Response of macadamia nut yield, quality, and soil health to the application of different rates of macadamia husk compost in a subtropical climatic zone of Vhembe District, South Africa

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DECLARATION

I, Silence Fhulufhelo Maemu, declare that this proposal has been prepared solely by myself and that it has not been submitted, in whole or in part, to any other university for a degree. Except where stated otherwise by reference or acknowledgment, the work presented is entirely my own.

Signed (Student):  **Date**: 25 -February-2025

Ms S.F Maemu

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DEDICATION

I dedicate this dissertation to Yahweh; the Great I am who made all this possible through his grace and mercy. To my parents, siblings, my great-grandmother Mrs. S.M. Mitileni and my grandmother Mrs. E.M. Mitileni for their unwavering faith in God that sustains me.

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ABSTRACT

Macadamia farmers are currently using macadamia husk compost as a supplement to chemical fertilizers in their respective orchards. Regardless of the good results from the application of macadamia husk compost, there is no consensus on the recommended amount of macadamia husk compost to apply in order to improve the fertility status of the soil as well as to increase crop yield and quality. A three-year study to investigate the value of using compost made from macadamia husks on macadamia trees was initiated in April 2020, on a sandy loam soil classified as Rhodic ferralsols . A Completely Randomized Block Design (CRBD) with four replications was used in this study. The aim of this study was to establish an application guideline that specifies the rates of macadamia husk compost application. However, the applied rates must be able to improve the fertility status of the soil and at the same time not compromise the yield and quality of macadamia nuts. Macadamia husk compost was mixed with pine bark and wood chips at the ratio of 30:35:35, respectively, and applied in August 2020, 2021 and 2022 after each harvest. Twelve months after macadamia husk compost application at the rate of 0 (control) t ha^{-1}, 4 t ha^{-1}, 8 t ha^{-1} and 12 t ha^{-1} of data on macadamia nut yield, nut quality, soil properties, and leaf nutrient concentration parameters were collected. The compost application process was repeated again after 24 months (2022). Collected data was subjected to a statistical analysis using GenStat® version 17 (VSN International, UK).

The soil pH values of the compost treated soils were significantly *($p<0.05$)* higher than those of the control and increased with increasing rate of compost application. The maximum pH value of 6.47 was observed after applying 12 t ha^{-1} of compost. This result could be attributed to a high number of exchangeable cations present in the compost. However, the pH values observed in this study were within the acceptable range for the growth and production of macadamia trees. Application of compost significantly increased *($p<0.05$)* the levels of Microbial carbon (MB-C), Microbial Nitrogen (MB-N), Soil Organic carbon (SOC) and Particulate Organic Matter (POM) contents in the study site. Applying 12 t ha^{-1} of macadamia husk compost to the soil at the study site increased SOC, POM, MB-C and MB-N contents by 149 %, 190 %, 319 % and 50 %, respectively This increment in soil biological properties emphasises the importance of adding compost to the soil with the aim of increasing the levels of organic matter content which is considered as the reservoir for plant nutrient. Exchangeable cations Potasium

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(K), Calcium (Ca) and Magnesium (Mg) significantly *(p<0.05)* increased with the compost applications of 8 t ha^{-1} and 12 t ha^{-1} compared to when no compost was applied. These increases can be attributed to a direct contribution of these nutrients from the compost itself and/or the increased cation exchange capacity of the soil as a result of compost addition. The incremental application of compost increased the available phosphorus content in the soil. The maximum values (16.93 and 13.22 mg kg^{-1}) of available phosphorus content were recorded with the application of 8 t ha^{-1}nd 12 t ha^{-1} of compost, respectively. However, the concentration of available phosphorus in the soil was below 30 mg kg^{-1} which is the recommended soil norm for macadamia production in South Africa for all soil types.

The results of this study found that the control treatment had the maximum bulk density value (1.34 g cm^{-3}). Soil amended with 8 t ha^{-1} and 12 t ha^{-1} of compost had the least bulk density values (1.28 and 1.29 g cm^{-3}, respectively). Soil bulk density tends to decrease with an increase in the quantity of compost application and is an indicative of an increase in soil pore space where water is moved through the soil more efficiently by large pores than by smaller ones. Macadamia husk compost application rates showed no *(p>0.05)* significant difference on the soil agregate stability of the different treatments. On the other hand, macadamia husk compost applied at different rates at the study site was more effective at increasing the infiltration rate of water in the soil. This could be associated with the fact that compost act as a surface mulch thus reducing evaporation. Mulching or covering the soil surface with a layer of plant residue is an effective method of conserving water, because it reduces surface runoff and increases infiltration of water into the soil.

The infiltration rate was higher for 12 t ha^{-1} compared to 0 t ha^{-1}, in a minute there was already an infiltration rate of 41.57 mm h^{-1} whereas for the control (0 t ha^{-1}) it was 17.71 mm h^{-1}. There was also a significant *(p<0.05)* effect on the water holding capacity related with an increase in the application rates of the compost with the least percentage at 0 t ha^{-1} (1.33%) and the maximum at 12 t $ha^{-1}$was (2.2%).

There was a significant *(p<0.05)* effect of treatments on the concentration of K and Mg in the leaves of macadamia trees. The maximum (0.66%) and minimum (0.58%) leaf K were observed on trees amended with 12 t ha^{-1} and control, respectively. Application of compost did not have significant effect on the concentration of Nitrogen (N), Phosphorus (P), Calcium (Ca), Cupper (Cu), Manganese (Mn), Iron) Fe and Boron (B) in the leaves of macadamia trees except for Zinc (Zn). The concentration of nutrient elements (N, P,

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Zn, Cu, and B) in the leaves of macadamia trees under investigation was considered low but not deficient when compared with recommended standard leaf norm, whereas Potasium (K), Calcium, Magnesium (Mg), Mn and Fe were sufficient for the growth and production of macadamia trees.

The results of this study have proved beyond reasonable doubt that the application of compost made from macadamia husks can increase yield and quality of nuts, and improve the fertility status (physical, chemical and biological properties) of the soil. In the light of the above, it was recommended that South African Macadamia Assocication Council (SAMAC) through its structures must encourage all macadamia farmers to start using compost made from macadamia husks as a supplement to inorganic fertilizers. In this study, application of 12 t ha^{-1} was the most appropriate rate of application. However, for meaningful recommendation for a wide range of macadamia growers, further studies need to be conducted over a long period of time in different macadamia growing locations covering different soil types.

Keywords: Compost, husks, quality, macadamia, soil health

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CHAPTER 1

1. INTRODUCTION

1.1. Background of study

Macadamia production in South Africa has substantially expanded because of a sharp increase in the number of new trees planted each year. This trend is expected to continue (SAMAC, 2020), with an estimated 6300 hectares of macadamia trees expected to be planted annually until 2030. According to recent information, over 44,775 hectares of macadamia in South Africa have been planted (SAMAC, 2020). Vhembe district is one of the few areas in Limpopo Province that contributes enormously to macadamia nut production in South Africa. The more hectares of land used for macadamia production the more the use of heavy chemical fertilizers to meet the rising demand for food. Even though it plays a crucial part in improving agricultural productivity, the growing usage of chemical fertilizers is becoming a major issue for the environment and farmers. The inappropriate application of chemical fertilizers can result in the leaching of chemicals to water streams and the emissions of harmful gases into the atmosphere (Rop *et al*., 2018, 2023). To overcome these problems, the application of compost can be seen as an alternative option to supplement chemical fertilizer while at the same time catering for the environment. Compost applications can improve soil quality and productivity by replenishing organic matter and supplying plants with necessary nutrient elements. Many macadamia growers are now using compost made from macadamia husks in addition to chemical fertilizers, to increase agricultural production and soil fertility (Galanti *et al*.,2019).

The quantity of macadamia husks produced yearly is partially equivalent to the nuts that are produced annually (SAMAC, 2018). In Vhembe district, an estimate of about 20,000 tons of macadamia husk is being produced annually. The yield of macadamia husk is dependent on the yield of macadamia nuts that are produced. Some producers apply raw macadamia husk as a mulch underneath their trees, meanwhile others use the husks to make compost. However, some individuals dispose of the husks as waste in landfills, while others feed their animals with them.

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A husk is the outer coat of the nut-in-shell and usually builds up in stockpiles after the nuts have been de-husked on the farm. Just like any other part of the tree, macadamia husks contain lots of nutrient elements that are found within them. These nutrient elements are transported into the soil and become readily available for plant uptake when husks are subjected to decomposition and consequent mineralization (Marschner, 2011). Composting is one of the quickest ways to unlock these nutrients so that they can be available for plant uptake. Macadamia husk compost compared to chemical fertilizer is not only environmentally friendly, but it is also economically viable for farm use.

Many people believe that applying compost to agricultural fields can improve the chemical, biological, and physical properties of most soils, especially those with poor structure and negligible amounts of organic matter. (Murphy, 2015; Mehta *et al*., 2014). Brown (2015) indicated that compost made from macadamia husks are cheaper and readily available than chemical fertilizers. In agricultural systems, not enough research has been conducted on how macadamia husk compost has an influence on crop yield and soil quality. Many research studies are more focused on the effect that macadamia husk compost has on soil properties (Galanti *et al*, 2013; Van Zwieten *et al*., 2003; Steyn *et al*., 2019).

The benefits of applying macadamia husk compost to improve soil health parameters and crop yields are not a lot. Sources other than macadamia husk compost purely based on studies done on other compost are being used by farmers as a guideline to apply macadamia husk compost. A research study on the effect of macadamia husk compost rate, compost application method, and depth of incorporation is important to improve the understanding of how this organic fertilizer impacts the quality of soils and crop yield. Therefore, the aim of this study was to determine a suitable amount or rate of macadamia husk compost to be used by farmers to improve both macadamia production and soil quality indices.

1.2. Problem statement

The number of macadamia farmers and the land covered by macadamia orchards is increasing at an alarming rate, as is the macadamia industry. This is somewhat because of the high market prices of macadamia nuts globally. Many farmers apply chemical fertilizers as they see it as the quickest way of supplying nutrients to macadamia trees to increase yields. However, the ever-increasing price of chemical fertilizers and their negative influence on the environment is compelling farmers to think otherwise. Farmers

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are currently using compost from macadamia husk as an alternative to chemical fertilizers. Unlike chemical fertilizers, compost from macadamia husk is cheap and accessible, especially to the smallholder farmers. Several studies have reported many advantages of using compost (Cox *et al*., 2004; Lovieno *et al*., 2009; Liu *et al*., 2007). However, apart from these advantages of using compost, there is truly little information regarding the use of compost made from macadamia husk and the literature regarding this is very sketchy. There is very slight information regarding the effect of macadamia husk compost on the properties of the soil. Furthermore, there are no standard nor guidelines which guide farmers on how much macadamia husk compost to apply. Farmers apply compost based on its availability without knowing its implication on soil properties, yield, and quality of the nuts. Farmer's insights regarding the utilization of compost made from macadamia husks as soil conditioners need to be evaluated and confirmed for the benefit of the farmers themselves as well as the environment.

1.3. Justification of the study

At present, there are few studies that have been conducted on the effect of different application rates of macadamia husk compost on soil health parameters, yield, and quality of macadamia nuts in South Africa (Maselesele *et al*., 2020, 2022). South Africa is currently the world leader in the production of macadamia with 59,050 tons of macadamia in shell produced in 2020 followed by Australia (SAMAC, 2020). After de-husking, thousands of tons of macadamia husks are dumped into the landfills as part of waste management. Anecdotal information has indicated that about 80,000 tons of macadamia husks are produced every year in South Africa and only 20% of these are used as animal feed and fuel for cooking. Macadamia husk can be subjected to composting to make compost that can be used by the farmers to improve the fertility status of the soil which is declining due to several reasons. Several studies have pinpointed the effects of compost made from various organic materials on soil properties as well as on the yield and quality of crops (Stratton *et al*., 1995; Strauss, 2003; Zhang *et al*., 2006; Zhen *et al*., 2014). However, there is little work done to establish the effect of compost made from macadamia husk on soil properties and crop yield. The results of this study will contribute towards the development of guidelines. which will inform farmers on how much compost is made from macadamia to apply. The results obtained in this study will benefit macadamia farmers not only in Vhembe district but the entire world as well as the researchers working in the field of macadamia and other related crops.

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1.4. Aim and objectives.

1.4.1. Aim of the study

The main aim of this study was to investigate the response of macadamia nut yield, quality, and soil health parameters to different application rates of macadamia husk compost mixed with pine bark and wood chips under the subtropical climatic conditions of Vhembe district of Limpopo Province, South Africa.

1.4.2. Objectives of the study

The study in question was initiated to achieve the following objectives:

To determine the effect of macadamia husk compost amendment or application on:

I. Physical properties of sandy clay loam soil (i.e., bulk density, soil aggregate stability, water infiltration and water holding capacity)

II. Chemical properties of sandy clay loam soil (i.e., pH, Ca, Mg, K, Al, P (Bray 1), OC and SOM)

III. Biological properties of sandy clay loam soil (i.e., microbial biomass carbon, microbial biomass nitrogen, microbial quotient, soil organic carbon and particulate organic matter)

IV. Leaf nutrient content of macadamia trees (i.e., N, P, K, Ca, Mg, Zn, Cu, Fe, Mn and B, and carbon content).

V. Yield and quality of macadamia nuts (i.e., immaturity, late insect damage, early insect damage, early germination, sound kernel, unusable kernel, commercial nuts, first grade nuts and total kernel).

1.5. Hypotheses of the study

The proposed study argued that:

I. Macadamia husk compost improves the physical properties of sandy clay loam soil.

II. Macadamia husk compost improves the chemical properties of sandy clay loam soil.

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III. Macadamia husk compost improves the biological properties of sandy clay loam soil.

IV. Application of macadamia husk compost increases the leaf nutrient concentration of macadamia trees.

V. Macadamia husk compost increases the yield and quality of macadamia nuts.

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CHAPTER 2

2. LITERATURE REVIEW

2.1. Introduction

The demand for macadamia nuts is remarkably high worldwide, but the supply cannot keep up with the demand. This is leading macadamia farmers to plant in a large scale in countries such as Brazil, Costa Rica, Mexico, Guatemala, Kenya, Israel, Zimbabwe, South Africa, Malawi, Australia and New Zealand (SAMAC, 2018). With many entries into the macadamia industry, sustaining and maintaining soil health might be a challenge as the aim of every producer would be to produce higher yields of outstanding quality. Therefore, using macadamia husk compost as soil conditioner at the optimum application rates would boost macadamia production while preserving the qualities of healthy soil. On the other hand, little is known about how compost made from macadamia husks affects the quality, yield and characteristics of the soil.

This section (chapter) covers the literature review and focuses on research problems and macadamia nut production in South Africa. The chapter also focuses on the complexity of compost from how it is prepared, its benefits and effects on soil health parameters (i.e., physical, biological and chemical properties). The influence of compost on various crops will also be highlighted and discussed, while at the same time finding gaps and unresolved problems regarding compost application by farmers and researchers.

2.2. Origin and botanical characteristics of macadamia trees

Macadamia trees are native to New Caledonia, Indonesia, and subtropical eastern Australia (Hardner, 2009). Most of macadamia production is in Australia, South Africa, Kenya, and the United state of America (USA). However, according to SAMAC (2020), macadamia nuts were first brought in South Africa around 1960's, with the first macadamia tree still found in the Durban Botanical Garden. Since then, South Africa's macadamia production has increased steadily, and it is estimated that this growth will continue as more additional land is established (SAMAC, 2020).

According to Mast *et al*. (2004) and Kriel (2020), there are four species in the genus Macadamia, which belongs to the *Proteacea* family. They are Macadamia *integrifolia*,

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Macadamia *jansenii*, Macadamia *ternifolia*, and Macadamia *tetraphylla*. Only two of the macadamia species are commercially important for their nuts and grow best as productive plants. The two commercial species are *Macadamia Integrefolia* which produces nuts with a smooth shell, and *Macadamia Tetraphylla* which produces nuts that have a rough shell. Macadamia trees grow slowly and may take about 5-10 years to mature and produce throughout their lives (Wood *et al*., 2011).

The macadamia tree is an evergreen medium to large tree that can reach a height of up to 15 m tall and consist of leaves that are arranged in whorls (Rosenstein, 2021). A fully mature tree can produce tens of thousands of flower racemes annually. The pendulous racemes are 10 to 15 cm long and produce over 200 to 400 single creamy to white (*M. intergrifolia*) or pink flowers (*M. tetraphylla*). Less than 5% of buds produce nuts, and most of them do so in the first 5 to 6 weeks following pollination. Most nuts naturally fall off when they are 5 to 6 months old (Wikinson, 2005). It can take a few more months, depending on the cultivar, for all the ripe nuts to fall off. Botanically, each nut develops two ovules, or immature seeds, but typically only one will mature into a typical round nut in shell (NIS). The nut consists of the outer layer (husk), the woody shell (shell) and the edible part commonly known as the kernel (Hardner *et al*., 2009). In the middle of December, the development of the nuts increases in a linear manner and from there, the starch from the nuts is being converted into oil. The period of oil accumulation is critical since nut quality is dependent on the oil content. The phenological phases of macadamia tree is shown on Figure 2.1.

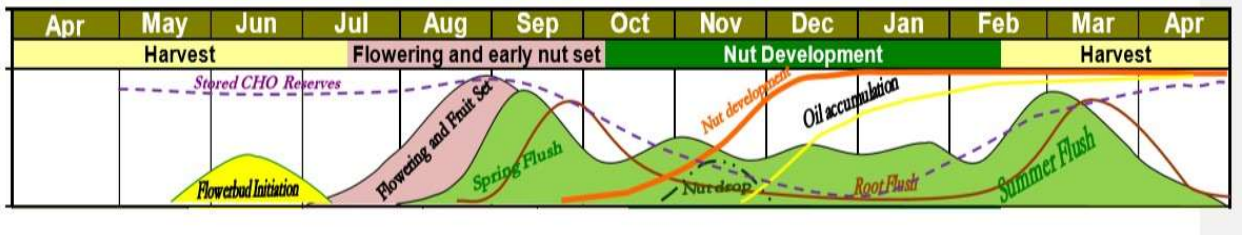


Figure 2.1: Macadamia phenological cycle in South Africa

Source: Mayo mac (2017)

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2.3. Production of macadamia in South Africa

Over the past two decades the production of macadamia nuts in South Africa has extremely increased. In the year 2020, there was almost 44 775 hectares of macadamia in South Africa and acreage is expected to continue to grow at approximately 6300 hectares per year until 2030 (SAMAC, 2020). In the year 2020 to 2021, the macadamia sector improved at a 16.5% annual rate, from 5351 hectares under production to over 6 235 hectares. From SAMAC (2022) statistics, an estimate was made that the industry would generate around 77891 Metric Tons of dry nut-in-shell in 2023, that is 13.1% higher when compared to the 68840 Metric Tons achieved in the year 2022. In 2020, SAMAC reported that there's approximately 700 macadamia producers located in the country, and this makes South Africa the world leader in macadamia production. Though, in the year 2020, the production of macadamia went down by 17.1 % (i.e., from 59050 tons to 48926 tons) (SAMAC, 2020). Although there are several factors contributing to this fall in macadamia production, the main one is the decrease in soil fertility brought on by different farm management practices. While the fertility of the soil on some macadamia farms is naturally low, the fertility of the soil on many other farms is declining at a high rate (Uys, 2018).

Application of chemical fertilizer has the capability of maximizing crop yield but cannot sustain soil fertility. Many farmers believe that applying compost as a supplement to chemical fertilizer is a viable solution to this issue (Parihar and Sharma, 2021; Ayilara *et al*., 2020; Manea *et al*., 2024). Application of compost increases crop productivity and quality by restoring soil organic matter, plants nutrients they need, and improves soil health and productivity (Brodie *et al*., 2000; Soheil *et al*., 2012).

In the year 2019 the macadamia industry in Southern Africa had established 5962 new hectares of macadamias trees (Figure 2.2.). Figure 2.2 shows that Kwa-Zulu Natal continues to be the province that planted the most hectares, followed by Mpumalanga and Limpopo provinces, respectively. In accordance with the new hectares of macadamias planted, KwaZulu-Natal planted 2348 new hectares in 2019 (SAMAC 2020).

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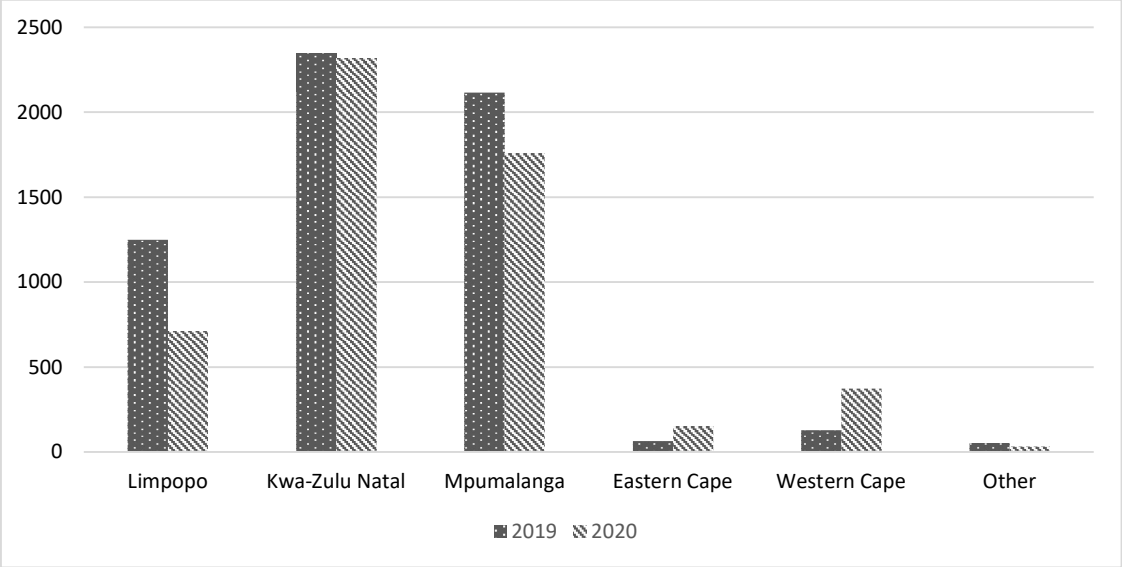


Figure 2.2: The area in hectares that was planted in macadamia producing regions for the year 2019 and 2020.

