EFFECTS OF MACADAMIA HUSK COMPOST ON PHYSICOCHEMICAL SOIL PROPERTIES, GROWTH AND YIELD OF CHINESE CABBAGE (*Brassica rapa L. Chinensis*) ON SANDY SOIL

BY

Dembe Maselesele

Student number: 11617842

Dissertation for Master of Science (MSc) degree in Agriculture (Plant Production)

Department of Plant Production

School of Agriculture

University of Venda

South Africa

Supervisor: Prof. J.B.O Ogola

Co-supervisor: Dr. R.N Murovhi

JULY 2020

DECLARATION

I, Dembe Maselesele (student number: 11617842), hereby declare that this dissertation for Master of Science (MSc.) degree in Agriculture (Plant Production) submitted to the Department of Plant Production, School of Agriculture, University of Venda, has not previously been submitted for a degree at this or any other University. It is original in design and execution, and all references have been duly acknowledged.

Student: Mr D. Maselesele		01 July 2020
	Signature	Date

As the supervisors/co-supervisor of the candidate, we agree to the submission of this dissertation

Supervisor: Prof J.B.O Ogola		1 July2020
	Signature	Date
Co-supervisor: Dr R.N Murovhi		01/July/2020
	Signature	Date

ACKNOWLEDGEMENTS

I acknowledge the ARC-ITSC, for financial support. I am very grateful to my supervisor, Prof J.B.O Ogola for giving me the opportunity to carry out this study. Thank you for your scientific support, encouragement, guidance and patience throughout the study period. I am also grateful to my co-supervisor Dr R.N Murovhi for his valuable support in this study. I also thank him for sacrificing his time and energy for the sake of this research. Gratitude is also due to Mr E. Mathebula for their assistance in analysing the data. I would like to extend my gratitude to the Levubu ARC-ITSC farm workers Mr N.J Sekhwama and Mr A. Mulaudzi who helped me with the field work. I also thank my fellow MSc Agriculture students at the university of Venda, with whom I shared a lot in common for their support and encouragement during the study period. I also acknowledge my family who backed me up from the beginning of this research until the end. Lastly, a great salute to our almighty God who gave me chance, time, and wisdom to conduct this research.

DEDICATION

I dedicate this Dissertation to the Lord Jesus Christ for the wonderful gift of life and good health throughout my study period, to my family and friends who supported me during this study.

ABSTRACT

Poor soil fertility caused by inadequate supply of nutrients on soil is one of the major constraints limiting crop production especially in the Vhembe District Municipality, Limpopo, South Africa. Therefore, management practices such as application of organic manure to minimize soil infertility is considered as good practice for smallholder farmers. This study aimed at evaluating the effect of macadamia husk compost on selected soil properties as well as the growth and yield of Chinese cabbage on sandy loam soil.

A field experiment was carried out during 2018 and 2019 winter season at the Agricultural Research Council (ARC) research farm in Levubu. The experiment was laid out in a randomized complete block design (RCBD) with 4 treatments (control (zero)), inorganic fertilizer (100:60:60 NPK Kg ha^{-1}) and compost at 15t ha^{-1} & 30t ha^{-1} replicated 3 times. Soil was analyzed before planting and after harvesting to determine the influence of applied compost on selected physical properties (soil bulk density and water holding capacity) and chemical properties (soil pH, soil organic matter, soil organic C, EC, total N, P, K, Ca, Mg, Na, Al, Zn and Mn). Number of leaves, fresh mass, dry mass and leaf area was collected at three harvests interval (28, 46 and 74 days after transplanting). After each harvest period, leaves were analysed for nutrient content (N, P, K, Ca, Mg, Zn, Cu, Mn and B). During the final harvest crops were uprooted and root biomass (fresh mass, dry mass and root length) were recorded. Analysis of variance (ANOVA) were conducted on all data using Genstat package 18th addition. Differences between treatment means were separated using the least significant differences (LSD) procedure and correlations analysis was determined using Pearson's simple correlation coefficient.

Macadamia husk compost application had a significant effect on soil bulk density and water holding capacity. Addition of macadamia husk compost significantly increased soil pH, OC, N, C: N K, P, Mg, Ca, Na, Al, Zn, Ca and Mn. In contrast, addition of macadamia husk compost had no effect on soil EC. Yield components (number of leaves, fresh mass, dry mass), root biomass, root length and leaf area increased with application of macadamia husk compost. Yield components, root biomass, root length and leaf area were significantly affected ($p<0.01$) by harvesting time. Yield components in the second cropping season was greater than yield components in the first season. Macadamia husk compost application showed no significant effect on leaf nutrient content of Chinese cabbage. However, leaf nutrient content was affected by harvesting time.

