) 55.7	18195	PS C	(vii) 14.2

Appendix E: Bemlab results on C% and pH

Verwysing No.	Lab. No.	C %	KUK (pH 7) cmol(+)/kg
GS A(i)	32912	1.85	11.29
GS A(ii)	32913	1.85	5.18
GS A(iii)	32914	2.64	13.72
GS A(iv)	32915	2.37	6.98
GS A(v)	32916	1.51	5.64
GS A(vi)	32917	2.37	5.59
GS A(vii)	32918	1.77	4.94
GS B(i)	32919	1.76	13.12
GS B(ii)	32920	1.77	6.20
GS B(iii)	32921	1.83	7.03
GS B(iv)	32922	1.61	4.72
GS B(v)	32923	1.53	4.60
GS B(vi)	32924	2.25	7.07
GS B(vii)	32925	2.02	7.50
GS C(i)	32926	1.81	7.11
GS C(ii)	32927	1.81	6.00
GS C(iii)	32928	1.77	4.96
GS C(iv)	32929	1.92	7.15
GS C(v)	32930	1.78	6.95
GS C(vi)	32931	1.43	9.69
GS C(vii)	32932	1.73	6.92
PS A(i)	32933	1.92	8.40
PS A(ii)	32934	0.82	13.71
PS A(iii)	32935	0.72	9.54
PS A(iv)	32936	1.27	15.58
PS A(v)	32937	2.05	3.73
PS A(vi)	32938	1.36	11.13
PS A(vii)	32939	0.76	12.26
PS B(i)	32940	1.39	10.97
PS B(ii)	32941	1.16	15.73
PS B(iii)	32942	1.42	5.46
PS B(iv)	32943	1.67	13.95
PS B(v)	32944	1.63	9.40
PS B(vi)	32945	0.96	11.04
PS B(vii)	32946	2.37	9.76
PS C(i)	32947	0.75	25.71
PS C(ii)	32948	0.86	14.86
PS C(iii)	32949	0.50	25.64
PS C(iv)	32950	0.48	12.56
PS C(v)	32951	0.81	9.66
PS C(vi)	32952	0.12	4.46
PS C(vii)	32953	0.16	31.32
Metodes#		3107	

Appendix F: Lab results on nematode species

Specie	log(Counts+1)	T-grouping
Acro	1.7504	a
Hel	1.4160	b
Euceph	1.3149	bc
Rhab	1.3119	bc
Mesor	1.1093	cd
Tyl	1.1036	cd
Rot	1.0256	d
Aph	0.7524	e
Pana	0.6062	ef
Plect	0.5152	efg
Doryl	0.4400	fgh
Aphel	0.4386	fghi
Dipl	0.3807	fghij
Cricon	0.3798	fghij
Dipther	0.3709	fghij
Prismat	0.3620	ghij
Chilop	0.3249	ghijk
Butl	0.2990	ghijkl
Mylon	0.2943	ghijklm
Pratl	0.2601	hijklmn
Aporc	0.2545	hijklmn
Actino	0.1973	ijklmn
Acrob	0.1934	jklmno
Prodo	0.1865	jklmno
Unk	0.1621	jklmno
Tylen	0.1505	jklmno
Para	0.1443	jklmno
Dityl	0.1203	klmno
Paratri	0.0811	lmno
Grano	0.0563	mno
Xiphin	0.0563	mno
Trip	0.0496	no
Eudo	0.0355	no
Parax	0.0355	no
Ceph	0.0315	no
Disc	0.0315	no
Monh	0.0315	no
Oxy	0.0248	no
Nothot	0.0000	o