Source: SAMAC (2020)

2.4. Nutritional value of macadamia and its demand from the market

Macadamia nut is valued for its delicate flavor, crispy texture, and nourishing oil content. The nut can be consumed fresh, roasted, covered in chocolate in the confectionery industry or made into edible oil (Bittenbender *et al*.,1998). Macadamia nuts are rich in oils, vitamins, minerals, fibre, and they have a high oxidative stability, which makes them to be resistant to rancid odors, hence they are widely used in sun care formulation and heavy creams industry. According to Nguyen (2008), unsaturated fatty acids make up most of the macadamia kernels' high nutrient content (78.2%), carbohydrates (10%), potassium (0.37%), phosphorus (0.17%), and magnesium (0.12%). The nut is also recognized for its major health benefit of reducing low density lipoprotein (LDL) cholesterol in humans (Garg *et al*., 2003). Cavalleto (1983), reported that macadamia nuts are high in monounsaturated fatty acids (MUFA), mainly oleic (60%) and palmitoleic (20%) acids. The level of MUFA in nuts is higher compared to other food sources. High MUFA diets lower plasma LDL cholesterol levels and lower the probability of cardiovascular disease (CVD) (Kris-Etherton *et al*., 1999a; Garg, Blake, and Wills, 2003). The high proportion of unsaturated fatty acids and other bioactive components including tocopherols, phytosterols, and squalene may be liable

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for this cholesterol-lowering and coronary-protective effect (Kris-Etherton *et al*., 1999b).

The demand for South African nuts is high because the country produces nuts of exceptional quality that meet the criteria founded by the International Nut and Dried Fruit Council (SAMAC, 2020). Driving the demand for nuts is the fact that more people are eating less carbohydrates in favor of plant-based proteins and oils. South African nuts are exported to countries such as China (29%), Europe (9%), USA and Canada (38%) (SAMAC, 2020). As the macadamia industry is growing, the chances of soil fertility deteriorating are extremely high; however, this can be minimized by the application of compost instead of using chemical fertilizers. Statistics from the World bank (2003) state that soil degradation was reported to have affected 30% of the world's irrigated lands, 40% of rainfed agricultural lands and 70% of rangelands which resulted in a 0.4 loss of the average annual rate of global productivity. Injudicious use of nitrogen-based fertilizers and regular exclusion of organic matter from the base of trees can be damaging to the soil food chain and should be limited by compost amendment (Van Zwieten, 2003). Management practices that are focused on preserving and increasing the quantity of organic matter can improve soil health.

2.5. Soil requirements for macadamia trees

Soil is one of the most important natural resources on the planet and is made up of 45% minerals, 25% water, 25% air, and 5% organic matter (FAO, 2015). The soil is the utmost principal factor for plant development because all the nutrients for plants are taken from the soil thus, most living things on earth relies on soil as a direct or indirect food source. Information on soil requirements for macadamia is important to crack issues of sustainability on the farming of macadamia nuts in orchards.

Macadamia trees can be planted in a variety of soil types provided it is well drained and has no restricting layers in the top 1 m of soil (Steyn, 2019). However, the trees can also grow in less suitable soil and still produce a decent crop if managed properly. Soil characteristics that have an influence on the production of macadamia include drainage, clay content, texture, depth, and moisture content. One of the most critical elements in cultivating macadamia trees is soil drainage, which refers to the earth's inherent capacity to allow water to pass through. If the water recedes fast and the soil is well-drained, trees can withstand floods for several days (Taylor *et al*., 2021).

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However, poorly draining loamy soils are not suitable because the roots of the trees in unsaturated soils can die off due to poor ventilation. The best conditions for tree growth are found in deep, fertile, well-drained soil. According to (Williamson-Benavides & Dhingra, 2021), drainage is needed to promote healthy roots, growth, and the prevention of root rot diseases as well as to allow access for machinery used in agricultural operations and harvesting.

The clay content of the soil influences the soil's cation exchange and buffering capacities, which in turn controls macadamia production (Zuza *et al*., 2023; Yao *et al*., 2024). Aggelides and Londra (2000) compared the impact of three different compost application rates assimilated to a depth of 15 cm on hydraulic conductivity in a clay and a loam soil. They found that when compost rate is increased so is the hydraulic conductivity and the effect was more pronounced in the clayey soil compared to the loamy soil. Meanwhile soil texture affects other physical properties of soil such as drainage, seepage and water holding capacity (Araya *et al*., 2019). The effective soil depth can be affected at a point where there are limitations such as soil compaction or a water table (Graham *et al*., 1992; Nuttall *et al*., 2004; Lisson *et al*., 2007). Water-holding capacity (WHC) is reduced as particle size decreases because organic matter decomposes more slowly (Giardina and Ryan, 2000). This implies that organic matter is reduced as particle size decreases.

Soil which macadamia trees are planted on should have an effective depth of 1 m for effective growth and optimal production (DAFF, 2000). The tree needs to be self-anchoring, and the soil should have at least 0.5 m of good soil before it gets too gritty, macadamia feeder roots incline laterally, enabling the tree to thrive in shallower soil (Smith, 2017). Although macadamia has several characteristics that enable it to withstand drought, vegetative growth is suppressed, and then the yield and quality of the nuts are lowered by moisture stress. Moisture stress is more noticeable throughout the flowering stage, nut growth, and particularly during oil formation (see Figure 2.1), the moisture stress is more pronounced (Wilkinson, 2005). Rain (or irrigation where available) in February and March is important because it coincides with a peak of vegetative flush and is related with high yield formation (Stephenson, 2003; Carr, 2013).

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2.6. Climatic requirements for macadamias

Climatic conditions play a significant role in deciding and influencing the growth, development, yield, and quality of macadamia. Factors such as temperature, relative humidity, rainfall, irrigation, altitude, and wind must be examined for optimal growth of macadamia trees (Bringhenti *et al*., 2023; Zuza, 2023).

2.6.1. Temperature and humidity requirement

Macadamia trees require a hot subtropical climate with a temperature of 16 °C to 25 °C. This range of temperature is therefore most suitable for maximum net photosynthesis. However, in early May at night over temperatures of 11 °C to 15 °C in southeast Queensland of Australia, the flowering initiation of macadamia typically happen (Moncur *et al*., 1985: Huett, 2004). Frost has a negative effect on the flowers, which in turn reduces the fruit set. Temperatures that are extremely cold (<3 °C) thickens the nut shells (lowering cracking out percentage) (Walton, 2005). Areas that produce macadamia must be frost free, because even light frost may damage young macadamia trees while extreme hot temperatures of >30 °C slow down the photosynthesis process (Zuza, 2023). The maximum accumulation of dry matter in leaves occurs between 20 °C and 25 °C, with no growth at 10 °C or lower (Trochoulias and Lahav, 1983: Walne and Reddy, 2022). Low nighttime temperatures (12° to 14 °C) promote floral initiation and postpone raceme development whereas low daytime temperatures limit vegetative growth. On the other side, raceme growth and flower initiation are inhibited by high nighttime temperatures (>20 °C). Large yields are most likely to be produced while flowers are in bloom, which occurs on warm days and nights (O'Hare *et al*., 2004: Howlett *et al*., 2015).

A climatic factor such as humidity can highly affect the crack out and development of the macadamia nut in a positive way (Allan and de Jager, 1978). During the maturation phase, cool temperatures and intense humidity create an ideal environment for blossom blight disease infection. Continuous hot temperatures (above 30 °C to 35 °C) might cause leaves to be yellow and tend to stifle vegetative growth. This could affect production, especially in low-humidity and moisture-stressed regions. When compared to other major producing nations like Hawaii, a higher oil content of macadamia kernels can be ascribed to the quantity of heat units produced during the oil accumulation phase.

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2.6.2. Rainfall and irrigation requirements

Majority of the macadamia production areas in South Africa have an annual average rainfall of 800 mm and 1200 mm. The minimum amount of rainfall required for macadamia production is about 1000 mm, distributed as much as possible over the year. Schoeman (2011) found that additional irrigation water of 700 mm is needed for the best yield as the usual annual rainfall of 819 mm in the Nelspruit region of Mpumalanga province is insufficient for macadamia cultivation. Irregular droughts that occur in these areas have a devastating impact on yield and loss resulting in the production of smaller nuts with underdeveloped kernels.

Irrigation can help reduce the negative effects of drought on production, yield and quality. The main benefit of irrigation is that young trees can be brought to production sooner than in dryland conditions as their growth is rarely stunted by stress as irrigation can be done during dry periods (Morrison *et al.*, 2008: Criley, 2010). Water stress because of low rainfall or under irrigation during nut setting may result in premature nut drop which depress the yield. Water stress during the early nut drop period was associated with a high kernel recovery, which promoted splitting of the thinner shells (Stephenson *et al*. 2003: Weier *et al*.,2024).

Alleviation of stress by irrigation is most critical during the period of flowering through nut set and nut development to the end of oil formation (refer to Figure 2.1). However, the use of irrigation on macadamia orchards has been an issue of debate as there are also risks from irrigation. Too much water application, particularly in poorly drained soils may add to tree health problem such as ‘macadamia quick decline’ (Nishijima *et al*., 1997). Macadamia trees, for instance, have different water needs depending on the locale. However, irrigation has important advantages such as controlling and preventing soil erosion, improve soil structure and maintain a balanced moisture level, particularly during drought (Ahrens,1998; Anon, 2002, 2003). According to Stephenson *et al*. (2003), water should be administered to reduce significant stress during critical phases of nut development and maturity to maximise kernel recovery.

2.6.3. Altitude

Altitude is the distance above sea level, and it is a climatic condition that can cause physiological changes on plants (Krömer *et al.*, 2013). At higher altitude, the air pressure is low, and the growing period of macadamia plants is shortened by low

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temperatures. Light penetration is limited to plants at high altitude, and this reduces plant growth and reproduction compared to areas at low altitude (Mętrak *et al*.,2012). Macadamia trees react in a unique way to changes in altitude (Zuza *et al*., 2019). At altitude above 600 m, the quantity of grade 1 kernels as well as total nut production is reduced. At an altitude above 650 m, growth is slower, and trees take longer to come into bearing. The higher the altitude, the thicker the shell of the nut becomes. This affects the kernels: shell ratio and the kernel recovery percentage (crack out). At an altitude above 700 m, lower light intensity can result in no new growth occurring in vining which resembles copper deficiency symptoms. This can be resolved by planting cultivars that are suitable for a specific altitude between 300 m - 650 m (Kinnan, 2003).

Table 2.1 presents different macadamia cultivars and their suitable altitudes. The 294 (Purvis) is a Hawaiian cultivar and is not widely planted in South Africa as it requires lower elevations. The 741 (Mauka) cultivar is suitable for higher and cooler elevations. The nuts are of decent quality, however in some seasons in Australia they can show discoloration (Stephenson, undated). 695 (Beaumont) cultivar is a late season harvest, and it does not perform well within 100 m above sea level but is better in a cooler climate (tropical bytes, 2020). The 816 integrifolia cultivar performs well even at higher altitude.

Table 2.1: Effects of altitude on different macadamia cultivars

Cultivar	Altitude	References
294 (Purvis)	Up to 300 m above sea level	(de Villiers and Joubert 2000)
741 (Mauka)	600 m -650 m	(de Villiers and Joubert 2000)
695 (Beaumont)	Does not do well within 100 m above sea level	(Tropical bytes, 2020)
816 (Integrifolia)	Total kernel recovery remains consistent, even at higher altitudes	(Tropical bytes, 2020)

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2.6.4. Wind

Macadamia trees are vulnerable to wind damage, as strong and persistent wind slows the growth and development of young macadamia trees and their subsequent flower and nut set (Van Nierkek, 2019). Adequate protection can be achieved through strategically placed natural forest environments; however, windbreaks may be required in highly exposed regions. Once dense hedges are formed, trees tend to protect each other and there is less need for windbreaks.

On the other hand, it has been discovered that extremely tall, thick windbreak trees are ineffective because they tend to produce turbulent wind currents and vortices that may be more harmful than unprotected trees (Tompson *et al*., 2009). Early tree training, such as training to a central leader and removing branches with narrow crotch angles, could later assist in reducing wind. Intense winds that cause substantial branch losses cause the tree to fill the void with fresh vegetative growth (Teskey, 2012). This may upset the vegetative to reproductive balance and suppress yields until the balance is re-established. The wind's impact over agriculture is shown in the evaporation rates and plant transpiration. Additionally, wind is extremely important for pollination and for running wind turbines that draw water from wells. High winds have the potential to cause soil erosion and the falling of fruits and grains. Plants are mechanically affected by it, bending and swaying. Such pushing will change the morphology of trees in climates where winds are constant. (karuku *et al*.,2014).

2.7. Nutrient requirements for macadamia trees

Macadamia trees are considered not to be heavy feeders and therefore do not require enormous amounts of nutrient elements. Their fine lateral roots are effective in absorbing nutrients, especially phosphorus and calcium, even where there are low levels of these nutrients in the soil (Nortje, 2018). The phenological cycle of the tree (refer to Figure 2.1) is the primary determining factor for macadamia nutrient management. Poor soil fertility on the other hand is the ultimate cause of declining macadamia production especially under the smallholder farms in Africa. Farmers have identified lack of fertilizer and lack of manure as factors that contribute to low soil fertility. According to Du Preez *et al*. (2011), South African soils are low in organic matter content, however, it differs from area and climatic zone. Nutrients required by macadamia trees can be added into the soil through fertilization. Fertilizers can either be organic or in an inorganic form.

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Macadamias need low phosphorus (P) and calcium (Ca) levels, but high iron (Fe) levels. Fe deficiencies will result in sparser leaf cover and possible tree dieback (Nortje, 2021). It is therefore especially important to monitor soil fertility over time and nutrient elements be replenished as trees require them. A history of soil fertility and nutrient status in orchards should be built over time as this will enable the producer to have a good track record on their soils and they will ensure superior soil quality. Soil health is important for productive agriculture and may play a significant role in the long-term sustainability of macadamia orchards. Therefore, an inspection of the impact of farm management practices on the physical, chemical, and biological status of macadamia-growing soils should be highly commended (Gurjar *et al*., 2017).

2.7.1. Chemical (inorganic) fertilizer

Chemical fertilizer is defined as any inorganic compound of a distributed or manufactured material that is added to the soil to sustain plant growth (Berova *et al*., 2010). The three critical nutrients Nitrogen (N), P, and Potassium (K), which are required by crops, are equally abundant in chemical fertilizers. About 63 kg of (N), 3,5 kg of (P), 70 kg of (K), 17.5 kg of sulfur (S), 35 kg of (Ca), and 5.25 kg of magnesium (Mg) would be absorbed per hectare annually with a yield of 3,5 t of (NIS), the average viable crop per hectare. By offering the proper ratio of nutrients, chemical fertilizers can assist increase the yield and quality of macadamia nuts. Inorganic fertilizers not only increase crop yield by supplying additional nutrients to the soil for plant uptake, but they also have harmful effects on the physical, chemical, and biological characteristics of the soil (Zaman *et al*., 2019). Nevertheless, injudicious fertilizer usage to assure adequate yields can result in runoff, nutrient contamination, and the promotion of eutrophication and toxic algal blooms downstream (Heisler *et al*., 2008), while resulting in the decline of total yield production (Stephenson and Gallagher, 1989).

2.7.2. Organic fertilizer

Organic fertilizers on the other hand can be defined as substances derived from the remains or by-products of natural organism (Larramendy and Soloneski, 2019). Organic fertilizers rely much on microorganisms to break them down and release essential nutrients (i.e., nutrient cycling). Organic fertilizers have a slow-release capability, making them efficient fertilizers as the risk of over-fertilization is minimised, soil and underground water pollution is also minimized (Rop *et al*., 2018,2022,2023).

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In addition to supplying major plant nutrients, organic fertilizers also supply micronutrients to plants and their effect last longer than inorganic fertilizers (Gabrielle *et al*., 2004; Tu *et al*., 2006).

Farmers across the universe consider replacing inorganic fertilizers with locally produced organic sources to be a high priority, and sourcing local inputs is ranked third on their list of barriers to increasing local crop production (Ahmad *et al*., 2016; Radovich *et al*., 2009). Just like other trees, macadamias require large amount of organic matter. The incorporation of as much compost as possible (up to 10 tons per hectare) prior to planting is an added benefit, especially on sandy soils such as an increase in plant available water (PAW) and soil carbon (Kranz *et al*., 2020). The incorporation of macadamia husk compost is anticipated to be beneficial as it will enhance water infiltration and improve soil water retention. Nortje (2017) reported on the advantages of applying organic-based fertilizers on macadamia nut quality. The author found significantly more grade 1 kernel and a slightly higher yield compared to inorganic fertilizers. Organic matter or residues are vital for soil health and resilience that's the key these days (Du Preez *et al*., 2011)

2.8. Compost and its role in crop production

Compost is organic matter that has been decomposed to simplify the material into organic and inorganic compound in a process called composting (Embrandiri *et al*., 2013). Compost is derived from biological conversions of organic materials into a soil-like fertilizer. It is a *term that describes a managed process of organic matter decomposition (*Insam *et al*., 2002). Compost application to agricultural land has been recognized as a reliable way to improve the physical properties of most soils, especially soils with poor structure and low levels of organic matter (Bauduin *et al*., 1987; Stratton *et al*., 1995). Compost can also be beneficial to the land as a soil conditioner; a fertilizer; addition of vital humus or humic acid, and as a natural pesticide for soil. It also promotes nutrient cycling through increased microbial activity and contains fertilizer value for plant nutrition (Raviv,1998; Embrandiri *et al*., 2013). Another advantage of applying compost is that it contains some of the major nutrients, particularly N, P, and K (Karuku *et al*., 2014; Ajayi, 2014).

For improved productivity (high yields and quality) and sustainability in the agricultural fields, the use of compost is one of the key factors. In addition, compost can solve

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problems faced by farmers especially with decreasing fertility of soils (Adugna, 2016). It is well documented that organic fertilizers increase soil fertility and offer long-term nutrients by gradual decomposition (Angin *et al*., 2017; Gaiotti *et al*., 2017; Zhou *et al*., 2016). The slow nutrient release pattern of compost enhances the net primary productivity and reduces the need for constant application of fertilizer (Ryals and Silver, 2013).

The application of compost is beneficial to a land in the sense that it encourages the accumulation of microorganisms that are essential in breaking down organic matter for the formation of humus to improve soil fertility. Natural fertilizer (compost) mostly comes from animal and plant waste (Edwards and Haraya, 2011). The particle size of mature compost is near to a soil like texture and the ratio of carbon to nitrogen (C: N) decreases, pH near to neutral and the exchange capacity of the material increases (Mehta *et al*., 2014). The presence of beneficial microbes in compost increases the resistance of plants against stress and diseases (Mehta *et al*., 2014). Microorganisms such as bacteria, fungi, cyanobacteria, and lichens are said to be well-identified 'soil engineers' that actively participate in pedogenesis through commencing the process of biological weathering of rocks, decomposition of organic matter and nutrient cycling (Amir Khan *et al*., 2020). Considering the above, the utilization of compost made from macadamia husk by farmers can result in the alteration of soil properties and therefore increase the quantity and quality of macadamia nuts.

2.8.1. Composting

Composting is seen as a practical and sustainable way to reduce the amount of waste that ends up in landfills, and is environmentally friendly (Al-Rumaihi *et al*., 2020). Christians *et al.* (2016) defines composting as a natural process whereby microorganisms recycle the organic material. This process usually takes place in a controlled condition or environment (Tweib *et al*., 2011). Composting deals with modifying the soil in ways that make it more suitable for the intended use. Composting or modifying a soil may be aimed at some specific aspect of soil fertility such as supplementing the supply of one or more plant nutrients, or it may be aimed at changing the physio-chemical properties of the soil over time. Composting is a natural way to deal with waste by transforming it and using it for soil improvement and plant nutrients. It can be defined as the mineralization and partial humification of organic

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substances by the action of microbes, under ideal conditions (Mehta *et al*., 2012; Mehta *et al*., 2014). The composting process can be either aerobic or anaerobic.

2.8.1.1. Aerobic composting processes

The aerobic process is the decomposition of organic material in the presence of oxygen. In this process, microbes use oxygen to consume organic materials to build their cell protoplasm from nutrients (N, P, and some carbon) present in the compost's starting material. Since aerobic respiration produces energy, organic matter decomposes more quickly and thoroughly in environments with ready oxygen availability (Evans, 2001; Cadena *et al*., 2009). Organic matter breaks down more rapidly and completely in conditions where there's oxygen because aerobic respiration generates energy (Evans, 2001; Cadena *et al*., 2009). Due to sufficient oxygen levels, aerobic decomposition naturally does not produce an unpleasant smell.

Pile creation is the initial step in aerobic composting. The bacteria needed for composting occurs naturally. The temperature increases quickly during the first several days of composting, reaching 70 – 80°C. Mesophilic organisms proliferate quickly because there are plenty of accessible carbohydrates and amino acids. Pseudomonas, Bacillus, Flavobacterium, Clostridium, Alternaria, Cladosporium, Aspergillus, Mucor, Humicola, Penicillium, and Streptomyces are the most prevalent mesophilic bacteria (FAO, 2003). Owing to the availability of an abundant amount of food source, these microbes proliferate quickly.

Bacillus and Thermus, two thermophilic bacteria, as well as a few actinomycetes (Streptomyces, Micropolyspora, Thermoactinomyces, and Thermomonospora), are responsible for boosting the pile's temperature to 65 °C or more. This peak heating phase is crucial for the destruction of most pathogens and weed seeds that could infect the compost, as well as the soil and crops that come into contact (Bertoldi, 2010; Mehta *et al*., 2012). The curing step is the last stage of the active composting stage. At this stage, some bacteria, particularly fungi, begin to break down the components of plant cell walls such as cellulose and hemicellulose.