It is evident from the results of this study that macadamia husk compost affects soil fertility and plant production. The results suggest that macadamia husk compost has a potential to be used as a reliable fertilizer by famers especially smallholder farmers who struggle to buy inorganic fertilizer because they are expensive. Since this study was conducted over two seasons and compost effect tend to be long term, further research is needed on application of macadamia husk compost on soil properties and yield of other crops over wide range of soils.

Key words: Macadamia husk compost, soil properties, Chinese cabbage, crop yield, harvesting time

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.INTRODUCTION

1.1 General introduction

Vhembe District Municipality (VDM) is one of the Limpopo Province's regions where there is high level of poverty. The poverty rate is about 12.8% with each family living on R160, 00 per day (Statistics South Africa, 2016). Majority of people in this District are smallholder farmers who own between 0.5 to 2.5-hectare fields where they grow different agricultural crops for family consumption while some of the farmers also sell their surplus products as means of generating income. However, the quality and quantity of the products is very low partly due to low inherent soil fertility, lack of agricultural inputs, lack of finance and low level of agricultural knowledge. Amongst these farmers there are farmers who are cultivating fruit and nut trees such as mango, avocado, litchi and macadamia. Poor soil fertility is considered by many as the major constraint that limit crop production in the Vhembe District Municipality (Odhiambo and Magandini, 2008). One way of improving crop yield is through the use of inorganic fertilizers. However, majority of smallholder farmers in the area cannot afford to use inorganic fertilizers because they are expensive. Moreover, inorganic fertilizers are detrimental to the environment and can cause health problems due to their toxicity (Basak *et al.,* 2017). To counteract that, farmers use different organic materials such as plant litters, chicken manure, cow dung manure and goat manure to improve the fertility of soil.

Vhembe District Municipality is one of the few regions in South Africa where a large number of farmers are cultivating macadamia nuts trees because of their market demand and high income. A report from Subtrop, (2008) indicated that the area under production of macadamia in South Africa is about 17 367 ha and out of this, 5 105 ha is in Limpopo Province where there are about one million five hundred and fifty thousand trees. After harvesting, macadamia go through the process of removing the husk called de-husk. As a result, farmers are left with tons of macadamia husks that can be used for other beneficial purpose other than dumping them in the landfills as waste materials. One way of achieving that is by composting the husk to make compost. Macadamia husk are known to decompose quickly and release nutrients rapidly (Cox *et al*., 2004).

The compost from macadamia husks can be used to enhance soil fertility and increase crop productivity especially on smallholder plots. Composting of macadamia husk for use in crop production may serve as an alternative waste disposal technique to landfill and incineration (Bittenbender *et al*., 1998). Composting has been shown to be an efficient treatment to recycling wastes and thus provide valuable resources for use in agriculture both for supplying nutrients and for maintaining soil organic matter (Bustamante *et al.,* 2008). The advantage of organic fertilizers is that they are environmentally friendly, and they encourage diverse population of beneficial microorganisms (Bulluck *et al.,* 2002). The use of organic inputs such as compost has great potential in improving soil fertility and crop yield through improvement of chemical, physical and microbiological properties of soil as well as nutrient supply (Stone and Elioff, 1998). Compost from agricultural wastes such as spent mushroom, carnation wastes, rice husk and others have been reported to improve soil fertility and other soil properties (Polat *et al.,* 2009; Sonmez and Kaplan, 2011; Barus, 2016). Studies have shown that application of compost can significantly increase soil organic carbon, soil pH, improves soil structure, decrease bulk density, provide macro and micronutrients and enhance microbial activity (Adugna, 2016). Organic manure is preferred by farmers as a source of nutrients to increase soil fertility over inorganic fertilizers as organic manure provides a full range of nutrients required for optimal plant growth (Nambiar and Ambrol, 1989). Application of organic manure increased Ca, Mg, Na and K than in NPK treatment (Sanni, 2016; Adekayode and Ogunkoya, 2011). However, these benefits depend on type of feedstock, soil type, composting procedure application rate and method of application (Bernal *et al.,* 2009).

Although the effect of compost from different feedstock on soil and yield of different crops have been well documented (Setyowati *et al.,* 2014; Joshi *et al.,* 2016; Barus, 2016; Ojobor *et al*., 2017), there are few studies in literature on the effect of macadamia husk compost on soil properties in Hawaii and Australia (Cox *et al.,* 2004; Bittenbender *et al.,* 1998). However, there are hardly any studies on the effect of macadamia husk compost on soil and crop yield in South Africa. Therefore, there is a need to evaluate the effect of macadamia husk compost on selected soil propertied and crop yield under field conditions of dry environment in Limpopo, South Africa.