Appendix G: Data on soil aggregation

	BAG	SAMPLE	FILTER + SOIL	SLAKED SOIL	TOTAL SOIL	STABLE SOIL	PLOT	WSTABLE
8.512	3.6277	58.6265	14.6747	6.1627	54.9988	48.8361	GS A 1	88.8
9.2337	3.4897	36.1819	13.2251	3.9914	32.6922	28.7008	GS A 2	87.8
8.6366	3.3779	103.4068	14.2648	5.6282	100.0289	94.4007	GS A 3	94.4
8.5313	3.393	112.4421	18.6899	10.1586	109.0491	98.8905	GS A 4	90.7
8.5572	3.3972	103.7628	17.2484	8.6912	100.3656	91.6744	GS A 5	91.3
8.6136	3.3787	119.2802	15.9351	7.3215	115.9015	108.58	GS A 6	93.7
8.6391	3.4805	110.8033	10.8831	2.244	107.3228	105.0788	GS A 7	97.9
8.7312	3.406	71.034	15.4435	6.7123	67.628	60.9157	GS B 1	90.1
9.1191	3.4266	100.5959	15.5294	6.4103	97.1693	90.759	GS B 2	93.4
8.5437	3.4027	114.3785	13.7077	5.164	110.9758	105.8118	GS B 3	95.3
8.313	3.4181	109.824	17.2636	8.9506	106.4059	97.4553	GS B 4	91.6
8.5213	3.4547	109.9335	14.2356	5.7143	106.4788	100.7645	GS B 5	94.6
8.8056	3.4834	102.8649	16.4863	7.6807	99.3815	91.7008	GS B 6	92.3
8.3298	3.347	112.8518	16.1338	7.804	109.5048	101.7008	GS B 7	92.9
8.3333	3.4407	103.4129	14.6856	6.3523	99.9722	93.6199	GS C 1	93.6
8.4077	3.4481	86.3706	13.1547	4.747	82.9225	78.1755	GS C 2	94.3
8.5274	3.4017	106.2454	19.3339	10.8065	102.8437	92.0372	GS C 3	89.5
8.8081	3.4032	67.2974	11.0722	2.2641	63.8942	61.6301	GS C 4	96.5
9.0944	3.4027	101.8909	13.0514	3.957	98.4882	94.5312	GS C 5	96.0
8.6695	3.379	82.5295	17.1964	8.5269	79.1505	70.6236	GS C 6	89.2
8.9196	3.4127	90.3577	17.6734	8.7538	86.945	78.1912	GS C 7	89.9
8.8804	3.3936	105.6498	20.7826	11.9022	102.2562	90.354	PS A 1	88.4
8.7023	3.3833	87.547	19.9139	11.2116	84.1637	72.9521	PS A 2	86.7
8.7646	8.4199	102.2474	16.2068	7.4422	93.8275	86.3853	PS A 3	92.1
7.1017	8.4641	77.4844	20.6208	13.5191	69.0203	55.5012	PS A 4	80.4
8.5663	8.2745	119.9304	12.6229	4.0566	111.6559	107.5993	PS A 5	96.4
8.5981	8.223	66.9067	14.4403	5.8422	58.6837	52.8415	PS A 6	90.0
8.0315	8.3748	117.6337	28.5767	20.5452	109.2589	88.7137	PS A 7	81.2
8.8154	8.4398	88.3491	14.6653	5.8499	79.9093	74.0594	PS B 1	92.7
8.544	8.252	89.8242	15.5899	7.0459	81.5722	74.5263	PS B 2	91.4
8.397	8.3904	101.3183	13.4379	5.0409	92.9279	87.887	PS B 3	94.6
8.4068	8.3618	89.7349	14.2948	5.888	81.3731	75.4851	PS B 4	92.8
6.9791	8.4458	97.3052	12.7554	5.7763	88.8594	83.0831	PS B 5	93.5
6.9388	8.3627	76.5682	20.0653	13.1265	68.2055	55.079	PS B 6	80.8
8.6346	8.3861	111.2049	14.7532	6.1186	102.8188	96.7002	PS B 7	94.0
7.1308	8.3552	118.8221	15.6645	8.5337	110.4669	101.9332	PS C 1	92.3
7.181	8.4449	93.2634	12.9726	5.7916	84.8185	79.0269	PS C 2	93.2

2.2432	8.3507	100.4771	13.7445	11.5013	92.1264	80.6251	PS C 3	87.5
2.2876	8.29	102.2203	19.7468	17.4592	93.9303	76.4711	PS C 4	81.4
7.1372	8.2705	98.8075	22.1121	14.9749	90.537	75.5621	PS C 5	83.5
2.2573	8.2608	103.4528	13.6959	11.4386	95.192	83.7534	PS C 6	88.0
2.2386	8.2403	96.0784	17.3345	15.0959	87.8381	72.7422	PS C 7	82.8

Appendix H: Additional data on chemical indicators of degraded soil

Chemical Indicator		Treatments Comparison			Treatments compared (p value)			Mean (treatments)		
					A vs B	A vs C	B vs C	A	B	C
pH (KCl)	mg/kg	A vs B	A vs C	B vs C		*** P<0.001	*** P<0.001	5.97	6.111	5.248
P (Bray1)	mg/kg	A vs B	A vs C	B vs C			** P<0.01	77.857	135.428	1.428
K	mg/kg	A vs B	A vs C	B vs C		* P<0.05	*** P<0.001	675.571	1221.714	78.428
Na	mg/kg	A vs B	A vs C	B vs C	* P<0.05	*** P<0.001	*** P<0.001	249.428	381.428	73.714
Ca	mg/kg	A vs B	A vs C	B vs C				2715.857	2599.857	1897.142
Mg	mg/kg	A vs B	A vs C	B vs C				1661.285	1516.285	1350.142
B	mg/kg						* P<0.05	0.155	0.172	0.038
S AmAc	mg/kg						** P<0.01	39.29	65.81	11.532857
K	%	A vs B	A vs C	B vs C			*** P<0.001	6.18	10.54	1.107
Na (%)	%	A vs B	A vs C	B vs C		* P<0.05	*** P<0.001	3.698	5.567	1.625
Ca:Mg	1.5-4.5							1.048	1.085	0.89
(Ca+Mg)/K	10.0-20.0							27.288	9.722	260.645
Mg:K	3.0-4.0							14.348	4.941	146.672
S-Value	cmol(+)/kg						* P<0.05	30.008	30.214	21.075
Na:K	cmol(+)/kg							0.978	0.577	3.75
T	cmol(+)/kg						* P<0.05	30.008	30.214	21.075
Bulk Density	g/cm3							0.924	0.922	0.924
Fe			HCl mg/kg			*** P<0.001	*** P<0.001	14.904	13.617	4.804
Mn			HCl mg/kg			* P<0.05	*** P<0.001	27.261	37.87	7.395
Cu			HCl mg/kg				* P<0.05	2.741	2.548	5.33
Zn			HCl mg/kg				*** P<0.001	15.667	24.635	2.557
Clay	%							38.714	37.142	40.714
Silt	%					* P<0.05		16.142	17	22.857
Sand	%							45.142	45.857	36.428