The problems with incomplete composting are associated with oxygen and nutrient deprivation, which can result in a shortage of nutrients in the soil. In addition, immature compost may cause the production of organic acids that may negatively impact plant growth on crops (Bernal *et al*., 2009; Mehta *et al*., 2014). The temperature finally drops

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to the surrounding air's temperature. Despite mesophilic microorganisms returning to the compost, mature compost piles become more homogenous and less active to the microbes. The amount of humus increases as the final decomposed material's colour transitions from deep brown to black. According to Mehta *et al*. (2014), mature compost has a texture that is like soil in terms of particle size, C: N ratio, pH, and exchange capacity (EC).

2.8.1.2. Anaerobic composting process

Composting without oxygen is known as anaerobic composting. It frequently occurs in the natural world. By using anaerobic microbes, it causes the breakdown of organic molecules. As it is with the aerobic process, anaerobic microbes also use nitrogen, phosphorus, and other nutrients to change their cell protoplasm. The primary distinction is on how organic and inorganic molecules in the compost pile decompose, such as how organic nitrogen breaks down into organic acids and ammonia. According to Jiang *et al*. (2011) and Cayuela *et al*., (2012), a large fraction of carbon is released as methane gas, whereas a smaller amount of carbon can be respired. Since the reduction of organic matter is a key component of anaerobic composting, the finished product may undergo some aerobic oxidation. This oxidation process has no effect on how the material is used because it only lasts for a brief time.

The anaerobic composting process involves four main stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. In the first stage, called hydrolysis, fermentative microbes convert complex organic matter, like cellulose, which is insoluble into soluble molecules like fatty acids, amino acids, and sugars. Given that it significantly affects raw materials with a high organic content, the hydrolytic activity is a rate-limiting factor (Vavilin *et al*., 2008). Acidogenesis, the second stage of anaerobic decomposition, involves more complicated molecular breakdown by acidogenic (fermentative) bacteria. Simple molecules produced in the acidogenesis phase are further broken down into acetic acid, carbon dioxide, and hydrogen in the subsequent phase of anaerobic digestion. Clostridium aceticum, Acetobacter woodii, and Clostridium termoautotrophicum are the main microorganisms in driving this phase. Methane is created by bacteria known as methane formers, such as methanosarcina, during the final phase of the process known as methanogenesis (Demirel and Scherer, 2008).

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Decent compost can be acknowledged by a pleasant smell, being moist and is not dry or powdery with a dark soil-like particles appearance where the inventive organic matter is not recognizable (Agnew, 2003). It is well documented that the application of compost at a required rate can enhance and restore the soil organic matter (SOM) and improve quality of degraded soils (Kranz *et al*., 2020).

2.9. Influence of compost on soil properties

The long-span capability of macadamia orchards may be influenced by soil quality, which is essential to profitable agriculture. An examination on the influence of compost on soil properties is very crucial since it can lead to an improved yield and quality of macadamia nuts. According to Bauduin *et al*. (1987) and Stratton *et al*. (1995), applying compost to agricultural areas is another option to improve the qualities of most soils, particularly those with weak structure and low quantities of organic matter. Compost can also be useful for the soil as a natural insecticide, fertilizer, soil conditioner, and adds humic acid. Furthermore, it contains fertilizer value for plant nutrition and boosts nutrient cycling through increased microbial activity (Raviv, 1998; Embrandiri *et al*., 2013). Another advantage of applying compost is that it promotes soil health (Maikhuri *et al*., 2011). Beneficial soil is the foundation for profitable, productive, and environmentally friendly agricultural systems (Kundhlande *et al*., 2004).

Application of compost to a field of agriculture has been recognized by many as a proper way to improve the characteristics of most soils. Most studies have concentrated on the results of compost (cattle manure compost, sewage slurry, chicken litter, leaf litter compost, and fruit waste compost) on soil properties in agricultural systems. However, there is extraordinarily little information available regarding the effect of compost made from macadamia husk.

2.9.1. Effect of compost on soil physical properties

Compost applications have been found to advance soil physical characteristics such as soil texture, soil porosity, bulk density, infiltration rate, water holding capacity and aggregate stability (Raviv, 1988; Kranz *et al*., 2020). Kranz *et al*. (2020) compared twenty-five peer-reviewed studies that assessed changes in soil physical properties (i.e., soil bulk density (BD), infiltration rate, and WHC) where compost was applied into the soil. The results indicated that the application of compost reduced BD, enhanced

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water infiltration, improved WHC, compared to the control treatments. The most important physical properties in the macadamia orchards include soil texture, drainage, soil density, WHC and (Smith, 2015; Maselesele *et al*., 2020).

2.9.1.1. Bulk density

According to Bouajila and Sanaa (2011), BD is the mass of dry soil per unit of bulk volume, including the air space. BD is affected by farm practices such as tillage, compost application and crop harvesting (Albiach *et al*., 2000; Crogger, 2005; Curtis and Claassen, 2009).

Compaction of the soil can be shown by the bulk density of the soil. When BD increases, extreme soil strength occurs especially in dry environments. Severe compaction can limit root growth (Albiach *et al*., 2000; Crogger, 2005). The expansion of plant roots, soil porosity, accessible water capacity, soil aeration, seed germination and soil microbial activity are all impacted by soil BD, which serves as a measure of soil compaction. Several variables, including soil texture and soil structure, affect soil BD and organic matter content. Several studies have found that applying compost into the soil will lower the BD, while processes that compact the soil will increase BD (Curtis and Claassen 2009; Bouajila and Sanaa, 2011). Babalola *et al*. (2012) studied the effect of three rates of compost (0, 10, 20 t ha-1) on selected soil physical properties. The results revealed that 2 years after compost application, BD significantly decreased by 4.8% for plots amended with 20 t ha-1. Curtis and Claassen (2009) applied about 540 Mg ha-1 of compost on four soils (lahar, decomposed granite, serpentinite, sandstone) with different parent materials. The BD of the four soils amended with compost were reduced by 19–21% compared to control.

Some researchers have observed that compost made from a mixture of different organic materials also do influence the soil BD (Curtis and Claassen, 2009; (Cannovo *et al*., 2012). A drastic reduction in bulk density was also observed by Aggelides and Londra (2000) after incorporating a mixed compost in both clay and loamy soil. The greatest reduction in bulk density was reported when compost was applied at the rate of 300 t ha-1 for both the loamy soil (19.7%) and the clayey soil (16.7%). Babalola *et al*. (2012) on the other hand reported a decrease in bulk density of 4.8% after applying compost at 20 t ha-1 in contrast to control. However, compared to neighbouring undeveloped sites, Van Zwieten *et al*. (2003) found a higher soil BD around the base

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of macadamia trees in a macadamia orchard. This could suggest that the health of the soil in macadamia orchards is not as good as it was in its natural state, and this could be due to human activity during farm operations like picking nuts during wet conditions. Reduction in soil bulk density reported by many authors was attributed to an increased organic matter which was found to increase the microporosity causing the BD of the soil to decrease (Karuku, 2011; Karuku *et al*., 2012).

2.9.1.2. Infiltration rate

The speed or velocity at which water penetrates the soil is known as the infiltration rate (IR) (Brouwer, 1990). The infiltration rate generally is a flux which depends on the hydraulic conductivity, but also on other variables and parameters such as the wetness of the soil, land use/ land cover, slope, and crust formation. Hydraulic conductivity is a property of the soil, whether it is the (highly varying) hydraulic conductivity in the unsaturated zone or the saturated hydraulic conductivity in the saturated zone (Booij,2007; Logsdon and Gray, 2002). Water movement in the vadose zone also is dependent on the hydraulic conductivity and linked to the infiltration rate, but not the same. The infiltration rate is the inflow into the soil, where the water movement in the vadose zone is the flow inside the soil.

Water is temporarily stored in the soil, where it is then made accessible for plant root uptake, plant growth, and soil microbial habitat. The single ring infiltrometer, double ring infiltrometer, Philip-Dunne permeameter, Guelph permeameter, and tension infiltrometer are just a few of the instruments that can measure infiltration rate (Asleson, 2007). Improved soil structure and enhanced aggregation from an increase in organic matter content will result in higher infiltration rates.

Crogger *et al*. (2008) investigated how compost affected water infiltration. Four years following compost application, the study's findings showed a significantly higher rate of water infiltration compared to the control. Likewise, Weindorf *et al*. (2006) showed that no matter how compost was applied, water infiltration rate increased in loamy soil. According to Mohammadshirazi *et al*. (2017), incorporating 5 cm of farmyard waste compost into a clay loamy soil (30 cm deep) resulted in a 396% increase in the rate of water infiltration. For farmyard waste composts, Logsdon *et al*. (2017) showed an increase in infiltration rates of 24 and 50%. Most of the research linked the enhanced infiltration rate to the soil's greater porosity and decreased BD of the soil with the

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addition of composted organic matter. Comparable results were reported on sandy soils by Tibor *et al*. (2016) who reported increased water infiltration, improved soil structure, reduced erosion, and reduced soil BD after applying 9, 18 and 27 Mg ha-1 of compost compared to control. These drastic changes in soil physical properties were attributed to an increase in soil organic matter from compost.

2.9.1. 3. Water holding capacity

The amount of water that a particular soil can store for crop use is known as the soil water holding capacity (Curell, 2011). More plant growth can be supported by soils that can store a lot of water, and these soils are also less prone to leaching of pesticides and nutrient losses. Soil WHC is controlled primarily by the soil texture and the SOM content. The application of compost is known to have a significant effect on the WHC of many soils which in turn provide water to plants over time (Crogger, 2005). Aggelides and Londra (2000) compared water retention with different rates of mixed source compost incorporated 15 cm deep into clay and loamy soil. An increase in water retention with higher compost rates in both the clay and loamy soils was found. Schmidt *et al*. (2017) investigated the effects of farmyard waste compost and tillage on compacted sandy loam soil. The addition of 1.52 cm^{-3} and 6.04 cm^{-3} of compost resulted in a 6% and 9% increase in water content, respectively. Compost plays a crucial role in the formation of soil aggregates which in turn plays a pivotal role in the WHC of the soil. Therefore, there is a positive association between organic matter from compost and the water holding capacity.

2.9.1.4. Aggregate stability

Aggregate stability (AS) measures how well soil aggregates hold up against external stresses such tillage, wind, and water erosion, and shrinking and swelling processes (Amezketa, 1999). Plant roots and microbial activity naturally create strong soil aggregates. However, tillage and other disturbances quickly disassemble soil aggregates. By breaking up soil aggregates, such as by ploughing, the soil pores can get clogged and hinder the flow of both air and water (Doran and Parkin, 1996). When acting as the cementing agent required for flocculating soil particles to form stable aggregates, soil organic matter provided by compost increases soil aggregate stability (Spaccini *et al*., 2004; Tejeda *et al*., 2006). Additionally, the development of soil micro-aggregates is eased by the production of mucilage by bacteria and fungi.

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Babalola *et al*. (2012) on the other hand studied the effect of three rates of compost (0, 10, 20 t ha -1) on selected soil aggregate stability. The results revealed that 2 years after compost application, aggregate stability and total porosity improved significantly by 15.7% and 2.9%, respectively. Annabi *et al*. (2011) related the effectiveness of repetitive application of municipal compost and manure on silty loam soil which had a low stability of soil aggregate. It was discovered that applying municipal organic waste typically had a greater favourable impact on aggregate stability than applying manure. The authors stated that such compost can be used to increase the soil´s resistance to water erosion.

Furthermore, several studies have reported the positive correlation between aggregate stability and soil microbial activities (Raviv, 1998; Cook *et al*., 1998; Buckerfield and Webster, 2000). The improvement of soil texture and aggregation by compost has been attributed to the contribution made by polysaccharides, humic acid, and other organic matter (Raviv, 1998; Cook *et al*., 1998; Buckerfield and Webster, 2000). In the light of the above, it is quite clear that the stability of the soil aggregates can be increased by incorporation of compost and other organic materials.

2.9.2. Effect of compost on soil chemical properties

The use of compost enhances the chemical properties of the soil by increasing the content of the nutrients, cation exchange capacity as well as the pH and EC (Gamal, 2009; Soheil *et al*., 2012) which are crucial for the growth of the crops.

2.9.2.1. Soil pH and EC

Soil pH is an indicator of soil acidity or soil alkalinity and is defined as the negative logarithm of hydrogen ions activity in a soil suspension (Okalebo, 1993). In addition to being used to calculate the amount of salt in soil, soil electrical conductivity is a numerical expression of a medium's innate capacity to transmit an electric current (Rhoades, 1999). It can be used to anticipate a variety of chemical activities in the soil. Measuring the pH of the soil is helpful since many plants and soil organisms prefer slightly acidic or alkaline conditions (Adugna, 2016). Additionally, pH has an impact on the soil's ability to hold onto nutrients. Through base-forming cations, compost application raises the pH of the soil, nutrient fixation and availability notably in acidic and slightly acidic soils (Erhart and Hartl, 2010; Leroy *et al*., 2007).

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Due to its abundance in alkaline cations like Ca, Mg, and K that are liberated from organic matter because of mineralization, compost has a liming effect (Agegnehu *et al*., 2014; Daniel and Bruno, 2012). Depending on the pH of compost in use, the addition of compost may raise or lower the pH status of the soil. If added in the correct amounts, a neutral to slightly alkaline compost will raise the pH of an acidic soil. Compost applications can also buffer or alleviate soil pH (Gamal, 2009; Soheil *et al*., 2012). This was also established by Kluge (2006) who noticed a significant increase in the pH value even at moderate compost applications. Cox *et al*. (2004) observed an increase of soil pH from 4.15 to 5.0 in the 0-2 cm soil layer after applying macadamia husk compost for the period of 18 months.

Ouédraogo *et al*. (2001) also reported an improvement in soil pH on plots treated with compost at rates between 0 and 10 t ha-1 compared to the control. Aggelides *et al*. (2000) studied the effect of municipal waste compost applied at the rate of 15, 30, 45 and 60 t ha-1 on corn forage crops. The application of compost significantly increased soil pH and EC compared to the control. The increased soil pH could be attributed to the reduction of exchangeable Al, through Al precipitation or chelation of organic colloids (Bulluck *et al*., 2002) while the reason for the increase in EC was attributed to the number of total salts in the compost. According to Iren *et al*. (2015), the application of compost made from cassava peels in Nigeria boosted EC in comparison to control treatment when applied at 4 t ha-1 and 8 t ha-1. The outcome also showed that the EC at 8 t ha-1 was greater than the EC at 4 t ha-1. According to Sarwar *et al*. (2008), EC increased when rice and wheat were treated with compost at the rates of 12 and 24t ha-1. EC increased after the application of municipal solid trash, according to Civeira (2010). Exchangeable calcium and potassium minerals can be dissolved by organic acids, compost increases base saturation. This can be due to EC rising when the soil was supplemented with organic matter, such as manure or compost. The electrolytic process of EC mostly occurs through pores that are filled with water. The soil's capacity to carry electrical currents increases with its porosity.

2.9.2.2. Soil nutrient elements

Important nutrients including N, P, K, Mg, Ca, and S that are easily absorbed by plants can be found in significant concentrations in compost (Agegnehu *et al*., 2014; Ferras *et al*., 2006; Madeleine *et al*., 2005). Although often seen as a reliable source of N, P, and K, compost also has important micronutrients such as Mn, Zn, Cu, B, and Fe

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which are essential for macadamia tree growth. Since compost has relatively stable sources of organic matter, these nutrients are supplied in a slow-release form. Compost, on the other hand, is typically applied at considerably higher rates; as a result, it can have a substantial cumulative impact on nutrient availability. According to Soheil *et al*. (2012), municipal waste compost (MWC) impacts on soil chemical characteristics and corn plants were established. The authors found that applying waste compost increased concentrations of accessible N, P, K and micronutrients (Pb, Cu, Cd, Ni, Mn, Zn and Fe), but particularly for the 60 t ha^{-1} treatment. The findings showed that soil micronutrient (Pb, Cu, Cd, Ni, Mn, Zn and Fe) concentration and content of N, P, and K rose as compost concentration increased. Gamal (2009) investigated compost's influence on soil characteristics. The rates of compost application were 0 t ha^{-1}, 5 t ha^{-1}, and 10 t ha^{-1}. In all plots that received compost, the author found an increase in the N, P, and K content; however, the rise was noticeably higher in plots receiving 10 t ha^{-1} of compost. On the other hand, after applying household waste compost at rates of 40 and 120 t ha^{-1}, Bouajila and Sanaa (2011) found a considerable increase in organic nitrogen. There is ample evidence that the application of compost indeed increases the concentration of nutrients in the soil. Comparable results can be attained after the application of macadamia husk compost. Studies, including that by Rutunga *et al*. (2008), highlight the positive effects of organic amendments like compost in boosting soil properties such as cation exchange capacity, microbial activity, and moisture retention.

2.9.2.3. Cation exchange capacity

Another important chemical property that can be influenced through using compost is the soil cation exchange capacity (CEC), which is an important indicator of soil fertility. CEC is a measure of the soil's capacity to hold positively charged ions (Brady *et al*., 2008). It is an important soil property that affects soil structural stability, nutrient availability, soil pH and the soil's response to fertilizers and other ameliorants (Hazleton and Murphy, 2007). The soil CEC plays a crucial role in the retention of nutrients and leaching of cations into groundwater. The type and quantity of organic and mineral material found in the soil has a significant impact on the CEC. The application of compost improves crop nutrient uptake while minimizing leaching-related nutrient loss. Because of this, soil fertility is frequently related to the amount of organic matter in the soil. The CEC is higher in soils with significant levels of clay and

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organic matter than in sandy, low-organic matter soils. The retention of plant nutrients in the roots section can be improved by increasing CEC, especially on sandy soils.

Low CEC soils are more prone to cation shortages in the form of potassium (K+), magnesium (Mg2+), and other cations, whereas high CEC soils are less prone to cation leaching (CUCE, 2007). Agegnehu *et al*. (2014), Gamal (2009), and Mohammad *et al*. (2004) discovered that adding compost to soil increased CEC because stabilized organic matter, which is rich in functional groups, was introduced into the soil.

2.9.3. Effect of compost on soil biological properties

Soil biological properties have had an immense role in agricultural crop production since the dawn of agriculture. Soil biological activity is a parameter that can be used to measure the functioning capacity, or quality or health of the soil. It is assumed that because soil contains living organisms, its biotic component is one of the most crucial factors in defining the health of a soil (FAO, 2020). Determination of soil biological property is crucial as its importance stems from the fact that soil microorganisms are significant in crop nutrient cycling and nutrient accessibility for crop uptake and decomposition of soil organic matter (Swami, 2019).

Soil biological properties include parameters such as microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), microbial biomass phosphorus (MBP), particulate organic matter (POM), microbial count, enzyme activity and soil basal respirations. Compost influences soil biological properties since they are the source of organic carbon and nutrients utilized by microbial biomass. In these processes, it is assumed that the higher the diversity and abundance of organisms, as well as the pace of decomposition of soil organic matter, the better the soil quality. Compost is a biological product which contains a wide range of microorganisms that are beneficial to plants and the environment. Furthermore, application of compost enhances total microbial, fungal, and bacterial biomass in soil (Annabi *et al*., 2007) which are responsible in the formation and cycling of nutrient elements.

2.9.3.1. Soil microbial biomass

Soil microbial biomass (MB) is defined as the small (0 - 4 %) living component of soil organic matter excluding macro-fauna and plant roots (Dalal, 1998) and it consists mostly of bacteria and fungi, which decompose crop residues and organic matter in

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soil to release carbon dioxide and plant available nutrients (Insam and de Bertoldi, 2007). About half the microbial biomass is situated in the top 10 cm layer of a soil profile (Jenkinson and Ladd, 1981).

Babalola *et al*. (2012) studied the effect of three rates of compost (0, 10, 20 t ha-1) on selected biological properties. The results revealed that total microbial and fungal count were significantly higher after compost amendment than in control. Microbial biomass nitrogen, microbial biomass phosphorus and MBC significantly ($p<0.05$) increased in plots amended with 20 t ha-1 of compost than control. Addition of soil amendments supplies substrate/food that increases microbial population and diversity (Karuku and Mochege, 2016 & 2018; Karuku, 2018)

2.9.3.2. Soil Organic carbon

Soil organic carbon is a measurable component of organic matter. Only 2-10% of most soils' mass is made up of organic matter, but this small amount plays a big part in how well agricultural soils perform physically, chemically, and biologically. Improved soil aggregate and structural stability, together with soil porosity, are crucial for soil aeration and water infiltration (FAO, 2005). Organic matter improves these properties. Many people view soil organic carbon (SOC) as a significant measure of soil quality and agricultural sustainability. Due to its ability to influence plant growth as a source of energy and a catalyst for nutrient availability through mineralization, it is one of the most significant soil components. Organic carbon enters the soil through the decomposition of plant and animal residues, root exudates, living and dead microorganisms, and soil biota (Edwards *et al*., 1999). Bouajila and Sanaa (2011) evaluated the effect of composted manure and household wastes compost on soil organic carbon. Their results indicated that the application of 120 t ha-1 household waste compost and manure improved organic carbon (1.74 % and 1.09 %, respectively) when compared with control (0.69 %). Similarly, Bañados *et al*. (2012) used municipal waste compost and manure at the rate of 15 and 45 t ha^{-1}. The results showed that manure and compost application to the soil improved the amount of organic matter in plots by 4.8 % and 9.5 %, respectively, compared to the control.

2.9.3.3. Particulate organic matter

Particulate organic matter (POM) fraction refers to soil organic matter particles less than 2 mm and greater than 0.053 mm in size (Cambardella and Elliot, 1992). POM is

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part of the labile pool of soil organic matter. It provides nutrients for plant growth in addition to serving as a source of food and energy for soil animals and microbes. POM improves cation exchange capacity, pH buffering, soil aeration, aggregate stability, and water infiltration. Additionally, it binds environmental toxins such heavy metals and pesticides. Among other practices, the application of compost, manure, and other organic materials is known to enhance particulate organic matter (Cambardella and Elliot, 1992).

Fronning *et al*. (2008) evaluated the effect of compost and manure on POM. The authors observed an increase of 240 and 120 % of POM after ameliorating soil with compost and manure, respectively. However, the rate of SOC was decreased by 40% in control treatment with no organic amendment. Chemical fertilizer applications are thought to have negative effects on POM and SOC. Fortuna *et al*. (2003) examined the effect of compost and crop rotation on POM. The results of the study reflected that the capacities of POM in the soil were 45 % higher and SOC was 16 % greater where compost was applied than where chemical fertilizers were applied. Likewise, Zhen *et al*. (2014) observed that the application of manure significantly increased the number of cultivable microorganisms and microbial biomass, thus improving soil respiration and enzyme activities.