.

1.2 Main objective

The main objective of the study was to evaluate the effect of macadamia husk compost on selected soil properties as well as the growth and yield of Chinese cabbage (*Brassica* rapa L. *Chinensis*).

1.3 Specific objectives of the study

(a) To evaluate the effect of macadamia husk compost on yield and growth of Chinese cabbage (*Brassica rapa L. Chinensis).*

(b) To determine the influence of macadamia husk compost on selected soil properties.

(c) To determine the effect of macadamia husk compost on nutrient content of Chinese cabbage (*Brassica rapa L. Chinensis)*.

1.4 Hypotheses

(a) Macadamia husk compost affects yield and growth of *Brassica rapa L. Chinensis*

(b) Macadamia husk compost affects selected physical and chemical properties of soil.

(c) Macadamia husk compost affects the nutrient content of Chinese cabbage (*Brassica rapa L. Chinensis).*

2. LITERATURE REVIEW

2.1 Compost

Compost is a product resulting from controlled biological decomposition of organic material from various sources (Tweib *et al.,* 2011; Bastida, *et al*., 2010). This process is based on microbial breakdown which transforms organic materials into complex organic molecules (Paulin and O'Malley, 2008). Mature compost is usually dark in colour and has a pleasant smell unlike premature compost (Farrell and Jones, 2009). A compost can be mature but can be of poor quality due to low nutrient levels. The nutrient value of compost varies widely, depending on material composted (Bernal *et al.,* 2009). Compost must be mature for its use as an organic fertilizer and if applied early, the leaves of plants may burn, the growth can stop and sensitive plants can die (Epstein, 1997). Immature compost smells poorly, has a wide C/N ratio and a high ammonium content (Epstein, 1997; Farrell and Jones, 2009). However, it continues to break down once it is incorporated into the soil (Morlat, 2008).

2.2 Soil fertility

Several studies have showed that the application of compost has lots of benefits as far as crop production is concerned (Barus, 2016; Polat *et al.,* 2009). These include an increase in water holding capacity, soil pH, cation exchange capacity (CEC), Electrical conductivity and habitat for soil organisms (Leroy *et al.,* 2008, Hossain and Ryu, 2017). However, these benefits vary depending on soil type, compost type, compost quality, application rate, application method and crop being grown (Campell and Sharma, 2007). Furthermore, compost provides beneficial micro-organisms that kill or compete with pathogens which result in suppressing disease such as root rot caused by *Pythium* and *Phytophthora* (Sullivan *et al*., 2004). The ability of compost to suppress diseases may help to reduce the high application rate of pesticides, and consequently reduce the cost of crop production as well as the detrimental effects of pesticides on the environment (Sullivan *et al*., 2004).

2.2.1 Effect of compost on physical properties of soil

Application of compost affects soil physical fertility mainly by improving aggregate stability, decreasing soil bulk density and increasing soil pore volume; which favour gas and water transfer in soils, water retention, plant root growth and reduces soil erosion (Manivannan *et al.,* 2009; Leroy *et al*., 2008; Olabode *et al.*, 2007). Compost limit water loss via evaporation and therefore increase water retention (Or and Wraith, 2002). Carter *et al*. (2004) reported improved aggregate stability, decrease of soil bulk density and decrease of soil water filled pore space with application of compost from sawdust and potato on fine sandy loam soil in Canada. Water holding capacity of soil was improved with application of compost from municipal solid waste compared to inorganic fertilizers (Laxminarayana, 2006). Addition of compost from municipal solid waste improved drainage and aeration while reducing bulk density on sandy soil (Shyamala and Belagali, 2012).

Application of fresh rice straw and maize stover compost at a rate of 10 t ha^{-1} reduced soil bulk density, improved total porosity, increased secondary pore structures, improved water retention and increased soil drainage pores together with moisture content compared to control (Barus, 2016) on silt soil in Indonesia. Addition of pineapple residue compost at 40 t ha^{-1} decreased bulk density in China (Liu *et al.,* 2013). Martinez-Blanco *et al*. (2013) reported an increase in aggregate stability, water holding capacity and decrease in bulk density after feedstock compost application.