Legend: A=2,5m^3 compost treatment applied as mulch

B=5m^3 compost treatment applied as mulch
C=Control
*=Significant
**=very Significant
***=Extremely Significant

Appendix I: Additional data on chemical indicators of healthy soil

Chemical Indicator		Treatments Comparison			Treatments compared (p value)			Mean (treatments)		
					A vs B	A vs C	B vs C	A	B	C
pH (KCl)	mg/kg	A vs B	A vs C	B vs C				6.408	6.584	6.227
P (Bray1)	mg/kg	A vs B	A vs C	B vs C		* P<0.05	*** P<0.001	157.857	254.857	28.714
K	mg/kg	A vs B	A vs C	B vs C		*** P<0.001	*** P<0.001	1479	1698.714	498
Na	mg/kg	A vs B	A vs C	B vs C			** P<0.01	170	216.142	65
Ca	mg/kg	A vs B	A vs C	B vs C	* P<0.05	*** P<0.001		3507.286	2381.143	1754.285
Mg	mg/kg	A vs B	A vs C	B vs C				439.285	531.857	293.285
B	mg/kg					*** P<0.001	*** P<0.001	0.301	0.318	0.074
S AmAc	mg/kg						* P<0.05	25.047	51.627	8.868
K	%	A vs B	A vs C	B vs C			*** P<0.001	15.225	20.032	10.191
Na	%	A vs B	A vs C	B vs C			* P<0.05	2.968	4.265	2.12
Ca:Mg	1.5-4.5				*** P<0.001			4.994	2.752	3.735
(Ca+Mg)/K	10.0-20.0							5.888	3.868	8.895
Mg:K	3.0-4.0							0.971	1.045	1.931
S-Value	cmol(+)/kg					*** P<0.001	* P<0.05	25.66	21.55	12.731
Na:K	cmol(+)/kg							0.194	0.208	0.227
T	cmol(+)/kg					*** P<0.001	* P<0.05	25.66	21.55	12.731
Bulk Density	g/cm3							1.008	1.004	1.024
Fe	HCl mg/kg				*** P<0.001		** P<0.01	4.788	11.87	6.234
Mn	HCl mg/kg						** P<0.01	36.888	51.058	25.74
Cu	HCl mg/kg						** P<0.01	2.347	2.092	8.744
Zn	HCl mg/kg				** P<0.01	* P<0.05	*** P<0.001	25.014	45.77	10.327
Clay	%							40.142	39.142	43.571
Silt	%							13.857	11	13.857
Sand	%							46	49.857	42.571

Appendix J: Guideline/norms for ideal nutrient element concentrations in soil

Table 5.26.1. Leaf analysis norms

Element	Norm
N	1.2 - 1.6%
P	0.08 - 0.10%
K	0.6 - 0.7%
S	0.18 - 0.25%
Ca	0.6 - 0.9%
Mg	0.08 - 0.10%
Na	< 0.02
Cl	0.03 - 0.05
Cu	5 - 10 mg kg^{-1}
Zn	15 - 50 mg kg^{-1}
Mn	100 - 1000 mg kg^{-1}
Fe	40 - 200 mg kg^{-1}
B	40 - 75 mg kg^{-1}

Source: SAMAC

Table 5.27.2. Soil analysis norms

Element	Method of extraction	Ideal level
pH	1:5 soil:water	At least 5.5
Organic carbon	Walkley-Black	4%
Nitrate nitrogen	1:5 water extraction	25 mg kg^{-1}
Sulphate sulphur	Phosphate extraction	20 mg kg^{-1}
Phosphorus	Bray 1	30 mg kg^{-1}
Potassium	Exchangeable	260 mg kg^{-1}
Calcium	Exchangeable	1 500 mg kg^{-1}
Magnesium	Exchangeable	210 mg kg^{-1}
Sodium	Exchangeable	< 5% of exchangeable cations on $cmol_c$ kg^{-1} basis
Acid saturation	Exchangeable	< 10%
Calcium as % of CEC		65 - 70
Magnesium as % of CEC		20 - 25
Potassium as % of CEC		6 - 10

Source: SAMAC (amended)

Fertilizer Handbook 292