2.10. Effect of compost on plant growth and yield

Macadamia trees, just like any other trees, need to be fertilized to add nutrients needed to optimize yield. The use of compost has a beneficial effect not only on soil properties but also on the growth, development, and yield of plants (Babolola *et al*., 2012). Compared to inorganic fertilizers, compost application appears to be the best option for farmers looking to increase crop productivity because it provides a range of nutrients necessary for the best possible plant development (Timsina, 2018; Sayara *et al*., 2020) .In a recent study conducted in the Northeastern (NE) region of South Africa by Maselesele *et al*. (2022), it was discovered that macadamia husk compost performed better than inorganic fertilizer, The author found that Chinese cabbage's root biomass and length increased when macadamia husk was applied, most likely as a result of improved soil physical characteristics and increased nutritional content, which produced ideal circumstances for root growth and development. This indicates the enormous potential of employing macadamia husk compost as a soil amendment to improve soil fertility and soil health in this area.

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As shown with maize (Ali, 2011) and a variety of vegetables (Amlinger *et al*., 2007), better soil quality led to greater crop yields and quality. A study on crops conducted by Gamal (2009) found that increasing the rate at which compost was applied enhanced the quality of the corn crop. An increase in tomato plant fruit yield was also found by Maynard (1993), compared to plants where compost was not applied, the plants were grown in unamended soil.

2.10.1. Compost application methods

There are two common ways in which compost can be administered on the soil; namely, mulching and incorporation (Bastida *et al*., 2010; Cogger *et al*., 2008). Mulching is a method where compost is placed on the surface of the soil, while incorporation is the mixing of the soil with the compost. To increase soil's health capacity, and obtain the best benefits of compost application, applying compost as a mulch on soil allows it to resist rapid breakdown and allow good aeration (Agnew, 2003). A disadvantage of mulching as a traditional practice includes the difficulty of broadcasting compost uniformly throughout the field; the difficulty of infusing the compost into the soil; and the potential for the compost to wash away in sloping fields (IIRR, 1992). However, mulched compost can lessen weed growth, fertilizer leaching, and soil surface evaporation (Pinamonti, 1998; Biala, 2000; Campell and Sharma, 2003). Also surface mulch can be eaten by soil fauna such as termites thus reducing its effects (Karuku *et al*.,2014).

Most farmers do not highly favour incorporation of compost because it disturbs the soil structure. Compost inclusion can, however, have positive effects on soil physical characteristics, nutrient dynamics, and vegetation establishment (Kranz *et al*., 2020). Due to the incorporation of compost onto the upper layers of the soil, it results in an increase in the accessibility of microbes, as well as the interaction with the roots of plants (Cogger *et al*., 2008). Mulches can enhance soil health indicators that affect tree development and productivity. After three years, Gao *et al*. (2009) found that wheat with straw mulch increased its nutrient usage efficiency by 53.6% while wheat without mulch increased it by 36%. In comparison to no mulch, wood chip mulch increased root activity by 24.5% and chlorophyll content by 6.47% in tea olives (Osmanthus fragrans) (Xue *et al*., 2016). In a study by Nguyen *et al*. (2013), incorporated compost had no influence. During dry and rainy times, mulched compost

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significantly enhanced soil water content only at a 10 cm depth. In this study, the mulching application method was selected due to its beneficial benefits.

2.10.2. Effect of compost application rates on plant growth and yield

The application rates depend on several factors such as tree age, targeted crop yield, soil test results, compost availability and crop type. Polat *et al*. (2009) conducted a trial to evaluate the significance of spent mushroom compost on cucumber under various application rates (0, 20, 40 and 80 t ha-1). A high yield was recorded at an application rate of 40 t ha-1 followed by 80 t ha-1 and then at 20 t ha-1. The lowest yield was noted for the control (0 t ha-1). Mahmoud *et al*. (2009) discovered that the addition of 20 g kg-1 compost gave the best reduction in soluble Na+, Cl- followed by treatment with 10 g kg-1 (2 WTR: 1 compost). The study by Albaladejo (2009) presented that applying municipal solid waste (MSW) compost increases soil water retention capacity with an increasing rate of application. Gamal (2009) applied compost at the rate of 0, 5, and 10 t ha-1 and examined the nutrient content at harvest. In all compost plots, the author noticed increased N, P, and K nutritional content; however, the rise was greater in the plots that had 10 t ha-1 of compost. According to Bouajila and Sanaa (2011), applying household compost at concentrations of 40 and 120 t ha-1 significantly increased the amount of organic nitrogen in the soil though, caution must be taken when one selects the organic materials for composting (Amlinger *et al*., 2007). The rate of compost application needs to be carefully considered since too little or too much compost can be harmful to the soil, microorganisms, the crop growth, and yields (Havlin *et al*., 2014). The results from this investigation will serve as a guide to the farmers who usually apply macadamia husk compost on their crops as a means of improving soil health and crop yields.

2.11. Effects of compost application on macadamia growth, nut quality and yield

There is a continuous utilisation of macadamia husk compost by the macadamia farmers around the world especially in Australia, Hawaii, and South Africa (Du preez, 2015). Macadamia nut husk has long been utilized for traditional uses, like making compost or chicken feed. Nevertheless, to reduce its detrimental effects on the environment of just being wasted and prevent the waste of natural resources (Vu *et al*., 2023). Macadamia nut husk still needs to be used in a more effective and sustainable manner. Compost made from macadamia nut husks can benefit soil health

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in nutrient addition, soil structure improvement, microbial stimulation pH stabilization (Cox *et al*., 2004; Maselesele *et al.,* 2021). This study aims to explore the effect of macadamia husk compost application rates on soil health and nut quality.

Porter *et al*. (2005) discovered that macadamia husk mulch applications increased macadamia root growth and yield than the control; however, they noticed that it could take a period of 2 to 3 years for results to be produced. In that investigation, a similar amount of time was needed to detect the elevated leaf concentrations in 'Giles' pecan (Carya illinoiensis). While it has been recognized that a higher microbial activity aids N cycling and availability for plants (Raviv, 1998), macadamia husk compost enhanced microbial biomass by 300% compared to bare soils for macadamia after 18 months (Cox *et al*., 2004). It is important to assess how well the soil amendments that are currently being used for macadamia production are working.

2.12. Summary

Macadamia trees originated in the subtropical eastern Australia, Indonesia, and New Caledonia (Sharma *et al*., 2015). It is from the family *Proteacea* and is a genus of four species. Nuts are an important food crop and have an enormous economic impact. The production of macadamia in South Africa has expanded steadily and the rate of production is projected to keep on increasing due to growth in new land establishment (SAMAC, 2020). Due to many entries into the macadamia industry, sustaining and maintaining soil health might be a challenge as the aim of every producer would be to produce higher yields and excellent quality nuts. Using macadamia husk compost (MHC) as a soil amendment with correct applications rates would therefore increase production while maintaining soil health properties. However, there is a dearth of information regarding the influence of macadamia husk compost on soil properties as well as on the yield and quality of macadamia nuts.

Macadamia trees require a hot subtropical climate. Soil acidity, phosphorous and iron content are important when establishing a healthy macadamia orchard. The effect of high pH and high phosphorous content on iron availability is detrimental to macadamia trees. To smallholder farms in Africa, declining food production is ultimately due to poor soil fertility (Sanchez, 2002). Farmers have discovered several issues that contribute to low soil fertility, including soil erosion, poor soil quality, a lack of fertilizer,

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and a lack of manure. The application of macadamia husk compost by farmers is seen as a solution to the above-mentioned challenges.

Compost made from macadamia husks can be used as a soil management method for a sustainable crop production system and can have a good and beneficial impact on the physical, chemical, and biological aspects of soil. As a soil conditioner, fertilizer, source of essential humus or humic acid, and soil pesticide, compost can be helpful to the land. Additionally, it contains fertilizer value for plant nutrition and boosts nutrient cycling through increased microbial activity (Raviv, 1998; Embrandiri *et al*., 2013; Bauduin *et al*., 1987; Stratton *et al*., 1995). Composting is recognized to have a major impact on the ability of many soils to hold water, which over time provides water to plants (Aggelides and Londra, 2000; Crogger, 2005).

Compost can alter soil biological parameter that are used as an indicator for a healthy soil (Azim *et al*., 2018). Several studies revealed that total microbial and fungal count were significantly higher after compost amendment than when there is no compost applied. The use of macadamia husk compost will increase the nutrient content of the soil, CEC as well as the pH and electrical conductivity. In the light of the above, this study is aimed at assessing the effect of compost made from macadamia husk on the yield, quality of macadamia nuts as well as on the selected soil parameters and leaf nutrient concentrations.

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CHAPTER 3

GENERAL MATERIALS AND METHODS

3.1. Characteristics of the study site

The research study was done at the Agricultural Research Council's research farm in Levubu (23.085˚S:30.284˚E), and it falls under Makhado local municipality. Figure 3.1 shows the map of Vhembe district whereas Figure 3.2 shows the ARC's Levubu research farm where the study was conducted. In Figure 3.2, the area with a pink line tag represents the orchard (Block C3) where the study was conducted. Levubu has a subtropical climate, with a long-term typical rainfall of 752 mm. Levubu temperatures range from 10°C in winter to a maximum of 40°C in summer and the average humidity is 52 %. The area is normally free of frost, which is good for the growth and production of subtropical crops. Agricultural crops such as macadamia, banana (*Musa paradisiaca Linn*), avocado (*Persea americana*), guava, and litchis are more dominant. With some small areas reserved for animal production especially rearing of beef cattle (Pinzgauer, Nguni.



Figure 3.1: Map of Vhembe district showing Makhado Local Municipality where the study area is situated.

Source: Google map (2018)

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Figure 3.2: Satellite photograph showing the ARC-TSC Levubu research farm.

Source: Google map (2018)

3.2. Treatments and experimental design

The study has 4 treatments, including a control (no amendment) and the application of compost made from macadamia husks at rates of 4, 8, and 12 t ha^{-1}. A Completely Randomized Block Design (CRBD) with four replications was used in this study (Figure 3.3). Different rates of macadamia husk compost were applied to the randomized blocks and was replicated 4 times resulting in 16 plots, where 1 plot contained 3 macadamia trees with the same application rate applied to them per treatment. Figure 3.3 represents the experimental layout where X represent the trees. The line marked with green colour represents all the trees that are on the border lines and are not included in the experiment as a means of avoiding the border effects. The first compost application was done in August 2020 using the band application method (Figure 3.4). Pine bark, wood chips, and composted macadamia husk were combined in the following proportions: 30:35:35. This was done because woodchips and pine bark are good for moisture conservation and serve as a good stabilizer of nutrients in the compost.

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Table 3.1: Actual amount of compost applied on each of the selected research tree.

Treatments	**Organic material**			
	MHC (30%)	PB (35%)	WC (35%)	Total Mixture (%)
T 1	0	0	0	0
T2	2.34	2.74	2.74	7.82
T3	14.64	17.08	17.08	48.80
T4	23.04	26.88	26.88	76.80

Keys: T1=0t ha^{-1}; T2 = 4 t ha^{-1}; T3=8 t ha^{-1}; T4=12 t ha^{-1} MHC= Macadamia Husk Compost, PB=Pine Bark, WC=Wood Chips

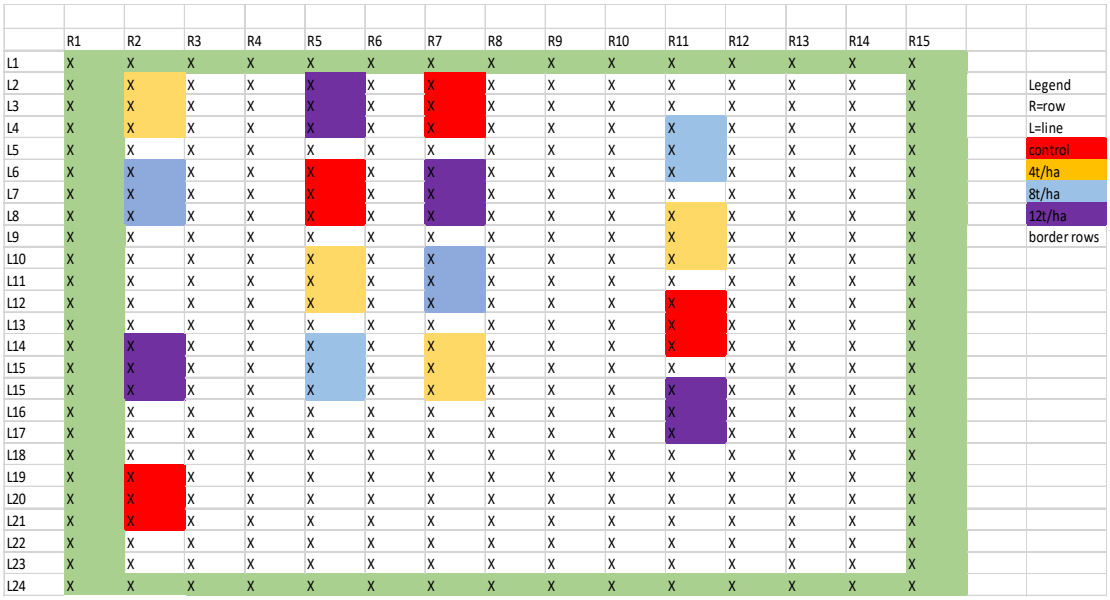


Figure 3.3: Experiment layout of the study.

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Figure 3.4: Compost applied around the macadamia tree.

3.3. Composting technique

The husks were collected during the harvesting season of macadamia nut which usually starts from May and ends up in July. The raw husks (Figure 3.5 a) were piled into heaps of almost 2 m height. The compost pile was turned once per week for the first month then once every other week for a period of five months. A sprinkler irrigation system was installed and used to moisten the compost pile for two days per week. After nine months of composting, a sample of the finished compost (Figure 3.5 b) was collected and analysed for pH, EC, N, P, K, S, Ca, Mg, Na, Fe, Zn, Mn, Cu, B, Carbon, and C: N ratio.



(a) (b)

Figure 3.5: Macadamia husk before (a) and after decomposition (b).

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3.4. Soil sampling and analysis

Soil samples were taken three times during the study period. The first soil samples were collected before the application of macadamia husk compost (MHC) whereas the other two samples were collected in August of 2021 and 2022, respectively. The samples were taken from soil surface at a depth of 0 to 30 cm since macadamia feeder roots are mostly concentrated on this depth. The soil samples were extracted using a Dutch soil auger and mixed to form a composite sample. Two kilograms (2 kg) of the composite soil sample were collected from each treatment and sent to the University of Venda soil laboratory to determine the physical properties while others were sent to ARC-TSC laboratory in Nelspruit for biological, and chemical analysis.

3.4.1 Soil chemical analysis

3.4.1.1. Soil pH

The pH of the soil was measured using a glass-calomel electrode in a supernatant with a soil: water ratio of 1:2.5 (McLean, 1982). A measure of 10 g of air-dried soil was weighed and poured into a beaker as well as 50 cm-3 of de-ionized. A glass rod was used to quickly stir the solution for five seconds before letting it to dissolve for 30 minutes. Electrodes were dipped in the supernatant to determine pH (Woodruff, 1948).

3.4.1.2. Available phosphorus

Available phosphorus was determined using the Bray-1 method of Bray and Kurtz (1945), where the filtrate was placed in extracting bottles. However, before that, each sample was extracted using 50 ml of the Bray-1 extracting solution (0.03N NH4F + 0.025HCL). By reducing phosphomolybdic acid, which produces a vivid blue colour, the concentration of phosphorus in the filtrate was measured using a spectrophotometer at a wavelength of 660 nm (Bray and Kurtz, 1945).

3.4.1.3. Extractable cations (Ca, Mg and K)

Three extractable cations (Ca, Mg, and K) were extracted using 1 mol dm^3 ammonium acetate (NH4OAC, pH 7.0). Atomic Absorption Spectrophotometry was used to measure Ca and Mg levels during which K was determined by flame photometry.

3.4.1.4. Copper, Iron, Zinc, Manganese.

Cu, Fe, Zn and Mn were determined using the atomic absorption spectrometry as

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described by Helaluddin *et al*. (2016). The method measures the concentration of the element by passing light in specific wavelength emitted by a radiation source of a particular element through a cloud of atoms from a sample, subsequently atoms will absorb light from an energy source (hollow cathode lamp). The reduction in the amount of light intensity reaching the detector is seen as a measure for the concentration of the element in the original sample.

3.4.2. Soil physical analysis

Physical characteristics are linked to the best chemical and biological qualities, which together optimize nutrient and water cycling and other vital soil processes. The soil samples used to analyse the physical property (aggregate stability and water holding capacity) were collected using a soil auger at a depth of 0-20 cm to get a representative of the topsoil and 20-30 cm of the subsoil. Soil samples were collected and placed in plastic bags and then sent to the laboratory at the University of Venda where the analysis was done. For bulk density, a core ring method was used where a known soil volume was taken and then weighed to get the weight of the wet soil, and the core rings were placed in the oven for 48 hours to get the soil dry mass. The double ring method (Reynolds, 2002) was used in the field to determine the infiltration of water into the soil.

3.4.2.1 Bulk density

Bulk density was calculated by dividing the dry weight of the soil by its volume, which is expressed in gcm^{-3}, (Blake and Hartge, 1986).

3.4.2.2 Soil aggregate stability

Soil aggregate stability was measured using the Kemper and Rosenau (1986) wet sieving method to assess the stability of soil aggregates.

3.4.2.3 Water holding capacity.

At Field Capacity (FC) and Permanent Wilting Point (PWP), soil moisture was measured to calculate water holding capacity. The water holding capacity was determined in the laboratory on soil cores using pressure membrane apparatus (Hillel, 2003). Soil samples were arranged on the porous ceramic plates. Each ceramic plate was assigned to a certain pressure; 10 kPa (field capacity) and 850 kPa (maximum lab pressure representative of permanent wilting point.

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3.4.2.4 Water infiltration rate

The double ring method proposed by (Reynolds, 2002) was used to calculate the water infiltration rate. An inner ring and an outer ring are needed for a double ring infiltrometer. When water flows in a single dimension under steady state conditions and there is a unit gradient in the rate of infiltration into the underlying soil is roughly equivalent to the saturated hydraulic conductivity.

3.4.3. Soil biological properties analysis

Several factors, including organic carbon, organic matter, microbial biomass carbon, microbial biomass nitrogen, and microbial quotient particulate organic matter, can be used to measure or evaluate soil biological activity (FAO, 2020). The soil samples used to analyse the biological properties were collected using a spade at a depth of 0-15 cm as most biological activity occurs in that layer. Soil samples were collected after irrigating and wrapped with a plastic bag to protect the microorganisms from desiccation.

3.4.3.1. Soil organic carbon and organic matter

The soil organic carbon (OC) was determined using the Walkley and Black method (Nelson and Sommers, 1982). One (1) gram of soil was digested in 20 ml of concentrated sulfuric acid (H_2SO_4) and 10 ml of aqueous potassium dichromate ($K_2Cr_2O_7$). After complete oxidation, the remaining $K_2Cr_2O_7$ was titrated against 0.5 N ferrous ammonium sulphate. The used $K_2Cr_2O_7$ and the difference between additional and residual $K_2Cr_2O_7$, was used to calculate the OC content of the soil. The determinations were done in triplicates. Organic carbon content was multiplied by a factor of 1.72 to determine the amount of organic matter in the soil.

3.4.3.2. Microbial biomass carbon, microbial biomass nitrogen and microbial quotient

Microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) were measured from the difference between carbon and nitrogen extracted by 0.5 M K_2SO_4 from alcohol-free fumigated and un-fumigated soil samples. About 15 g of fresh soil samples were placed into two 50 ml beakers. The beakers were placed into the two paired desiccators. In one desiccator, a 100 ml beaker containing 25 ml of chloroform (alcohol-free) was placed into the centre of the desiccator. The second desiccator contained the non-fumigated (control). A vacuum was applied to the fumigated

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treatment until the chloroform was rapidly boiling. The desiccator was closed and stored under darkened conditions for 72 hours at room temperature. The fumigated treatments were extracted using the vacuum pump repeatedly (8-12 times). The soil samples were transferred to shaking bottles. 50 ml of 0.5 M K_2SO_4 was added and shaken for 25 minutes. The soil suspensions were filtered using No 42-filter paper to obtain a clear extract. The sample was digested and analysed for total N and for C. Microbial quotient was determined by expressing the percentage of microbial carbon in the total carbon which reflected the live microbial proportion of the carbon (Sparling, 1998).

3.4.3.3. Particulate organic matter

Particulate organic matter (POM) fraction was analysed using the modification method described by Okalebo *et al*. (1993). Fifty (50) grams of soil sample was dispersed with 10% Calgon solution (sodium hexametaphosphate). The dispersed soil sample was placed on the 2 mm sieve and was wet sieved. The dispersed soil sample was sieved through a set of sieves of 2.0 mm and 53 µm in diameter by washing the soil with distilled water. The portion greater than 2.0 mm was considered as waste while that retained on the 53 µm sieve was kept. Particulate organic matter consists of materials which when dispersed with water floats and passes a 2 mm, but not at 0.25 mm sieve. The procedure was repeated until the entire POM was removed. The material floating in the suspension that was drained out and placed inside an oven for three days at 50°C was referred to as the POM fraction.

3.5. Leaf sampling and analysis

The leaf samples were collected from the non-fruiting terminals following the ARC-TSC procedure (Figure 3.6). The 4th pair leaf from the first fully open leaf at the tip of a primary branch were collected (Aylward, 2003) from each of the selected macadamia tree in November 2021 and 2022, respectively. Collected leaves were rinsed with distilled water, dried in the oven at 70 °C for 60 hours and ground using a Willey Mill for chemical analysis. Leaf samples were analysed for total carbon, total N, P, K, Ca, Mg, Zn, Fe, Cu, Mn, and B.