In a 5-year experiment with compost from cattle manure at 25 t ha^{-1}, Celik *et al.* (2010) reported that compost reduced bulk density compared to treatment fertilized with NPK. Furthermore, it was reported that application of compost increased water content of soil by 58 – 86%. In a 9 years study, Leroy *et al. (*2008) found that application of vegetable, fruit and garden waste compost at 0, 22.5 and 45 t ha^{-1} reduced bulk densities compared to unfertilized and mineral fertilized treatments on sandy loam soil in Belgium. Moreover, the bulk densities decreased as application of compost increased. Ibrahim and Fadni (2013) compared the effect of compost with chicken and cattle manure each applied at 10 t ha^{-1} on sandy soil and reported that the highest bulk density was recorded in compost treatment while the untreated control treatment gave the lowest value.

In Argentina, Civeira (2010) reported that medium and high compost doses of municipal solid waste improved moisture retention, water infiltration and reduced bulk density as compared to control treatment. Similarly, a study by Albaladejo *et al.* (2009) showed that application of municipal solid waste compost improved soil water retention capacity, moisture retention, helped in sustaining aggregate stability and improved soil fertility. Moreover, the results of Tadesse *et al.* (2013) indicated that application of farm manure compost at 7.5 t ha^{-1} and 15 t ha^{-1} increased water holding capacity compared to inorganic fertilizer and control. In Australia Cox *et al.* (2004) indicated that macadamia husk compost improved water holding capacity and bulk density compared with bare soil (control).

Studies have shown that compost from different sources affect physical properties of soil in different soil types across diverse geographic regions. Also, a study by Cox *et al*. (2004) in Australia indicated that macadamia husk compost affects physical properties. However, there is hardly any evidence in literature of macadamia husk compost in dry areas of South Africa and other countries except for Australia. Therefore, a thorough investigation on effect of macadamia husk compost on soil physical properties is needed since compost effect vary with environments.

2.2.2 Effect of compost on chemical properties of soil

Apart from improving the physical properties of the soil, application of compost enhances soil chemical properties by increasing organic matter content, soil pH, carbon content, Total N, electrical conductivity (EC) and exchangeable cations (Bakayoko *et al.,* 2009; Ogbonna *et al.,* 2012; Liu *et al.,* 2013; Teshome *et al*., 2017).

Application of compost has been reported to either increase and decrease soil pH depending on compost type and soil pH (Butler *et al.,* 2008). Arthur *et al.* (2012) investigated the effect of compost applied at 7.5 t ha^{-1} from garden waste and spent mushroom on soil properties and observed a significant increase in pH over control on sandy loam soil in Iran. Similarly, Ouedraogo *et al*. (2001) reported increase of soil pH with application of compost from household waste, crop residues and ashes at different sites on loamy sand soil in Burkina Faso. Mandal *et al*. (2013) reported that application of poultry litter compost increased soil pH compared to control and inorganic fertilizer in United states of America. Bittenbender *et al*. (1998) and Cox *et al*. (2004) indicated that macadamia husk compost increased soil pH on sandy and ferrosol soil in Hawaii and Australia, respectively. Demelash *et al*. (2014) reported that application of compost from cactus, crop residue, vegetable and fruit peels did not have a significant effect on soil pH in Ethiopia.

The application of compost on soil has a significant influence on the electrical conductivity of the soil. Sarwar *et al. (*2008) attributed increase of EC after compost from rice and wheat was applied at 12 and 24 t ha^{-1}. Civeira (2010) reported increase of EC after application of municipal solid waste compost. In contrast, Results by Hossain and Ryu (2017) showed that there was no significant effect on EC after organic fertilizer application. In Nigeria, Iren *et al*. (2015) reported that application of cassava peels compost applied at 4 t ha^{-1} and 8 t ha^{-1} increased EC compared to control treatment. Moreover, the results also indicated than EC at 8 t ha^{-1} was higher that EC at 4 t ha^{-1}.

Soil organic matter and organic carbon is improved by the application of compost. Nutrients in compost are in organic forms which are released slowly and are less subject to leaching compared to synthetic fertilizers (Larney *et al.,* 2008). A study by Lee *et al.* (2015) in Korea reported that organic matter was increased by the application of rice straw compost compared to synthetic fertilizer treatment and control on sandy loam soil. Aranyos *et al*. (2016) reported that application of sewage sludge compost and straw compost combination applied at 9, 12 and 18 t ha^{-1} increased organic matter on soil compared to control treatment on sandy soil in Hungary. Moreover, results by Mandal *et al.* (2013) indicated that incorporated poultry litter compost at 12.7 cm depth increased soil organic matter compared to unfertilized treatment and synthetic fertilizer treatment on silt loam soil in United States of America.

Application of compost improves soil fertility by increasing concentration of N, P, K and other nutrients. However, these effects vary with application method, compost type and compost rate (Hargreaves *et al.,* 2008; Lakhdar *et al.,* 2009). Iren *et al.* (2015) applied cassava peels and poultry manure-based compost at two rates (4 t ha^{-1} and 8 t ha^{-1}) on sandy loam soil in Nigeria and found that soil N, P, K, Mg and Ca were increased with levels of application compared to control. Their results showed that plots fertilized with 8 t ha^{-1} had higher influence on soil chemical properties compared to 4 t ha^{-1}. A study by Obiamaka (2011) indicated that soil K, P, Na was increased by application of household compost at 20, 40 and 60 t ha^{-1} compared to inorganic fertilizer and control. Demelesh *et al*. (2016) attributed the increase of P to release of various organic acids which result in improvement of soil available P. A study by Adekayode and Ogunkoya (2011) showed that compost from maize stalks and shelled cobs at 2 t ha^{-1} increased organic matter compared to NPK in three consecutive years on sandy soil in Nigeria. Furthermore, their results showed NPK was only superior in the first season. Most research has been done on the effect of compost from different feedstocks on soil chemical properties, but limited research has been conducted on macadamia husk compost in the dry environment of Limpopo province.

2.2.3 Effect of compost on growth and yield of plants

The improvement of chemical and physical properties by compost is likely to improve plant growth. Compost application to soils increases crop productivity. Compared to unfertilized soils compost can improve plant growth parameters and root depth (Curtis and Claassen, 2005). In Indonesia, Setyowati *et al.* (2014) compared application of weed-based compost at 20 t ha^{-1} with nitrogen fertilizer at 0.2 t ha^{-1} on chilli pepper and reported that compost increased fruit length and fresh fruit weight compared to nitrogen application. Ogbonna *et al.* (2012) both reported that compost from poultry droppings, spent mushroom wastes increased maize stem length, girth, number of leaves and leaf length Nigeria. Also, application of stover compost, straw compost, banana compost, composted pineapple residues and combination of poultry dropping & spent mushroom compost increased yield and yield components of rice, sorghum, pineapples and maize, respectively (Barus, 2016; ElNour *et al.,* 2015; Liu *et al.,* 2013). Peyvast and Abbasi (2006) reported that total yield, number of leaves and dry matter of Chinese cabbage was increased by application of commercial compost at 37.5 t ha^{-1}, 75 t ha^{-1} and 150 t ha^{-1} compared to unfertilized treatment on sandy loam soil.

A study by Elfeel and Abohasan (2016) revealed that application of NPK fertilizer and compost increased leaf area of leguminous tree but the increase was greater with NPK fertilizer. Effect of compost from different feedstock on growth and yield of plants are well documented (Polat *et al.,* 2004; Hernandez *et al.,* 2010; Sanni, 2016). However, there is hardly any evidence on the effect of macadamia husk compost on growth and yield of crop plants. Therefore, this study evaluated the effect of macadamia husk compost on growth and yield of Chinese cabbage.

2.2.4 Effect of compost on plant nutrient uptake

Compost can improve plant nutrient availability, particularly by supplying nutrients such as N, P and K (Mylavarapu and Zinati, 2009). Although compost increases plant growth and N mineralization, high rates are required to meet crop N needs to ensure continuous provision of N supply to plants from compost similar to N that is supplied from synthetic fertilizers (Mylavarupu and Zinati, 2009). Compared to same amount of nitrogen and P added to soil, plant N and P uptake from compost may be lower than that of synthetic fertilizers because of the organic N in compost must be mineralised before it can be taken up by plants (Odlare and Pell 2009).

A field study by Lee *et al.* (2015) reported that compost from rice straw and cattle manure increased P content on red pepper compared to inorganic fertilizer and control treatment. Furthermore, it was reported that compost did not have an effect on K and Ca content. Similarly, Polat *et al.* (2004) reported that compost from spent mushroom compost at 20, 40 and 80 t ha^{-1} had no effect on P, K, Ca, Mg, Fe, Mg, Cu in cucumber content in Turkey. There was an increase in content of nitrogen, phosphorus, potassium, calcium, magnesium and the vitamin C content after application of 2 t ha^{-1} of composted maize stalks and shelled amaranth compared to 200 kg ha^{-1} of inorganic fertilizer in a study by Adekayode and Ogunkoya (2011). It is clear from previous studies that compost effect on nutrient content varies with location, compost type and crop being grown. Moreover, there is scant literature about the effect of macadamia husk compost on nutrient content of crops. Therefore, this study assessed the effect of macadamia husk compost on Chinese cabbage nutrient leaf content in the dry environments of Limpopo Province.