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Figure 3.6: A schematic diagram of a macadamia branch showing the position of the leaves to be sampled. Macadamia leaf sampling procedure of the ARC-TSC.
Source: Koen, (1993)

3.5.1. Total nitrogen

The Okalebo *et al*. (1993) micro-Kjeldahl technique was used to calculate total nitrogen. Ground leaf samples were digested using concentrated sulfuric acid (H_2SO_4) in this technique. The distillate was collected in saturated boric acid (H_3BO_3), and then the colour was adjusted using diluted H_2SO_4 until it changed from green to grey and then finally to a definite pink.

3.5.2. Total P, K, Ca, Mg, Zn, Fe, B and Mn

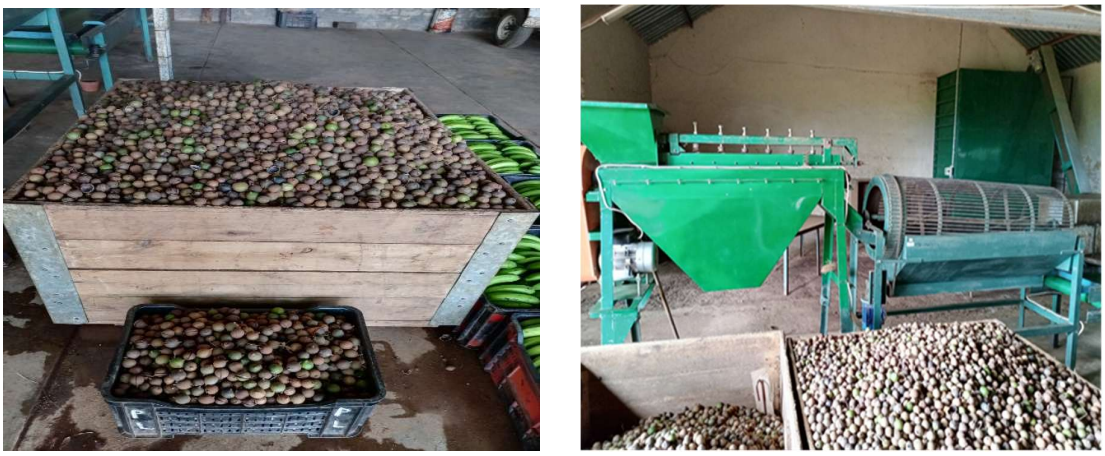
Perchloric acid digestion was used to analyse P, Ca, Mg, Z, and Mn in the leaf tissues. 0.3 g of each treatment from the sample was heated by an oscillating electromagnetic field and then oxidized with nitric acid, hydrogen peroxide and strong hydrochloric acid to break them down.

Total phosphorus was determined using a spectrophotometer at a wavelength of 660 nm whereas K, Ca, Mg, Zn, and Mn were determined using the Atomic Absorption Spectrometer (Motsara and Roy, 2008). Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) was used to analyse and measure the amount of boron (B) in the leaves (Karla and Maynard, 1991).

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3.6. Macadamia harvesting, yield and nut quality determination

The yield of nuts was measured after the harvesting period which starts in May and ends during July. The Beaumont cultivar is a late harvest cultivar, and the nuts do not drop on their own. About 600 ml of Ethephon 480 SL was mixed in a 400-L water tank and applied on the trees to stimulate the trees to release the nuts. After application, it took about 7 days for the nuts to fall. Nuts that remained on the tree were gently stripped off the trees using bamboo sticks. The nuts were collected into the crates and then transported to the pack house where they were stored in the wooden bin (Figure 3.7 a). The nuts in husk (NIH) were subjected to a process where husks are removed using a de-husking machine (Figure 3.7 b). This is a process whereby the shell and outer cover of the nut (husk) are separated. The husks were collected to the composting area where it was piled.



(a) (b)

Figure 3.7: Harvested macadamia nuts (a) and de husking machine (b).

A nut sample of about 3 kg from each treatment was sent to Royal Macadamia in Levubu for quality determination. The nuts were cracked open to separate the kernel from the shell (Figure 3.8 a) and then sorted by removing the damaged kernel from the sound kernel (Figure 3.8 b). The shell is also of value as it can be used as a carbon filter, to make homeware, industrial nano powder, and renewable energy (charcoal). Quality parameters such as sound kernel (SK), unsound kernel (UK), total kernel (TK), first grade nuts (1st G), commercial grade (CG), early insect damage (EID), late insect damage (LID), early germination (EG), and number of immature nuts (IN) were

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assessed and recorded. Calculations were made from the analysis to determine the quality of the nuts and then expressed as percentage.



(a)



(b)

Figure 3.8: Cracked macadamia nuts with shells (a) and cleaned kernels (b) during the quality analysis process.

3.7. Data analysis

GenStat® version 17 (VSN International, UK) was used to perform analyses of variance (ANOVA) on data related to soil, leaf nutrient concentrations, yield, and nut quality. At a probability level of 0.05, the Least Significant Difference (LSD) test was used to compare the mean values.

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CHAPTER 4

4.THE EFFECTS OF MACADAMIA HUSK COMPOST ON THE MACADAMIA NUT YIELD, QUALITY AND LEAF NUTRIENT CONCENTRATION

4.1. Introduction

Production of macadamia in the subtropical district of Vhembe, in South Africa is among others limited by poor soil fertility and inadequate rainfall. As a result, inorganic fertilizers are being used to maximise macadamia yield but with adverse impacts on the environment (Savci, 2012) and human health (Sharma and Singhvi, 2017). Several efforts have been made in the agricultural fraternity to limit chemical fertilizer use by developing compost produced from organic materials (Bittenbender *et al.*, 1998; Cox *et al.*,2004; Maselesele *et al.*, 2021). One of the efforts made includes the utilisation of macadamia husk to make compost. Most of the farmers now use compost made from macadamia husks in place of artificial fertilizers in their own orchards. Regardless of the positive outcomes from the use of macadamia husk compost, there is no consensus on the amount that should be applied to enhance the soil's fertility and boost crop output and quality.

Apart from being the world's largest macadamia nuts producer, South African nuts are in high demand due to their high-quality standard (Sutton, 2018). Several authors have related macadamia quality to factors such as soil preparation, climate, altitude, fertilisation, irrigation, and harvesting technique. (Zuza *et al.*,2023). Cavaletto (1981) defines quality as a standard of all the measures that gives a product value or a degree of excellence. As far as macadamia is concerned, the definition of quality differs from one market to the other. For example, markets in the United States of America, focus their definition on food safety while the European markets pay more attention on the chemical residues. The Chinese market on the other hand focuses on the lower unsound kernels and enormous size nuts. However, for the purpose of this study, quality of macadamia nuts was defined based on the parameters such as: (i.e., sound kernel (SK), unsound kernel (UK), total kernel (TK), first grade nuts (1st G), commercial grade (CG), early insect damage (EID), late insect damage (LID) and number of immature nuts (IN). There is substantial evidence that compost application has a beneficial effect on the yield and quality of macadamia nuts (Trouchoulias, 1988; Swanepoel, 1998; Porter *et al.*, 2013; Galanti *et al.*, 2019). However, some

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researchers have not found any measurable effects of compost on the quality parameters of macadamia nuts (Trouchoulias, 1988; Swanepoel, 1998). Apart from improving yield and quality, application of compost has been viewed by many as having the ability to increase nutrient uptake of the crop and thereby improving crop performance (Adak *et al*., 2014; Mohale *et al*., 2023). This is probably because compost holds many essential nutrient elements which are the building blocks for tree performance (Mkhabela and Warman, 2005).

Currently, there are no specific recommendations on MHC application rates in relation to the yield and quality of macadamia nuts. Therefore, there is a need to conduct a thorough study through which we will be able to show a desirable standard application rate of MHC, which will be used as a guideline by farmers. However, the right amounts of compost to apply will depend on factors like chemical composition of soil, crop type, tree age, availability and targeted crop yield. The applied rates must be able to advance the condition of the soil fertility status and at the same time does not compromise the yield and quality of macadamia nuts. This study's goal was to evaluate the impact of macadamia husk compost application on the macadamia trees' nut yield, quality, and leaf nutrient concentration.

4.2. Materials and methods

A complete description of the materials and methods used for this chapter is shown in chapter 3 sections 3.5 and 3.6.

4.3. Results

4.3.1 Macadamia nut and husk yields

Findings of the mean square analysis of variance for the nuts and husks yields are presented in Table 4.1. There was no significant effect of years on both nut and husk yields as well as on the wet in shell (WIS) yield. A significant variation ($p<0.05$) was seen amongst the treatments. However, no significant interaction by treatment and year of study.

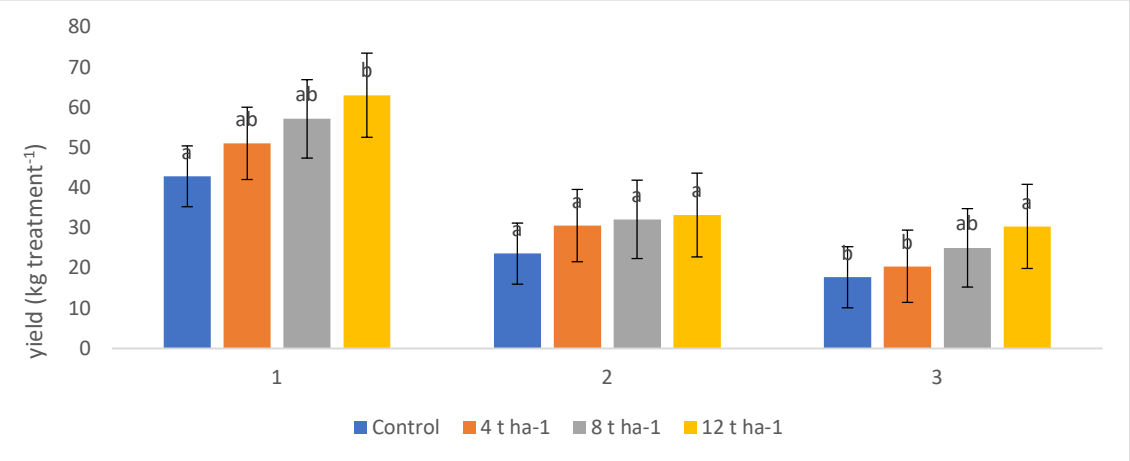
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Table 4.1 Mean square of analysis of variance for macadamia nut and husk yields.

Source of variance	Df	NIH	Husks	WIS
Year (Y)	1	110.45ns	140.07ns	1.64ns
Treatment (T)	3	597.44*	148.80ns	238.91*
T x Y	4	0.001ns	17.36ns	14.58ns

* Significant at p<0.05 level of probability, ns Not significant at p<0.05 level of probability, NIH Nut in husk, WIS nut with shell

Figure 4.1 illustrates how treatment affected yield (NIH and WIS) and raw macadamia husks. The study's findings showed that there was a significant effect (*p<0.05*) of treatments on the yield of macadamia nut (NIH and WIS). However, there wasn't a substantial difference among the treatments with respect to raw macadamia husk. The average yield (NIH) of macadamia nuts was in the order: T4 (63.10 kg tree^{-1}) = T3 (57.22 kg tree^{-1}) > T2 (51.09 kg tree^{-1}) > T1 (42.90 kg tree^{-1}). Increasing the compost rate resulted in large amount of WIS (30.40 kg tree^{-1}) compared to control (17.53 kg tree^{-1}). There was, however, no statistical difference observed on the nut yield between the two years (i.e., 2021 and 2022) of study (Table 4.2).



Means within each parameter with similar letters are not significantly different by the T-Grouping test at 5% (p<0.05) level of probability, NIH Nut in husk, WIS nut with shell

Figure 4.1: Effect of different levels of macadamia husk compost on the nut and husk yield.

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Table 4.2: Macadamia nut and husk yields in the two years of study (2021 and 2022).

Year	NIH	HUSK	WIS
	(yield treatment^{-1})		
2021	55.43±19.26 a	32.01±11.64 a	24.44±8.61 a
2022	51.72±20.85 a	27.83±12.26 a	23.15±9.64 a
	ns	ns	ns

Means within the column with similar letters are not significantly different by the LSD (T-Grouping test) at 5% level of probability, ns Not significant, NIH Nut in husk, WIS nut with shell

4.3.2. Macadamia nut quality

Table 4.3 shows the mean square analysis of variance for macadamia nut qualities (i.e., sound kernel recovery (SK), unsound kernel recovery (USK), total kernel recovery (TK), first grade nuts (1st Grade), commercial grade (COM), early insect damage (EID), late insect damage (LID) and number of immature nuts (IN). There was significant ($p<0.05$) effect of years and treatments on all the macadamia nut qualities except for early germination (EG). However, no significant interaction effect of years and treatments was observed.

Figure 4.2 shows the effect treatment of quality parameters of macadamia nuts (i.e., SKR, USKR, TKR, 1st Grade, COM, EID, LID, and IN). Application of compost resulted in maximum percent of sound kernel recovery of 24.45% which is great as the standard is from 20% - 30%. The total kernel recovery was 28.1% of which 25% - 30% is the standard. A percentage from 15-25% is considered as first grade nuts and at an application of 12 t ha^{-1} a maximum of 21.15% was observed. Minimum percent of unsound kernel recovery should not be higher than 6% as well as early insect damage and late insect damage. A low number of immature nuts were observed under control (Figure 4.2). However, no significant differences were observed among the four treatments with respect to commercial nuts grade and early insect damage.

The effect of macadamia husk compost on quality parameters during the two years of study is shown in Table 4.4. Except for the 1st grade nuts and the total kernel recovery,

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the quality parameters of the nuts from the study site improved with time whereby high-quality nuts were observed in 2022 compared to 2021. EIG, LID, EG was low in 2022 compared to 2021 which is a great improvement as this will result in good quality nuts.

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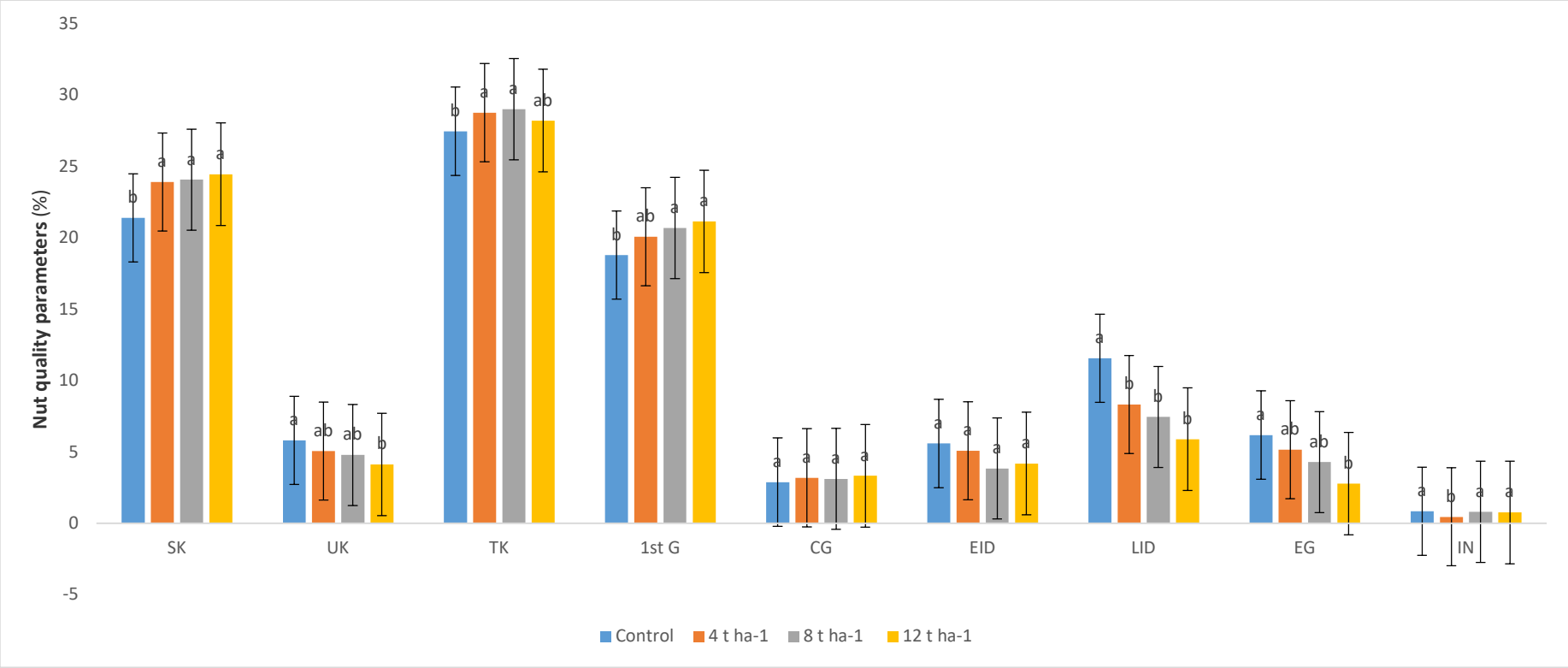
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Table 4.3: Mean square of analysis of variance for macadamia nut quality parameters.

Source	Df	SKR	USKR	TKR	1st Grade	COM	EID	LID	EG	IN
		(%)								
Year (Y)	1	40.79**	30.13**	0.39**	22.35**	10.48**	65.84**	447.75**	13.38ns	6.26**
Treatment (T)	3	15.48**	3.91**	5.06**	8.35*	0.28*	5.17ns	135.85**	16.74ns	0.15**
Y x T	3	1.93ns	1.29ns	1.32ns	4.72ns	1.58ns	0.11ns	5.27ns	1.19ns	0.32**

* Significant at p<0.05 level of probability, ns Not significant at p<0.05 level of probability, SK=Sound kernel recovery, UK=Unsound kernel recovery, TK=Total kernel, 1stG= First grade, COM=Commercial grade, EID=early insect damage, LID=Late insect damage, EG=Early germination, IN=Immature nuts.

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Means within each parameter with similar letters are not significantly different by the T-Grouping test at 5% level of probability. SK=Sound kernel recovery, UK=Unsound kernel recovery, TK=Total kernel, 1stG= First grade, COM=Commercial grade, EID=early insect damage, LID=Late insect damage, EG=Early germination, IN=Immature nuts.

Figure 4.2: Effect of different rates of compost on quality parameters of macadamia nuts

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Table 4.4: Quality parameters of macadamia nuts measured during the two years of study (2021 and 2022).

Year	SKR	USKR	TKR	1st Grade	COM	EID	LID	EG	IN
	(%)								
2021	16.58±1.29	3.98±1.07	28.47±0.96	21.73±1.65	2.57±1.0	6.12±2.65	12.06±5.02	5.23±3.39	0.28±0.20
2022	22.33±2.79	5.92±1.84	28.25±1.23	18.62±2.53	3.71±1.14	3.25±1.61	4.58±2.52	3.94±1.96	1.20±0.35
	*	*	ns	*	*	*	*	ns	*

* Significant at $p<0.05$ level of probability, ns Not significant at $p<0.05$ level of probability, SK=Sound kernel recovery, UK=Unsound kernel recovery, TK=Total kernel, 1stG= First grade, COM=Commercial grade, EID=early insect damage, LID=Late insect damage, EG=Early germination, IN=Immature nuts.

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4.3.3. Concentration of nutrient in the leaves of macadamia trees

Using the ARC-TSC sampling protocol, leaf samples were taken in October 2021 and 2022 from the chosen trees and sent to ARC-TSC soil laboratory in Nelspruit for chemical analysis. The mean square of analysis of variance for leaf nutrient concentration on the leaves of macadamia trees is presented in Table 4.5. There was significant) effect of years on the ……concentration of nutrient such as P, Zn, Cu and Fe. Only K, Mg and Zn concentrations was significantly (*p<0.05*) influenced by the treatments. However, no significant interaction effect of years and treatments was observed for these nutrients.

Figure 4.3 shows the effect of treatment on the concentration of macro nutrients in the leaves of macadamia trees amended with different rates of compost (i.e., N, P, K, Ca, and Mg). There was a statistically significant *(p<0.05*) effect of treatment on the concentration of K and Mg but not the others N, P and Ca. The maximum (0.66%) and minimum (0.58%) leaf K were observed for T4 (12 t ha^{-1}) and T1 (0 t ha^{-1}), respectively. The maximum (0.15%) and minimum (0.12%) leaf Mg was observed for T3 (8 t ha^{-1}) and T1 (0 t ha^{-1}), respectively. N, P and Ca were not significantly different among the four treatments (Figure 4.2). Application of compost did not have a significant effect on the concentration of micro-nutrients (Cu, Mn, Fe and B) on the leaves of macadamia trees except for Zn (Table 4.6). There was a significant ($p<0.05$) effect of year on the concentration of P, Zn, Cu and Fe in the leaves of macadamia trees (Table 4.7). Maximum leaf P (0.06 %), leaf Zn (11.60 $mgkg^{-1}$) and Cu (3.61 $mgkg^{-1}$) were observed in 2022 indicating that the concentration of nutrient elements in leaves was increasing with time. Maximum leaf Fe (165.7 $mgkg^{-1}$) was recorded in 2021 compared with 2022. However, there was no significant difference between the two years (2021 and 2022) with respect to leaf N, K, Ca, N and B concentration.