2.3 General description of Chinese cabbage

2.3.1 Description of Chinese cabbage

Chinese cabbage (*Barassica rapa L*.) belongs to the family Cruciferae (Van Rensburg *et al.,* 2007). It is commonly known as Chinese cabbage, Chinese mustard cabbage or rape in English, Sjinese koo*l* in Afrikaans and mutshaina in Tshivenda. The crop was introduced to China more than 200 years ago where the heading (*Brassica rapa L. subsp. pekinensis)* and non-heading (*Brassica rapa L. subsp. chinesis*) types were developed (Van Rensburg *et al.,* 2007). Heading Chinese cabbage forms a compact to elongated head with green crinkled leaves and white midribs whilst in non-heading Chinese cabbage, dark green leaves supported by light green to white petioles form a rosette (Hill, 1990; Rubatzky and Yamaguchi, 1997). The crop probably found its way to Africa from Asia as a result of trade between these two continents (DAFF, 2013).

Brassica rapa L. subsp. chinensis (Non-heading Chinese cabbage) is by far the most dominant one in the northern parts of South Africa (Van Averbeke *et al.,* 2007). It is closely related to *Brassica napus* or rape kale which are very common popular in Limpopo and Mpumalanga Provinces as well in Zimbabwe (Schippers, 2000). A typical *Brassica rapa L.* is presented in Figure 2.1

Figure 2.1 The Chinese cabbage (*Brassica rapa L*.*Chinensis*)

2.3.2 Growth and development of Chinese cabbage

Chinese cabbage is an annual vegetable that takes about six to eleven weeks from planting to the end of vegetative stage (Manrique, 1993). It is a leafy vegetable that can grow up to 15 cm to 30 cm and it has broad, thick and tender leaves that are arranged spirally in a rosette during vegetative stage (Van Rensburg *et al.,* 2007). Chinese cabbage is a cool season crop which requires adequate availability of soil water and plant nutrients for optimum growth (Hill, 1990). In South Africa, Chinese cabbage growing season is winter in April, May, June and July (Okorogbona *et al.,* 2011).

2.3.3 Significance of Chinese cabbage and production areas

Chinese cabbage is one of the most important planted vegetables in Vhembe District Municipality by smallholder farmers. Most of them plant the crop to generate income by selling the product to the supermarkets and on the streets while others grow the vegetable for home consumption. Challenges associated with food insecurity and unemployment have led to promotion of its cultivation, especially among smallholders in the area (Manyelo *et al.,* 2015). In South Africa, the crop is mainly grown in Limpopo, Mpumalanga, Gauteng, Eastern Cape, KwaZulu-Natal and North West Provinces (Okorogbona *et al.,* 2011). Chinese cabbage was used in this investigation since its production it is very common in the area of Vhembe District Municipality. The crop is used for both home consumption and for selling at local and national markets and there is also a huge demand for this vegetable especially on the peri-urban and urban areas. It is anticipated that this study will add new literature as there is scant information about the use of compost or organic fertilizer on Chinese cabbage in South Africa.

3. GENERAL METHODOLOGY

3.1 Study location

The experiment was conducted at the Agricultural Research Council Farm at Levubu (latitude 25º 27' S and longitude 30º 58' E with an elevation of 670 m) in Limpopo Province, South Africa (Figure 3.1). Levubu is characterized by subtropical climate zone with an average annual rainfall of 752 mm that comes between November and February. The lowest amount of rainfall is experienced between May and September. Daily temperatures in Levubu vary from about 24˚C to 40˚C in summer and between 20˚C and 26˚C in winter (Schulze and Maharaj, 2003). The area experiences high evaporation between December and February whereas wind speed is highest between June and September (Schulze and Maharaj, 2003).

Figure 3.1. Study area (ARC-ITSC research station in Levubu, Limpopo Province, South Africa). Red line indicates the farm demarcation whereas the blue rectangle shows the site were the experiment was carried out.