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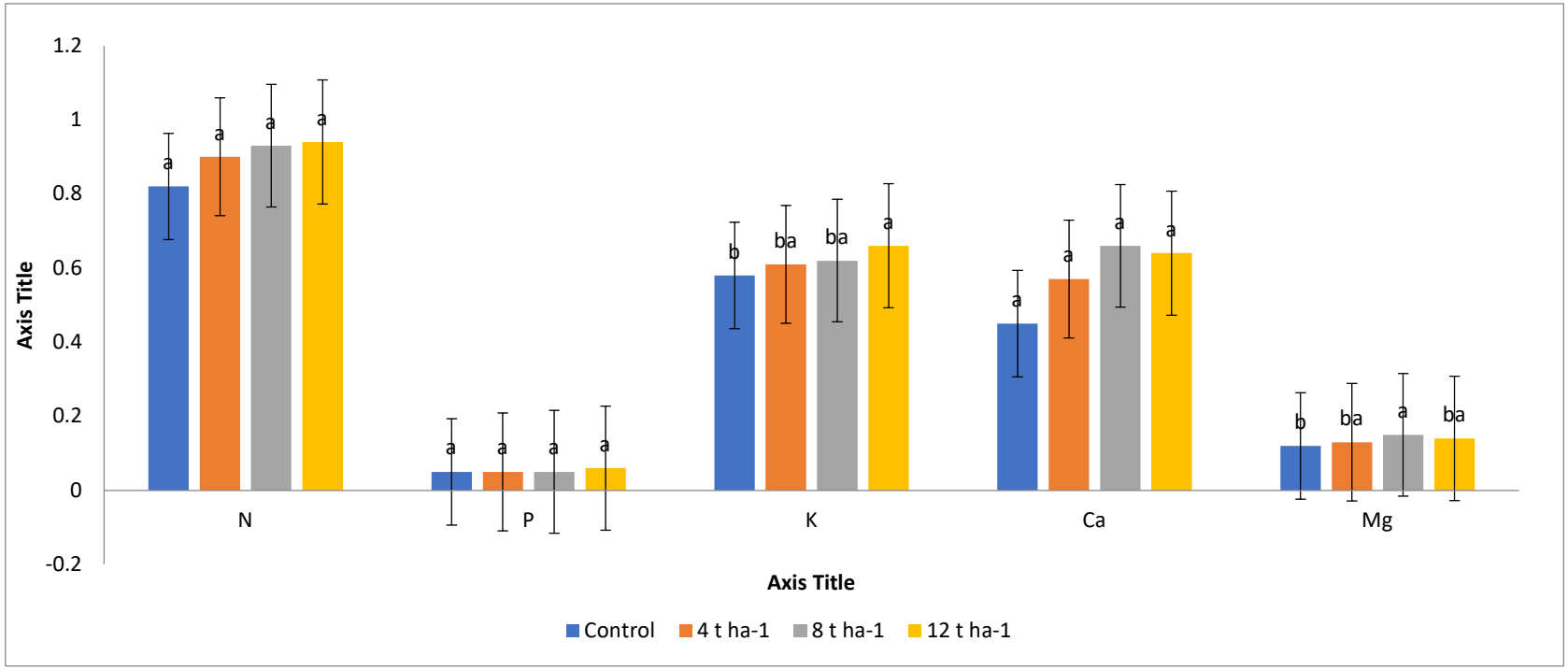
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Table 4.5: Mean square of analysis of variance for leaf chemical properties after the application of macadamia husk compost.

Source	Df	N	P	K	Ca	Mg	Zn	C	Mn	Fe	B
		(%)					($mgkg^{-1}$)				
Year (Y)	1	0.054ns	0.001*	0.014	0.052ns	0.001ns	230.43*	4.55**	46100.14ns	36597.3**	3.15ns
Treatment (T)	3	0.025ns	0.0001ns	0.009*	0.025ns	0.0006*	30.52*	0.067ns	68552.15ns	324.06ns	16.62ns
Y x T	3	0.003ns	0.000001 ns	0.00009ns	0.025ns	0.0002ns	2.04ns	0.331ns	16156.54ns	3178.75ns	22.14ns

* Significant at $p<0.05$ level of probability, ns Not significant at $p<0.05$ level of probability, N=Nitrogen , P= Phosphorus, K=Potassium, Ca=Calcium, Mg=Magnesium, Z=Zinc, C=Carbon, Mn=Mangenese, Fe=Iron, B=Boron

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Means within each parameter with similar letters are not significantly different by the T-Grouping test at 5% ($p<0.05$) level of probability. N=Nitrogen, P= Phosphorus, K=Potassium, Ca=Calcium, Mg=Magnesium, Z=Zinc, C=Carbon, Mn=Manganese, Fe=Iron, B=Boron

Figure 4.3: Effects of different rates of compost on leaf macro-nutrient concentration.

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Table 4.6: Effects of different rates of compost on leaf micro-nutrient concentration.

Treatment	Zn	Cu	Mn	Fe	B
			(mgkg^{-1})		
Control	6.79±4.65 b	3.32±0.82 a	543.1±283.18 a	128.37±39.97 a	16.34±2.55 a
4 t ha^{-1}	7.73±3.77 ab	3.07±0.57 a	560.5±223.64 a	130.59±31.09 a	18.27±4.46 a
8 t ha^{-1}	10.46±4.18 a	3.29±0.55 a	702.5±297.26 a	127.35±48.96 a	18.18±4.45 a
12 t ha^{-1}	13.22±4.68 ab	3.17±0.31 a	719.8±300.52 a	141.21±71.58 a	19.78±4.05 a

Means within the column with similar letters are not significantly different at 5% *($p<0.05$)* level of probability by the T Grouping test, N=Nitrogen, P= Phosphorus, K=Potassium, Ca=Calcium, Mg=Magnesium, Z=Zinc, C=Carbon, Mn=Manganese, Fe=Iron, B=Boron

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Table 4.7: Effects of macadamia husk compost on the concentration of nutrient elements in the two years of study (2021 and 2022).

Year	N	P	K	Ca	Mg	Zn	Cu	Mn	Fe	B
	(%)					(mgkg^{-1})				
2020	0.86	0.05	0.60	0.64	0.14	6.23	2.84	669.4	165.7	17.81
2021	0.94	0.06	0.64	0.56	0.13	11.60	3.61	593.5	98.06	18.39
	ns	*	ns	ns	ns	*	*	ns	*	ns

* Significant at $p<0.05$ level of probability, ns Not significant at $p<0.05$ level of probability, N=Nitrogen, P= Phosphorus, K=Potassium, Ca=Calcium, Mg=Magnesium, Z=Zinc, C=Carbon, Mn=Manganese, Fe=Iron, B=Boron.

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4.4. Discussion

4.4.1. Macadamia nut yield and husks

The results of this study revealed a significant ($p<0.05$) effect of treatments on the yield of macadamia nut (NIH and WIS). This might be due to the availability of sufficient number of nutrient elements which were released from the compost throughout the plant growing period resulting in better uptake and plant vigour. This agrees with the findings of Porter *et al*. (2005), who found an increased macadamia yield from MHC in drier conditions. The study found that applying MHC enhanced macadamia root growth and larger trunks when compared to the control but also suggested that results might not be seen for two to three years. Similarly, Bhat *et al*. (2017) reported significantly ($p<0.05$) high litchi yield when he used organic amendments. Mohale *et al*. (2021) observed high yield on avocado fruits when he applied eucalyptus wood-based compost in Moeketsi and Politsi at the rate of 10 t ha-1. Wolsterholme *et al*. (1997) found significant increase in the yield and size of avocado fruits after the application of composted pine bark. Mulching is a popular cropping technique for both annual and perennial crops. It improves crop performance and soil fertility (Campiglia *et al*., 2010) and increases soil temperature as well as moisture conservation (Zegada-Lizarazu and Berliner, 2011).

Macadamia husk compost is rich in essential nutrient elements such as N (0.94), P (0.06), K (0.66), Ca (0.64), and Mg (0.14). These nutrient elements play a major role in different phenological stages of the plant. According to Devi *et al*. (2012), nutrients like P and K are important in flowering and fruit setting which in turn promote yield increment. High nut yield seen from the trees amended with 8 and 12 t ha-1of macadamia husk compost may also be due to increase of the compost application rate. Apart from supplying major nutrients, macadamia husk compost also has enormous amounts of micronutrients (Daramola *et al*., 2013) such as Zn (10.69), Mn (719.8), Cu (3.29), B (141.21), and Fe (19.78) micronutrient availability in compost. According to Akanbi *et al*. (2002), micronutrients Fe, Zn, and Mn promote vegetative growth of the plants as well as chlorophyll and the photosynthetic rate which promote flower formation and fruit setting. On the contrary, Barreto *et al*. (2021) recorded no significant difference on tree yield, the number of fruits, fruit mass and the diameter of Nectarines after the application of organic compost at three levels of compost (0, 20 and 40 t dw ha-1). This contrasts with results obtained using macadamia husk compost, which showed a significant impact on the yield and quality of the nuts. This

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contradiction may be attributed to the variation of the compost chemical composition as well as the growth and nutrient uptake pattern of the different plants. The main issue of compost supply is having excess of nitrate available in period when plants do not need them. Since macadamia husk compost is relatively high in carbon but lower in nitrogen compared to other composts, its mineralization rate might be slower. Application of compost promotes soil microbiological activity which stimulate nutrient mineralisation and better uptake by the crops due to vigorous root development. When compost is applied on the soil surface, it creates a constructive microclimate for soil micro-organisms which aid to enhance biological and physical properties of the soil which in turn promotes the growth performance of plants (Oso *et al*., 2010).

Although not measured in this study, several other studies have linked high fruit yield to the production of humic acids from the compost (Eissa *et al*., 2007). Compost has a huge amount of humic acid such as polymeric polyhydroxy acid, which has hormonal effects on root elongation and plant development, and this enhance shoot biomass. Humic acid acts as a plant growth bio-stimulant and it raises nutrient uptake as a chelating agent. Chelates prevent loss of nutrients through leaching or wash out. Chelation increases the mobility of nutrients in soil. This increased mobility enhances the uptake of nutrients by plants. Chelating agents reduce the growth of plant pathogens by reducing available iron. This results in improved vegetative characteristics of the plant, thus promoting flowering, nut set and ultimately fruit yield (Eissa *et al*., 2007). This was also emphasised by Seyedbagheri (1999) who mentioned that compost holds substantial amounts of amino acids, vitamins, and hormones which in turn stimulate the accessibility of nutrients for plant uptake. The fact that there wasn't a statistical *($p>0.05$)* difference observed on the nut yield between the two years of study (i.e., 2021 and 2022) is probably due to the nationwide decline in the yield of macadamia nuts in the year 2022 (SAMAC, 2021). Over the past three years, macadamia industry / orchards have experienced a constant decline in yield going from 3 t ha^{-1} in 2019 to 2.1 t ha^{-1} in 2021 (Winter, 2022). The decline was due to extreme (Appendices 1) heat and in some areas, drought which adversely affected the Beaumont flowering period. In return the nut set was affected and produced lower yields than expected.

There is a need for a further study to determine the humic acid content and other important substrates of macadamia husk compost that play a role in the growth, development, and production of macadamia trees.

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4.4.2. Macadamia nut quality

The results show that compost made from macadamia husk has positive effects on the quality of macadamia nuts under field conditions. Application of compost resulted in maximum percent of sound kernel recovery, total kernel recovery, and first grade nuts, minimum percent of unsound kernel recovery, less early insect damage, less late insect damage as well as low number of immature nuts were also observed on the nuts that were harvested from the trees amended with macadamia husk compost. These quality parameters (Table 4.4) and (Figure 4.2) are of great concern to the macadamia farmers since they are the ones that determine the price of the nuts in the market.

Therefore, any means to maximise them is of outmost importance in the macadamia industry. Compost has been shown by many authors to enhance fruit and nut qualities of various species. Marzouk and Kassem (2011), NNNNin their study on 'Zaghloul' date palms, the researchers applied compost at a rate of 20 kg per tree. This application was part of their investigation into the effects of organic and mineral fertilizers on fruit quality and yield. Aminifard et al. (2013) examined the impact of vermicompost on the fruit quality and yield of sweet pepper. The researchers used vermicompost at rates of 5 and 10 tons per hectare. Zengin et al. (2016), in their research on the effects of different organic fertilizers on strawberry yield and quality, compost was applied at a rate of 30 tons per hectare. Vásquez and Maravi (2017) applied compost at a rate of 10 kg per tree to investigate the use of compost in avocado cultivation. The observed increase in nut quality in this study could be due to macadamia husk compost, which encourages soil microorganisms' activities and leads to the release of essential nutrients to the soil. These nutrients become available for plant uptake and assist in the formation of flowers, nut setting, oil accumulation, resistance to pest and insect's attack. Similar explanation was provided by Jianming *et al*. (2008) and Adebayo *et al*. (2014) who found an improvement in total soluble salts, total sugars, protein, vitamin C and moisture contents in cucumbers after increasing the rates of compost. Similarly, Gliessman *et al*. (1996b) and Cayuela *et al*. (1997) reported high sugar application rates in strawberry fruits because of organic compost application. After applying organic amendments, soil micro-organisms flush and flushes increasing their population and diversity (Karuku and Mochoge, 2016; Karuku and Mochoge, 2018; Karuku, 2019), speed up the process of nutrient mineralisation which in turn stimulates plants to synthesize more vitamins, amino acids and total sugar content, anthocyanins, phenolic content and antioxidant (El-Sheikh and Salama, 1997; Wang and Lin, 2003).

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Increasing the rates of macadamia husk compost might have resulted in the improvement of nut quality. This agrees with the results of Galanti *et al*. (2019) who found that organic amendment application at different rates improved the kernel quality. According to *et al*. Abou-El-Hassan (2010), compost had a prevalent action in plants and involved in maintenance of ionic balance in cell and bond ionically to many enzymes which are responsible in respiration and metabolism. This increases the build-up of dry matter during the flowering stage and offers adequate nutrients for reproductive growth to improve fruit quality. Organic matter increases water storage in soil and WUE by crops, hence improving quality and yields as moisture stress is reduced (Karuku *et al*., 2014), porosity is increased in the soil by organic matter's improvement of soil structure. This gives plant roots more time to absorb water by allowing water to seep in and travel more slowly rather than instantly draining away.

Macadamia farms in South Africa are affected by insects and pests which results in several million rand of estimated crop loss. It has been estimated in South Africa that the macadamia industry is losing R200 million a year because of insect pest damage which is associated with premature nut drop and unsound kernel (SAMAC, 2020). As a result, macadamia farmers are forced to use massive quantities of expensive insecticides as a means of controlling pests and insects. Some of these notorious insects include stink bugs, nut borers, macadamia felt coccid and thrips. However, results from this investigation have shown that by applying compost made from macadamia husks, the number of insect damage (both early and late insects damage) was reduced. The nuts harvested from the trees which were amended with 8 and 12 tons of compost per hectare had a low incidence of insect damage as compared to those from control (without compost). Due to soil fertility problems, crop returns often decrease and the crops are more susceptible to pest and disease because they are in bad condition (Madeleine *et al*., 2005; Inckel *et al*., 2005). Compost contains beneficial microbes that compete with harmful pathogens. These microbes can supress soil-borne diseases, indirectly benefiting crop health and reducing the attractiveness of plants to pests.

The incidence of insect damage to the nuts decreased with an increase in compost application rate which emphasizes the importance of applying compost. Therefore, applying compost in macadamia orchards can assist farmers in many folds. Apart from reducing the amount of chemical fertilizer, farmers can reduce the amount of chemicals

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(insecticides and pesticides) that they use to control insects and pests while at the same time increasing the fertility status of their soils.

Reducing the number of insecticides can also be beneficial to the environment since most of these chemicals have a negative impact on the environment. However, there is a need to conduct a detailed study to establish the cause and effects of compost made from macadamia on the pests and diseases of macadamia trees.

4.4.3. Leaf nutrient concentration

The concentrations of nutrient elements (N, P, Zn, Cu, and B) in leaves of macadamia trees under investigation was considered low when compared with recommended standard leaf norms for macadamia as proposed by the Fertiliser Society of South Africa (Table 4.8). However, K, Ca, Mg, Mn, and Fe was sufficient for the growth and production of macadamia trees. Although there was low concentration of some of the nutrient elements (N, P, Zn, Cu, and B), it was fascinating to note that there was no single nutrient element that was deficient in all the treatments (FSSA, 2007) and credit was given to the addition of nutrients from macadamia husk compost. The observed increase in leaf N, P, K, Ca, and Mg levels with years could be due to the slow release of the nutrients from the added compost. Generally, organic fertilizers are slow-release and can steadily supply plant nutrients throughout the growing season. The fact that nutrient concentration in macadamia tree leaves in the research area was found to be low might be the result of wrong timing in the collection of leaf samples for analysis. The time of year, leaf age, and stage of shoot development all have an impact on the nutrient composition of the leaf tissue (Nagao *et al*., 1992). Weather variations, such as high temperatures or droughts that cause moisture stress, could also be a problem. The leaf samples were collected during October which is the time that coincides with flowering, fruit setting and oil accumulation in some macadamia cultivars (FSSA, 2007). These are very critical reproductive stages of plants and requires adequate water and nutrients-hence these could have been channelled elsewhere from leaves. While leaves are crucial for photosynthesis, they also serve as nutrient reservoirs. During fruiting or seed development, nutrients can be mobilized from older leaves to developing fruits or seeds. The plant prioritizes the reproductive structures, ensuring they receive sufficient nutrients for growth and maturation. The plant prioritizes the reproductive structures, ensuring they receive sufficient nutrients for growth and maturation. These are used for fertilizer recommendations/diagnostic for yield-limiting

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nutrients (Stephen *et al* 2002; 2020). However, this is a correct time to collect leaf samples specifically for fertiliser programming. For this study, leaf samples were supposed to have been collected based on the phenological stages of the macadamia trees. Unlike other trees, macadamia has a tendency of directing lots of nutrients and energy to the flowers, nuts, and transfer very little to the leaves. Therefore, this is not considered the most desirable time to collect leaf samples if the purpose is to determine the amount of nutrient taken up by leaves. Moreover, compost is considered as a slow-release fertiliser (Duong *et al*., 2013) which therefore might be one of the reasons why there was no significance difference on the amount of nutrients in the macadamia leaves.

There are, however, several options which can be employed by the macadamia farmers to increase concentration of nutrient elements in the leaves of macadamia trees. Compost can be mixed with chemical fertilisers or mixed with nutrient rich organic manure such as chicken litter or guano. Increasing the rate of compost from 12 t ha^{-1} to a higher rate in the long term since it is slowly released need to be explored since this can assist to increase the nutrient concentration in the leaves of macadamia trees.

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Table 4.8: Comparison of the observed leaf nutrient range and leaf norm analysis for macadamia.

Nutrients	N	P	K	Ca	Mg	Zn	Cu	Mn	Fe	B
	_____ Macro nutrients (%)___					_____ Micronutrients ($mgkg^{-1}$) _____				
Leaf norm:	1.2 – 1.6	0.6 – 0.7	0.6 – 0.7	0.6 – 0.9	0.08 – 0.10	15 – 50	5 – 10	100 – 1000	40 – 75	40 – 200
Observed range:	0.82 – 0.94	0.05 – 0.06	0.58 – 0.66	0.54 – 0.64	0.12 – 0.15	6.79 – 10.69	3.07 – 3.29	543.1 – 719.8	16.34 – 19.78	128.37 – 141.21
Results:	Low	Low	Sufficient	Sufficient	Sufficient	Low	Low	Sufficient	Sufficient	Low

* Source: FSSA (2007)

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4.5. Conclusions

From the results of this research, it can be concluded that:

- the nut yield of macadamia trees was improved by the application of macadamia husks compost.
- Applying 12 t ha^{-1} of macadamia husk compost was seen as the best rate to increase macadamia yield. However, the addition of macadamia husk compost did not impose significant effect on the husk yield.
- It was concluded from this study that the addition of compost at 12 t ha^{-1} made from macadamia husk reduces the incidence of nut damage by the insects and pests especially stink bug.
- The amount of macronutrient (K and Mg) and micronutrient (Fe, Cu, Mn, and B) in the leaves of macadamia trees were enhanced significantly by the application of macadamia husk compost.
- Leaf N, P, K, Ca, Mg, Fe, Zn, Mn, and Cu levels were all within the range considered best for macadamia trees in South Africa.

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CHAPTER 5

5. THE EFFECTS OF MACADAMIA HUSK COMPOST ON THE PHYSICO-CHEMICAL AND BIOLOGICAL PROPERTIES OF THE SOIL

5.1. Introduction

There is a remarkably high demand for macadamia nuts around the world, yet the current supply is not sufficient to cover the demand. Therefore, growers in many countries have begun planting large macadamia orchards (SAMAC, 2018). In 2020, global macadamia production was at 240,000 tonnes (nut in shell) and by 2025, this is expected to double to around 480,000 tonnes. By 2030, productions are expected to exceed 600,000 tonnes (SAMAC, 2022). South Africa is currently the world leader in macadamia production. The growth is due to new expansion of production from several macadamia growing areas.

Due to many entries into the macadamia industry, sustaining and maintaining soil fertility might be a challenge as the aim of every producer would be to produce higher yields of excellent quality. Consequently, soil fertility status of many macadamia farms is declining at an alarming rate while other farms have soils of inherently low fertility (Uys, 2018). Soil is one of the most important natural resources for plant growth and development because all the nutrients for plants are taken from the soil thus, most life on earth depends on soil as a direct or indirect source of food. Information on soil requirements for macadamia is important to crack issues of sustainability in macadamia orchard's farming. Applying inorganic fertilizer has the capability of maximizing crop yield but cannot sustain soil fertility as it can influence the loss of soil organic matter, decrease soil fertility, and increase susceptibility to erosion. In response to this challenge, supplementing chemical fertilizers with compost is seen by many as the best option to maximize crop yield and recover soil fertility status (Parihar and Sharma, 2021). Compost applications can enhance soil quality and productivity by replenishing soil organic matter and supplying plants with necessary nutrient elements and in so doing, increase crop yield and quality (Brodie *et al*., 2000; Soheil *et al*., 2012). To increase agricultural production and soil fertility, many macadamia growers are now using compost made from macadamia husks in addition to chemical fertilizers. The amount of macadamia husks produced annually is partially equivalent to the nuts that are produced annually (SAMAC, 2018).

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Anecdotal information has indicated that about 80000 tons of macadamia husks are produced every year in South Africa and only 20% of these are used as animal feed and fuel for cooking. Macadamia husk can be subjected to composting to make compost that can be used by the farmers to improve the fertility status of the soil which is declining due to distinct reasons. The use of macadamia husk compost as a soil amendment with correct applications rate may therefore increase macadamia production while maintaining soil fertility properties. However, there is a lack of information regarding the influence of macadamia husk compost on soil fertility properties (i.e., physical, chemical, and biological properties). In the light of the above, this study was initiated to establish the impact of applying different rates of compost made from macadamia husks on the physical, chemical, and biological properties of the soil.

5.2 Materials and methods

A complete description of the of the materials and methods used for this chapter is shown in chapter 3, sections: 3.1, 3.2, 3.3, 3.4.1,3.4.2 and 3.4.3.

5.3 Results

5.3.1 Effect of macadamia husk compost on soil chemical properties

A summary of the analysis of variance for chemical properties is presented in Table 5.1. The table shows that the treatments had significant influence on the concentration of nutrients on the soil at the study site. However, there was no significant effect of treatments on soil Mg, P, and Al. There was no significant interaction of year by treatments (Y x T) on all measured parameters. The effect of treatments on the chemical properties of the soil is presented in Figure 5.1. Except for OC and SOM content, all parameters were significantly influenced by year (Table 5.2.). The soil pH values of the compost treated soils were significantly *($p<0.05$)* higher compared to the control and increased with an increasing rate of compost. The maximum pH value of 6.5 was seen after applying 12 t ha^{-1} of compost compared to 6.1 observed under control. However, the pH values observed in this study were within the acceptable range for the growth and production of macadamia trees.

All the exchangeable cations (K, Ca, and Mg) significantly (*($p<0.05$)* increased with the compost applications of 8 t ha^{-1} (T3) and 12 t ha^{-1} (T4) compared to the control (T1). The maximum values of calcium content (1162.21 and 1104 mg kg^{-1}) were recorded on soils amended with 8 t ha^{-1} and 12 t ha^{-1} of compost, respectively. However, no statistically significant difference was observed between T1 (control) and T2 (4 t ha^{-1}) with reference

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to calcium content. Soil amended with 12 t ha^{-1} and 8 t ha^{-1} of compost resulted in high amount of potassium (263.13 and 225.25 mg kg^{-1}), respectively. However, no statistically significant *difference* was observed between T1 (control) and T2 (4 t ha^{-1}). It was observed in this study that the application of compost did not alter the Al status of the soil.

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Table 5.1 Mean square of analysis of variance for soil chemical properties after the application of macadamia husk compost.

Source	**Df**	**pH** (H_2O)	**Ca**	**Mg**	**K**	**Al**	**P** (Bray-1)	**OC**	**SOM**
			($mgkg^{-1}$)					(%)	
Year (Y)	1	0.56**	171968.01**	248336.28**	62216.25**	19.53**	224.19*	0.17ns	0.52ns
Treatment (T)	3	0.31**	95104.97**	501.28ns	28558.20**	2.20ns	55.42ns	0.28**	0.84**
Y x T	3	0.13ns	3775 ns	630.86ns	3960.61ns	1.25ns	21.99ns	0.02ns	0.06ns

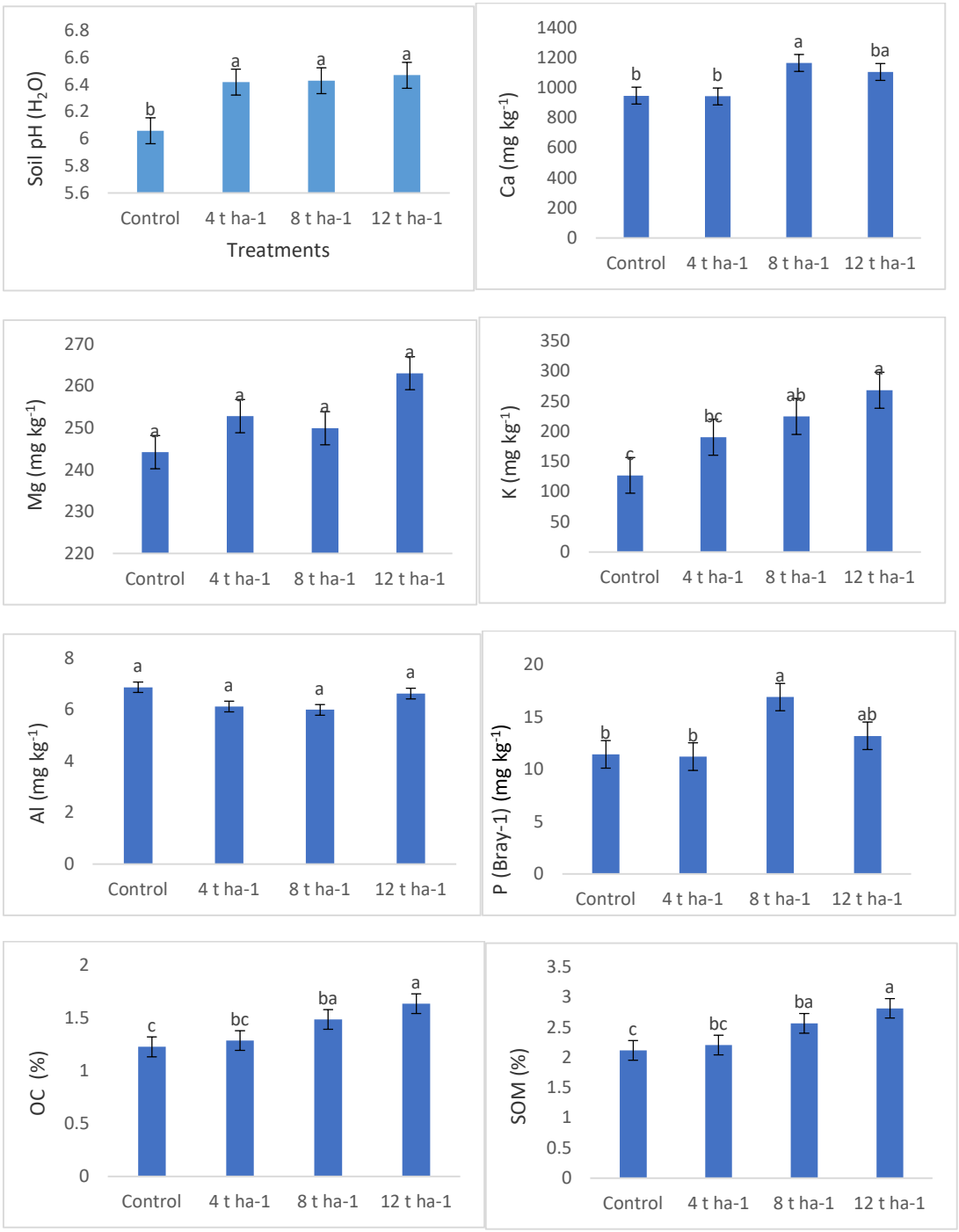
* Significant at *P<0.01*, ** Significant at *P<0.001*, ns Not significant, pH=Acidity/Basicity, Ca= Calcium, Mg=Magnesium, K=Potassium, Al= Aluminium, P=Phosphorus , OC= Organic Carbon ,SOM =Soil Organic Matter

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Data presented in Figure 5.1 revealed that the incremental application of compost increased the available phosphorus content in the soil. The maximum values (16.93 and 13.22 mg kg^{-1}) of available phosphorus content were recorded with the application of 8 t ha^{-1} and 12 t ha^{-1} of compost, respectively. There was, however, no statistical *($p>0.05$)* significant difference between T1 (control) and T2 (4 t ha^{-1}) with reference to available phosphorus content of the soil. However, the concentration of available phosphorus in soil was below 30 mg kg^{-1} which is the recommended soil norm for macadamia production in South Africa.

The study revealed that both SOC and SOM content of the soil increased with the application of compost. Applying 8 t ha^{-1} and 12 t ha^{-1} of compost significantly *($p<0.05$)* increased the SOC and SOM content compared to control. There was, however, no statistically significant difference between T1 (control) and T2 (4 t ha^{-1}) with reference to SOC and SOM content of the soil. It is obvious from the results of this study that application of compost to macadamia orchards could increase the amount of carbon stored in the soils and play a significant role in the reduction of greenhouse gas emissions (Botha & Nortje, 2021). Almost all nutrient elements were significantly *($p<0.05$)* influenced by the years of study with maximum values of all nutrients observed in 2022 compared to 2021 (Table 5.1). Variation in climatic conditions (Appendix 1) between the two growing seasons might have a significant impact on the way nutrients were released from the compost which in turn might have influenced the concentration of nutrients in the soil.

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Means within each parameter with similar letters are not significantly different by the T-Grouping test at 5% ($p<0.05$) level of probability, pH=Acidity/Basicity, Ca= Calcium, Mg=Magnesium, K=Potassium, Al= Aluminium, P=Phosphorus, OC= Organic Carbon, SOM =Soil Organic Matter

Figure 5.1: Effects of different rates of compost on the physicochemical properties of soil in the study site.

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Table 5.2: Soil chemical properties measured during the two years of study (2021 and 2022).

Year	pH (H_2O)	Ca	Mg	K	Al	P (Bray-1)	OC	SOM
		($mgkg^{-1}$)					(%)	
2020	6.22±0.34	959.13±99.26	164.44±32.52	158.88±56.99	5.38±1.09	10.56±3.49	1.34±0.39	2.30±0.66
2021	6.48±0.20	1114.00±290.98	340.63±49.71	247.08±101.46	6.94±1.43	15.86±6.92	1.49±0.37	2.56±0.64
	*	*	*	*	*	*	ns	ns

Means within the column with similar letters are not significantly different by the LSD (T-Grouping test) at 5% ($p<0.05$) level of probability, ns Not significant. C pH=Acidity/Basicity, Ca= Calcium, Mg=Magnesium, K=Potassium, Al= Aluminium, P=Phosphorus, OC= Organic Carbon, SOM =Soil Organic Matter

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5.3.2. Effect of macadamia husk compost on biological properties

The application of macadamia husk compost increased the biological properties of the soil. Table 5.3 shows the results of the mean square analysis of variance for soil health parameters. The results show that there was a significant ($p<0.05$) difference amongst the treatments. Soil organic carbon (SOC) is significant for year by treatment interaction (Table 5.3.); however, there was no significant interaction on particulate organic matter (POM), microbial biomass nitrogen (MB-N), microbial quotient (MQ) and microbial biomass carbon (MB-C).

Data presented in Figure 5.2 shows the response of soil biological parameters to the application of different rates of compost in the macadamia orchard. The results of this study indicated a statistically significant *($p<0.05$)* influence of compost on the biological parameters of the soil at the study site. Soil collected from the trees amended with a maximum rate of compost (12 t ha^{-1}) had high percent of SOC (1.80) with lowest percent recorded under the T 1 (control) treatment. Similar trend was also observed for POM (2.50), MB-C (5.30) and MB-N (0.80).

Applying 12 t ha^{-1} of macadamia husk compost to the soil at the study site increased SOC, POM, MB-C and MB-N contents by 149 %, 190 %, 319 % and 50 %, respectively. However, the MQ was decreased by 320 %. Compared to the control treatment, increment of 11 %, 35 %, and 50 % were observed for the MB-N content of T2, T3 and T4, respectively. In general, the order of the rating for all the biological properties was 12 t ha^{-1}> 8 t ha^{-1}> 4 t ha^{-1}> control. This is not a surprise since biological properties are very sensitive to the addition of organic matter.

Table 5.4 shows the effect of years on soil biological properties in the study site during the two growing seasons (i.e., 2021 and 2022). Only the SOC and MQ were significantly influenced by year with high rate of SOC (1.09 %) observed in 2022 compared to 0.99 % in 2021 while the opposite was the case with MQ.

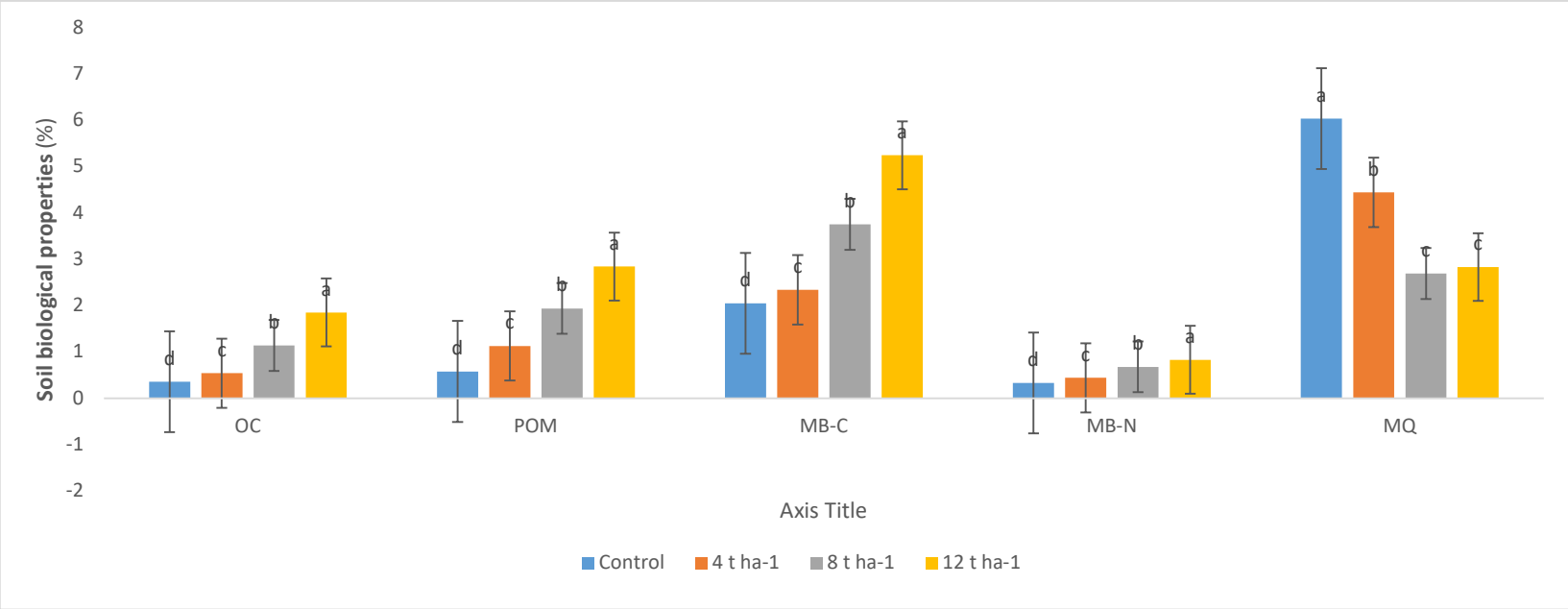
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Table 5.3: The mean square of analysis of variance for biological properties of soil from trees amended with macadamia husk compost.

Source	Df	SOC	POM	MB-C	MB-N	MQ
		(%)				
Year (Y)	1	0.07**	0.0003ns	0.125ns	0.0003ns	1.21**
Treatment (T)	3	4.02**	5.69**	17.17**	0.41**	18.55**
T x Y	3	0.02**	0.01ns	0.02ns	0.003ns	0.32ns

** significant at *p<0.01* level of probability, ns not significant, SOC Soil organic carbon, POM Particle organic matter, MB-C microbial carbon, MB-N microbial nitrogen, MQ Microbial Quotient.

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Means within each parameter with similar letters are not significantly different by the T-Grouping test at 5% ($p<0.05$) level of probability. SOC Soil organic carbon, POM Particle organic matter, MB-C microbial carbon, MB-N microbial nitrogen, MQ Microbial Quotient.

Figure 5.2: Effects of different treatments on biological properties of soil amended with macadamia husk compost.

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Table 5.4: Soil biological parameters measured during the two years of study (2021 and 2022).

Year	SOC	POM	MB-C	MB-N	MQ
			(%)		
2021	0.99±0.69	1.53±0.74	3.41±1.29	0.57±0.20	4.18±1.62
2022	1.09±0.62	1.53±0.79	3.28±1.36	0.56±0.24	3.69±1.33
	*	ns	ns	ns	*

* Significant at *p<0.05* level of probability, ns Not significant, SOC Soil organic carbon, POM Particle organic matter, MB-C microbial carbon, MB-N microbial nitrogen, MQ Microbial Quotient.

5.3.3. Effect of macadamia husk compost on physical properties

A summary of the analysis of variance for physical properties (water holding capacity (WHC), soil bulk density (BD) and aggregate stability (AI) is presented in Table 5.5. The result of this study shows that macadamia husk compost had significant influence on the WHC and BD. However, there was no considerable influence of both years and treatment on soil aggregate stability. There was a significant interaction of year by treatments (Y x T) on the WHC and BD. The WHC was significantly *(p<0.05)* higher on soil amended with macadamia husk compost than the control. The effect of compost improved with increasing rates of compost application. Figure 5.3 shows the effect of different rates of macadamia husk compost on the selected soil physical properties. Amending soil with MHC resulted in 8 t ha^{-1} and 12 t ha^{-1}compost application rates yielding the least values (1.28 and 1.29 g cm^{-3}) of bulk density respectively, meanwhile the control treatment had the highest bulk density value of 1.34 g cm^{-3} (Figure 5.3).

Figure 5.4 shows the effect of macadamia husk compost on the water infiltration rates at different time intervals. Applying MHC had a significant effect on water infiltration

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into the soil at different time interval. High rate of water infiltration was observed on soil amended with 12 t ha^{-1} of MHC followed by those treated with 8 t ha^{-1} and 4 t ha^{-1} of compost. Control treatment always had the least value of water infiltration at 17 mm min^{-1} whereas for 12 t ha^{-1} an amount of 41.57 mm min^{-1} infiltration was observed.

Table 5.5: The mean square of analysis of variance for physical properties of soil from trees amended with macadamia husk compost.

Source	Df	WHC	AI	BD
		(%)		gcm^{-3}
Year (Y)	1	23.153**	0.004ns	0.026**
Treatment (T)	3	1.077**	0.148ns	0.005**
T x Y	3	0.371*	0.021ns	0.0017*

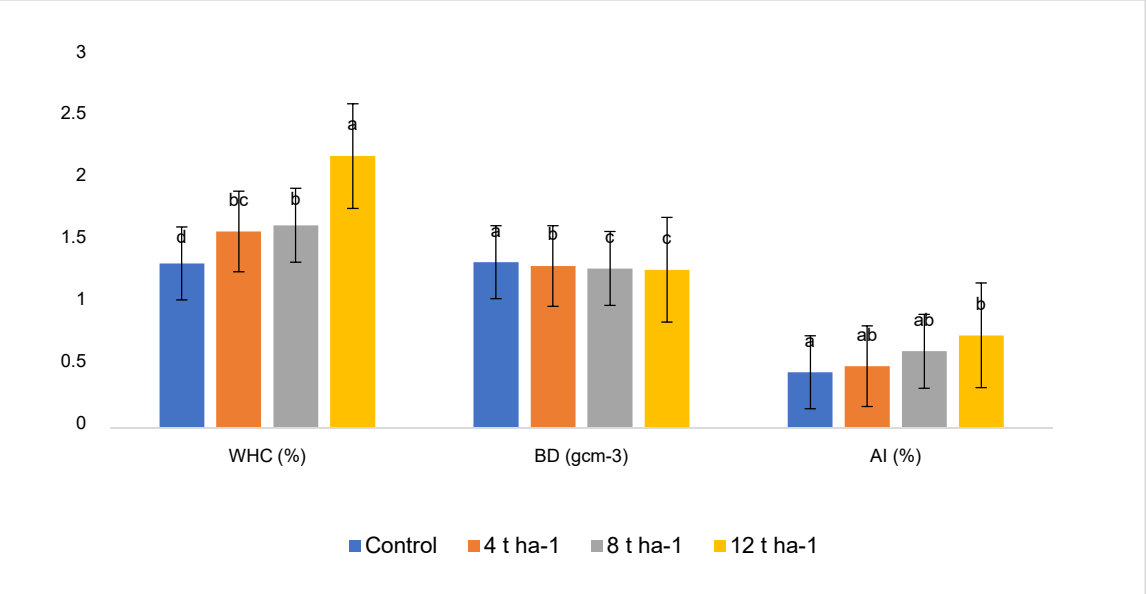
** significant at *p<0.01* level of probability, ns not significant, WHC= Water holding capacity, AI=Aggregate index, BD= Bulk Density

Table 5.6: Physical parameters of soils amended with different rates of compost during the two years of study (2021 and 2022).

Year	WHC	AI	BD
	%		gcm^{-3}
2021	2.53±0.55	0.57±0.30	1.44±0.29
2022	0.80±0.35	0.59±0.18	1.28±0.04
	*	ns	*

* Significant at *p<0.05* level of probability, ns Not significant, SOC Soil organic carbon, POM Particle organic matter, MB-C microbial carbon, MB-N microbial nitrogen, MQ Microbial Quotient.

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Means within each parameter with similar letters are not significantly different by the T-Grouping test at 5% ($p<0.05$) level of probability, SOC Soil organic carbon, POM Particle organic matter, MB-C microbial carbon, MB-N microbial nitrogen, MQ Microbial Quotient.

Figure 5.3: Effects of different treatments on physical properties of soil amended with macadamia husk compost.

Table 5.7 shows the analysis of variance for infiltration rate of water into the soil. The results show a significant effect of macadamia husk compost on the infiltration rate at different time intervals (1 ,3 ,5, and 10 min) of measurement. The study revealed that infiltration of water increased with increased application of compost.

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Table 5.7: The mean square of analysis of variance for infiltration rate of soil from trees amended with macadamia husk compost.