Source: Google Map, 2018

3.2 Composting process and procedure

Macadamia husks are the outer coating of the nut-in-shell and usually accumulate in stockpiles on the farm because of de-husking processes. The ARC-ITSC ‘s research station in Levubu, produces about 50 tons of macadamia nuts annually. The harvesting time is usually from May to August. After harvesting, macadamia go through the process of removing the outer covers (husks). After de-husking, the husks are dumped in the composting site with the aim of making compost. The macadamia husks were piled at the composting site to form a heap (Figure

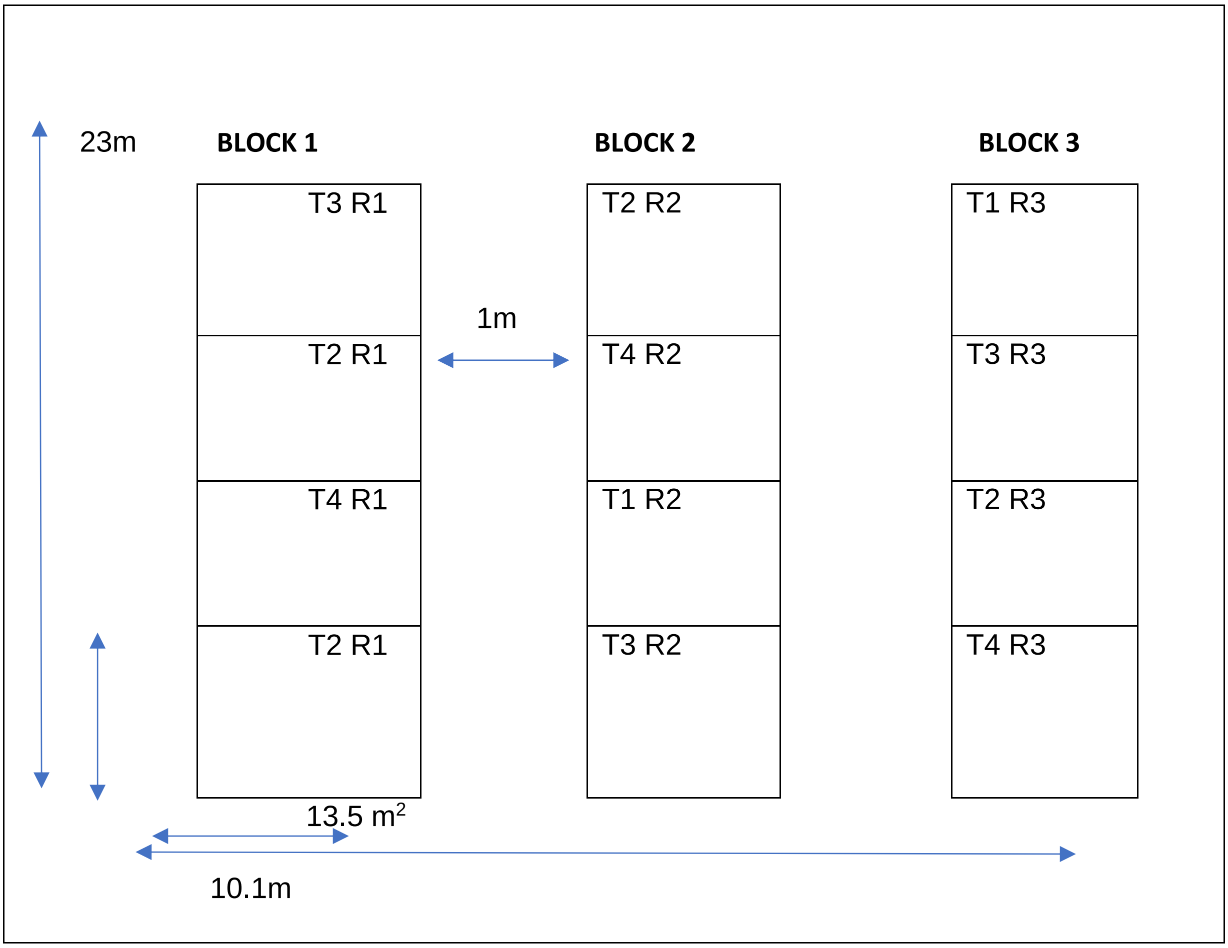
3.2a) where they were left to decompose until they are matured (Figure 3.2b). During the composting process, the composting materials were turned and tossed, using a tractor, to enhance and speed up the decomposition process. In the absence of rain, water was applied in the form of sprinkling to increase moisture content on compost because moisture is essential for survival and activity of microbes required for composting (Dalzell *et al*., 1987). Composting process took four months from the start until maturity. However, a time for compost to mature can differ depending on the climate, management and chemical composition of the organic materials (Bittenbender *et al*., 1998). A mature compost is characterized by a dark black colour and a unique smell (Bittenbender *et al.,* 1998). For this study, a composite sample of compost was drawn from different angles of the finished compost heap to form a composite sample of about 3 kg. Compost samples were analyzed for the following chemical properties: pH, N, total C, available P, K, Ca, Mg, Na, Zn, Cu, Mn, Al, C:N ratio (Table 4.1).