Source	Df	1	3	5	10
		mm min^{-1}			
Year (Y)	1	811.04*	208.59ns	224.19ns	1558.38*
Treatment (T)	3	949.62*	127.20*	1035.29*	794.88*
T x Y	3	286.04ns	175.67ns	368.26ns	1558.38*

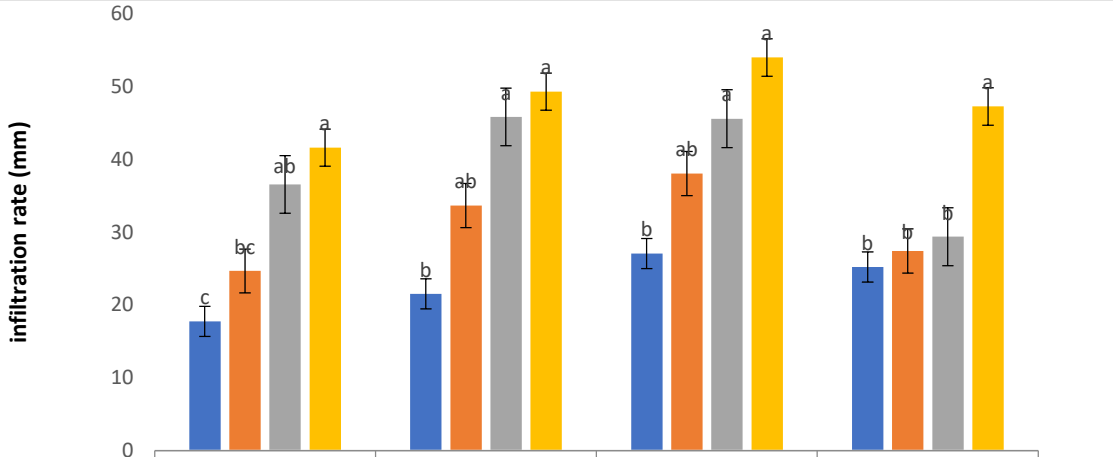
** significant at *p<0.01* level of probability, ns not significant

Table 5.8: Physical parameters of soils amended with different rates of compost during the two year of study (2021 and 2022)

Year	1	3	5	10
	mm min^{-1}			
2021	25.08±11.73	35.00±18.38	38.65±19.58	39.29±19.44
2022	35.15±18.21	40.11±19.28	43.94±18.24	25.89± 12.13
*	ns	ns	*	

* Significant at *p<0.05* level of probability, ns Not significant

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	1 min	3 min	5 min	10 min
Control	17.71	21.52	27.05	25.18
4 t ha-1	24.65	33.62	38.03	27.38
8 t ha-1	36.52	45.8	45.55	29.34
12 t ha-1	41.57	49.26	53.95	47.22

Means within each parameter with similar letters are not significantly different at 5% ($p<0.05$) level of probability by the T Grouping test.

Figure 5.4: Effects of different treatments on water infiltration rate at different time intervals.

5.4. Discussion

5.4.1. Soil chemical properties

The soil that was used in this study was slightly acidic, and after macadamia husk compost addition, the pH of the soil increased dramatically from 6.06 control treatment to 6.47 when 12 t ha^{-1} was applied, demonstrating the compost's efficiency in ameliorating acidity. Adding macadamia husk compost to the soil increased the pH level of the soil compared to the control. Similar enhancement of soil pH was reported previously because of the addition of organic amendment to the soil (Murovhi *et al*., 2015; Materechera and Mkhabela, 2002; Hue, 1992). According to Cahyono *et al*. (2020), applying 50 t ha^{-1} of raw materials originated from cow dung, bromelain waste and bamboo chopping through composting process, increased the pH of the soil by 0.20 units more compared to applying 25 t ha^{-1} of compost. The high concentration of bases in the compost may be liable for this outcome because organic compost

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contains a lot of calcium and other basic elements, it exerts a liming effect on the soil and increases its pH (Majingos *et al*., 2010).

The alkaline characteristic of the macadamia husk compost might be the reason for soil pH increase. Apart from that, applying compost is known to provide enough base ions in the soil, which can act as buffering agent against the acidification of soil. Dai *et al*. (2021) reported that the application of manure compost made for 10 years increased soil pH on a sandy loam texture soil of 53% sand, 24% silt and 4% clay by 0.18 units whereas mineral fertilizer decreased soil pH by 0.84 units. This was in consistent with the finding of Kluge (2006) also confirmed a significant increase of the pH value even at moderate compost applications. A mean increase of the pH value of 6.4 to 6.8 at 10 Mg d.m. Dai *et al*. (2021) further reported that application of compost has the capacity to reduce soil exchangeable acid content and increased the total amount of exchangeable base compared to mineral fertilizer (Dai *et al*., 2010). Therefore, it is very crucial to make sure that the soil pH stays within a reasonable range which is conducive to the crop in question. Moreover, each nutrient has a specific pH range that makes it more easily absorbed by plants and, if the pH is outside of this range, plant growth suffers accordingly. If the pH becomes too high or too low, certain elements in the soil becomes unavailable to the plants and will cause nutrient deficiencies.

All the exchangeable cations (K, Ca, and Mg) significantly increased with the compost applications of 8 t ha^{-1} (T3) and 12 t ha^{-1} (T4) compared to the control (T1). This agrees with the results of Cahyono *et al*. (2020) who reported significant increase in exchangeable cations after applying 25 t ha-1 and 50 t ha-1 of compost. The compost was made from raw components of bamboo, cow manure, and bromelain waste, which were composted for almost a month.

These increments can be attributed to a direct contribution of the nutrients from the compost itself and or the increased cation exchange capacity of the soil because of compost addition. According to Shirale *et al*. (2017), adding organic compost to the soil increased the availability of Ca2+, Mg2+ which exchange Na+ of clay particles and create favourable soil environment for microbial multiplication and activities. This means that addition of macadamia husk compost can be very useful for macadamia orchard as a source of exchangeable cations (Adugna, 2016).

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Data presented in Figure 4 revealed that the incremental application of compost increased the available phosphorus content in the soil. The maximum values (16.93 and 13.22 mg kg^{-1}) of available phosphorus content recorded after the application of 8 t ha^{-1} and 12 t ha^{-1} of compost. This is an indication that increasing the rate of macadamia husk compost to a certain level also increased the amount of phosphorus in the soil. Phosphorus is one of three macronutrients needed by all plants and its solubility in water depend on soil pH (i.e., 6.0 – 7.5) (ref and explain). If soil pH goes beyond or above this range, it becomes difficult for the plants to absorb phosphorus. However, although there was statistically significant difference among the four treatments with reference to available phosphorus content of the soil, the concentration of available phosphorus in soils from the study site was below 30 mg kg^{-1} which is the recommended soil norm for macadamia production in South Africa (FSSA, 2007). To mitigate this shortfall of phosphorus, macadamia husk compost can be supplemented with chemical fertilizers or mixed with phosphorus rich organic materials such as rock phosphate.

The study revealed that both OC and SOM content of the soil increased with the application of macadamia husk compost. It is obvious from the results of this study that application of compost to macadamia orchard could increase the amount of carbon stored in the soils and play a significant role in the reduction of greenhouse gas emissions (Maselesele *et al*., 2021: Wong *et al*., 2023). Moreover, applications of compost can lead to a build-up of soil organic carbon over time, and at the same time play a major role in reducing the rate at which organic matter is depleted from soils which is a serious concern especially in the macadamia orchards. Increasing the amount of soil organic matter and soil organic carbon content is very crucial in improving soil quality and increasing crop productivity because it plays a pivotal role in the cycling and mineralisation of nutrients by affecting soil chemical, physical and biological properties (Gerke, 2022). Compost supplies not only carbon but also essential nutrients that are utilised by soil microbes which are responsible for the formation of soil organic matter. According to Gerke (2022), organic matter produced from compost is responsible for supplying essential nutrients such nitrogen, sulphur, phosphorus, iron, zinc and copper.

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Except for OC and SOM, it was observed that all the nutrient elements significantly *(p<0.05)* differed between the two years of study (i.e., 2021 and 2022) with maximum values of all nutrients observed in 2022 compared to 2021 (Table 7). This was a clear indication that there were some variations between the two growing seasons. Variation in climatic conditions between the two growing seasons might have a significant impact on the way nutrients were released from the compost which in turn might have influenced the concentration of nutrients in the soil. For example, rainfall is an important driver of plant growth and biological activity which influences the mineralisation and release of nutrients from compost (Zhu *et al*., 2020). Unlike inorganic fertilizers, compost releases nutrients slowly over months or years, thus providing nutrients to the soil and plants throughout the growing period. It can be concluded based on the results of this study that the addition of compost made from macadamia husk improved the chemical properties of the soil at the study site. Adding 8 and 12 t $ha^{-1}$of macadamia husk compost increased the soil pH level and the amount of Ca, Mg, K, P, OC, and SOM contents of the soil. These elements are very crucial to the growth, development, and productivity of macadamia trees. Aluminium is very low in the middle, and highest with control and at 12 t ha^{-1} .

5.4.2. Effect of macadamia husk compost on biological properties

Macadamia (Figure 5.2) husk compost applied at different rates at the study site was more effective in increasing microbial biomass (SOC, POM, MB-C, MB-N) while at the same time decreasing the microbial quotient (MQ). This is consistent with the findings of Cox *et al*. (2004) who reported an increase in microbial biomass by 300% compared with bare soils 18 months after the application of macadamia husk compost. Similarly, Raviv (1988) noted an increase in microbial activities because of improved soil microbial biomass after the application of compost. Addition of macadamia husk compost increased from 0.99 to 1.09 the amount of soil organic carbon (SOC) stock during two years of the study. This concurs with the finding of Ren *et al*. (2019) who reported that an application of composted manure increased SOC by 40 % compared to control treatment with no compost amendment. Organic materials are recognised as the source and sink of carbon. As organic matter decomposes, it releases large quantity of carbon into the soil (Sainju *et al*., 2008). The released carbon plays a crucial role with respect to soil fertility because it improves soil structure, health and function. Increasing soil carbon is also seen to achieve carbon sequestration.

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Increasing the rate of macadamia husk compost from 4 t ha^{-1} to 12 t ha^{-1} resulted in the increase of POM in the study site. This result is an indication that the level of POM in the soil was low (as it can be seen from the control treatment) and thereby was improved by the addition of composted macadamia husks. It has been widely indicated that POM serves as a source of food for microorganisms and nutrients for plant growth and productivity (Hoffland et al., 2020). Apart from supplying nutrients and carbon to the soil, POM enhances soil aggregate stability, water infiltration and soil aeration (McCauley *et al*., 2009; Karuku *et al*.,2012). Furthermore, it increases cation exchange capacity and improves soil buffering capacity. This can also explain the in soil pH at the study site after the application of macadamia husk compost.

Soil collected from the trees amended with macadamia husk compost had significantly *($p<0.05$)* higher MB-C and MB-N compared to the control. This agrees with the finding of Ren *et al*. (2019) who reported that an application of composted manure increased MB-C and MB-N by 55 % and 21 %, respectively, compared to control treatment with no amendments. Similar results were shared by Amaral and Abelho (2016) who found higher MB-C, MB-N as well as MB-P contents on soil amended with compost compared to control treatment. Lower values of MB-C and MB-N which observed in the control treatment may explain the negative impact of chemical fertilisers since the study block is under conventional farming where chemical fertilizers are applied every year to supply nutrient elements to the macadamia tress. Injudicious use of mineral fertilizer can have a negative impact on soil microbial biomass because of soil acidification which changes the nature and behaviour of microbial communities (Treseder, 2008). Addition of fertilizer salts have a primming effect in the soil and release of occluded materials in organic combination. They affect species population and diversity until the substrate is gone and biomass goes down (Karuku and Mochoge, 2016) release Bittman *et al*. (2005) and Qiu *et al*. (2016) reported about 12 and 48 % decrease in MB-C and MB-N on soil after the application of chemical fertilizers as compared to the plots that received organic amendments. When using chemical fertilisers and compost, one must find a balance between the two to avoid the issue of soil destabilisation and destruction of beneficial soil organisms.

However, not all researchers have observed the positive effects of compost on MB-C and MB-N content of the soil. In contrast to these results, Logan *et al*. (2010) found no significant effects of organic amendments on the MB-C and MB-N contents of the soil.

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This might be due to the amount and quality of compost which were used in the study. Higher MB-C in the study site was observed in 2022 than in 2021. This could probably be the result of the cumulative or residual effect of the macadamia husk compost which was applied on the orchard during the two growing seasons.

The improvement of soil biological parameters which were observed in this study might probably be due to the action of soil microorganisms (Gregorich *et al*., 1994). Raviv (1988) has also associated the increase in soil biological parameters with high number of microbes which in turn enhance organic matter decomposition and the release of nutrients in the forms that are available for plant uptake. These microbial activities have assisted in the liberation and cycling of nutrients and their availability to plants. Although not evaluated in this study, the incorporation of composted macadamia husks in soil might have influenced soil enzymatic activity because of the intra- and extracellular enzymes which may have stimulated microbial activity in the soil. This study has concluded that the addition of macadamia husk compost at different rates significantly increased the levels of all the soil biological properties (SOC, POM, MB-C and MB-N) that were evaluated in the study site. This emphasises the importance of adding compost to the soil with the idea of increasing the levels of organic matter content. However, applying 12 t ha^{-1} of macadamia husk compost seem to be effective and efficient as compared to the other rates. Utilisation of macadamia husk compost can be beneficial in the macadamia orchards which are deficient in soil biological properties.

5.4.3. Effect of macadamia husk compost on physical properties

The most important objective was to determine the effect of macadamia husk compost application rates (0, 4, 8, and 12 t ha^{-1}) on soil physical properties, including bulk density, water holding capacity, aggregate stability, and infiltration rate. In this study, the bulk density was reduced by the application of macadamia husk compost, and this could be because of an increase of soil organic matter.

According to the study's findings, the control treatment had the highest soil bulk density (1.34 g cm^{-3}), whereas T3 (8t ha^{-1}) and T4 (12t ha^{-1}) had the lowest values (1.28 and 1.29 g cm^{-3}, respectively). According to Lusiba *et al*. (2017) and Brown and Cotton (2011), adding organic material like compost to the soil is crucial to the total soil organic carbon, which reduces soil bulk density and improves stable soil aggregates and porosity. This

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observation is like the results reported by Meena *et al*. (2018), who found significant reduction in bulk density after applying farmyard manure (FYM). The authors mentioned increased macro- porosity space, organic carbon, and improved soil structure as the causes of the decline in bulk density. Liu *et al*. (2007) found that compost application reduced the bulk density and associated this decrease as indicative of an increase in pore space. High soil bulk density on the other hand can limit root penetration and elongation, and this can result in the limitation of critical nutrients, and reduced water transmission which in turn reduces the plant's entire growth.

The study revealed that soils amended with macadamia husk compost had high water holding capacity than the control treatment. Applying 12 t $ha^{-1}$of macadamia husk compost to the soil in the study site increased the water holding capacity, with the lowest percent recorded under the T 1 (control) treatment. This comes as no surprise because compost is known to have a great capacity to store water and can eventually supply water to plants (Crogger, 2005). According to Brown and Cotton (2011), increasing organic carbon is an important component for enhancing soil water holding capacity. This study agrees with the findings of Campbell *et al*. (1994) who reported an increase in water holding capacity and porosity after applying compost to the soil. Compost acts as a surface mulch thus reducing direct evaporation and enhancing water retention in the soil. Askin and Aygun (2018) found that applying hazelnut husk compost into the soil increased soil moisture content in hazelnut orchard. The highest water content was observed after applying 10 t ha-1whereas a low water content was seen at the control treatment. According to their findings, the treated soil had a water-holding capacity that was almost 1.57 times more than that of the control soil. In another study, Maynard (2000) found that increasing the water holding capacity of the soil by adding compost improved all crops during summer droughts by reducing periods of water stress. This means that addition of macadamia husk compost can be very useful for macadamia orchard as a source of water retention, especially in dryland areas where water scarcity is a major concern.

Macadamia husk compost applied at different rates at the study site was more effective in increasing the infiltration rate of water in the soil. When compared to the control, two years after the macadamia husk compost application, both treatments considerably increased the rate of water infiltration with the maximum amount of water found after applying 12 tha^{-1} of compost. This finding concurs with the results of Crogger *et al*. (2008) who found high

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water infiltration after applying compost on the soil surface for over six years. The increase in water infiltration observed in this study can be attributed to an increase in porosity and reduced bulk density of the soil material with the addition of composted macadamia husks. The increased infiltration might also be due to increased rate of macadamia husk compost from 4 t $ha^{-1}$to 12 t ha^{-1}which resulted in the increase in POM at the study site. POM has always been associated with high water infiltration and aggregate stability.

Aggregate stability of the soil was also influenced significantly by the application of compost made from macadamia husk. Aggregate stability is an important soil property because it affects water infiltration and flow in soil. The work described here sought to understand how the amount of composted organic matter could affect aggregate stability and to relate any changes to the amount of composted macadamia husk used. The result of this study shows an increase in aggregate stability in relation to the treatments with the least values obtained under control while the maximum aggregate stability values were observed after applying 12 t $ha^{-1}$of MHC. This is in line with the results of Cebula, (2013), Nciizah, (2011), and Materechera, (2009), which demonstrated an increase in aggregate stability following cow manure application compared to the control treatment. This could be due to different organic fractions that contribute to aggregate stabilisation and microbial biomass in particular fungi (Degens, 1997) and the POM which forms a nucleus or core around which clay packets and small micro-aggregate are bound into larger micro-aggregates (Elliot, 1996; Golchin *et al.*,1994). According to these findings, it can be concluded that the physical properties of soil were improved by the application of macadamia husk compost, especially at the application rate of 12 t ha^{-1}. Stability of aggregates depends on cementing agents of SOM and the water films that binds them (Karuku *et al.*, 2012; Daraghmeh *et al.*, 2007). This can greatly contribute to improve degraded soils in macadamia orchards and improve agronomic quality of the soil which in turn will have a positive effect on the yield and quality of macadamia nuts.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study investigated the response of MHC application rates on the yield and quality of the nuts as well as soil health.

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- The application of different rates of MHC had a beneficial influence on the parameters investigated. The results show that there was an improvement in the bulk density, infiltration rate and water holding capacity.
- The application of different rates of compost was beneficial to the soil physicochemical properties, soil biological properties, macadamia nut yield and quality, and physiological parameters of macadamia during the study period.
- The compost application rates of 8 t $ha^{-1}$and 12 t ha^{-1}produced the highest nut yield per tree. On the other hand, increasing compost rates led to an increase in soil organic matter content, carbon content and nutrient content of the soil.
- Furthermore, the use of compost has demonstrable positive effects on the quality of the nuts such as increasing the sound kernel, total kernel, first grade nuts, increased nut mass and diameter at nut set stage, while reducing the incidence of early germination and early and late insect damage.

Since there is a limited availability of macadamia husks, the rate of macadamia husk compost that can be used to optimize yield, nut quality, soil properties and physiological parameters of macadamia trees is 12 t ha^{-1}. It can be concluded that compost made from macadamia husk is a good source of nutrients and organic matter for macadamia orchard soils and, as noted in this study, using it can substantially reduce the amount of chemical fertilizer needed.

6.2 Recommendations

The results of this study proved beyond reasonable doubt that the application of compost made from macadamia husks can increase yield, improve the quality of nuts, and the fertility status (physical, chemical, and biological properties) of the soil. In the light of the above, the following recommendations are made:

- Macadamia farmers should be encouraged to start using compost made from macadamia husks as soil conditioner. If properly applied, the following benefits can be achieved by the farmers:
- Increase nut yield and quality: It has been shown in this study that application of compost made from macadamia husks increases nut yield. Application of compost improved soil fertility (i.e., physical, chemical, and biological properties), thereby creating favourable conditions for growth, development, and productivity of macadamia trees. Increasing nut yield is the primary goal

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for all macadamia farmers since this will enable them to obtain a higher income. Applying compost in macadamia orchards can play a significant role in enhancing nut quality. There is a possibility that increasing the rate of macadamia husk compost above 12 t ha^{-1}can further increase the yield of macadamia and improve soil fertility. However, this requires further research. Quality is one of the main aspects which determines the market price of the nuts. Nut quality can be improved drastically using compost and therefore it is recommended for the macadamia farmers to include compost in their fertilisation programmes if their aim is to attract high market prices. Farmers can use the money that they have saved for expanding their production capacities.

- Reduce losses: Applying compost was shown to significantly enhance the physiological parameters of macadamia trees in this study. For example, applying compost reduces the incidence of early nut germination, early and late insect damage to the nuts which in turn increased nut yield. This translates into greater income potential. Water is lost from the farm through leaching, evaporation, and runoff. The study revealed high soil water content after the application of compost which implies that farmers can cut the cost of irrigation and save a large quantity of water.
- Improve soil fertility (sustainability): Application of compost as a soil amendment could be an integral part of macadamia production best management practices. Compost application can potentially improve soil quality and provide additional nourishment to trees. Compost addition tends to enhance the soil's ability to retain both nutrients and water, thereby improving fertilizer-use efficiency. Unlike inorganic fertiliser that provides immediate nutrients for plant uptake, compost adds organic matter into the soil which is the store house of nutrients. These nutrients are released to the soil gradually over a long period of time and makes farming more sustainable. However, further research is needed to determine the presence of heavy metals in the macadamia husk compost and to monitor the accumulation of heavy metals in the macadamia orchard after long term application of compost.
- Macadamia farmers must measure the quantity of macadamia husks immediately after de-husking. Knowing the quantity of husks that are being

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produced annually will assist in future research and will facilitate determination of the monetary value of using macadamia husk compost. This will also assist the macadamia industry in calculating the contribution of, and impact that they are making, in mitigating climate change by reducing landfills through the recycling of macadamia husks.

- For those farmers who are already utilising macadamia husk compost on their farms, heavy metal analysis of their compost should be encouraged to comply with the National Environmental Management: Waste Act 2008 (Act No: 59 of 2008).

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Appendix A: Temperature range at Levubu during the two years of study (2022 and 2021).

Months	T	T_{max}	T_{min}	H	PP	T	T_{max}	T_{min}	H	PP
	Year 2022					(Year 2021)				
Jan	23.1	29.5	19.4	77.1	150.37	23.4	29.9	19.7	81.9	248.39
Feb	24.1	32.3	18.8	69.6	15.23	22.4	30.2	19.2	84.2	219.98
Mar	22.6	30.7	17.5	70.4	67.81	23.4	31.1	18.3	72.5	8.63
Apr	20.5	27.9	16	76.9	161.3	20.6	29.3	14.9	67.1	4.82
May	18.3	26.2	12.9	70.8	0	18.5	27.9	12.1	59.3	2.29
Jun	18	26.9	11.5	59.9	0	16.7	25.4	10.3	60.2	5.07
Jul	17.6	27.6	10.1	49	0.25	15.8	24.8	9.5	55.8	10.41
Aug	18.8	29.3	12.2	49.2	3.81	18.2	26.8	12.1	58.9	15.75
Sep	22	30.2	13.5	49.9	2.03	20.2	29.3	13.9	55.9	9.65
Oct	24.7	32.4	17.6	57.9	5.83	20.3	27.8	15.1	68.1	64
Nov	23.7	30.5	18.2	69.2	33.53	24.8	33.2	18.5	58.9	11.94
Dec	24.5	32.4	19	71.1	37.34	23.5	30.5	19	76.4	198.12

T= Temperature, Tmax = Maximum temperature , T_{min} = Minimum temperature , H= Humidity PP= Precipitation

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