(a) (b)

Figure 3.2 Macadamia husk before decomposing (a) and after decomposing (b).

3.3 Experimental design

The experiment was conducted in 2018 and 2019 winter season. The experiment was laid out in a randomized complete block design with four treatments i.e control (no fertilizer), inorganic fertilizer, compost at 15 t ha^{-1} and compost at 30 t ha^{-1} replicated three times giving a total of 12 plots with individual experimental plot measuring 13.5 m^2 (2.7 m x 5 m). The plots were 1 m apart from each other to avoid encroachment of macadamia husk compost and inorganic fertilizer. Therefore, the area of the whole experimental site was 232.3 m^2 (10.1 m x 23 m) including 1 m length separating the plots. Inorganic fertilizer was applied at a rate of 100:60:60 kg NPK ha^{-1}. The selection of NPK fertilizer rates were based on previous studies (Tripathi *et al*. 2015). Compost was incorporated into the soil a month before planting at a depth of 15 cm and inorganic fertilizer was applied 2 weeks after planting by ringing around Chinese cabbage.



T1 = Control (zero), T2 = NPK fertilizer, T3= 15 t ha^{-1} macadamia husk compost

T4= 30 t ha^{-1} macadamia husk compost

Figure 3.2 Field experimental design

3.4 Soil sampling and analysis

Soil samples were taken from the experimental site before planting and at the end of the experiment. The soil surface was cleared to remove any debris or obstacles before sampling. Before planting, samples were randomly collected from three points in each plot at 0-15 cm soil depth to represent the whole study area and to eliminate any systematic biasness. The samples were bulked, dried, sieved (2mm) and stored in laboratory bag for subsequent physical and chemical analysis. At the end of the experiment after harvesting, representative soil samples from three points in each individual plot were collected for analysis at depth of 0-15 cm using soil auger. Soil samples were analysed for selected soil physical (soil texture, bulk density and water holding capacity) and chemical properties (pH, organic carbon, organic matter, total N, available phosphorus (P), extractable calcium (Ca), magnesium (Mg), potassium (K), zinc (Zn), manganese (Mn) and electrical conductivity (EC) as described in 3.4.1 to 3.4.10.

3.4.1 Soil texture

A 50g sample of air-dried soil was dispersed in calgon solution and distribution of particles sizes was measured with a hydrometer using the method outlined by Okalebo *et al.* (1993). Soil texture was obtained from particle size distribution by using a textural triangle.

3.4.2 Bulk density

Bulk density was determined using the core method (Blake and Hartge, 1986). The soil samples were taken using a 98.17 cm^{-3} core ring (5 cm inner diameter and 5 cm height) with cylindrical core sampler. The core ring was fitted on the cylindrical core sampler, placed against the soil surface and carefully pressed downwards into the soil until the core ring was sufficiently filled with soil. The core ring was then excavated from the soil with the aid of cylindrical a core sampler. Both ends of the core ring were trimmed with a trowel and put on the caps. The samples were then taken to the laboratory and dried in an oven at 105 ^{o}C for 24 hours. Bulk density was calculated using the following equation:

$$BD = m/V \qquad (1)$$

Whereby BD is dry bulk density in g cm^{-3} , m is the mass of the dry soil in g, and V is the volume of the soil in cm^3.

3.4.3 Water holding capacity

Water holding capacity is the amount of water held in the soil after excess water has drained away and after the rate of downward movement of water has ceased. Water holding capacity was determined using the filter paper method. Tubes were attached and clamped to the bottom of funnel and the funnel was attached to ring stand. Then filter paper was placed in the funnel. The funnel was placed with 50 g soil sample. 100 ml of water was measured out using the graduated cylinder and was gradually added to the sample until the sample was covered with 100ml water. Samples were stirred gently and let sit until they were fully saturated. The clamp was released, and excess water was collected in the graduated cylinder. Thereafter, the amount of water retained in the cylinder was recorded (Smith and Mullins, 1996).

$$\frac{\text{mL water retained}}{\text{100ml sample}} = \text{water added (mL)} - \text{water drained (mL)} \qquad (1)$$

$$\text{(water holding capacity (ml/L)=10x } \left(\frac{\text{mL water retained}}{\text{100ml sample}}\right) \qquad (2)$$

3.4.4 Soil pH (H_2O)

pH of the soil was measured in a supernatant of 1:5 (soil water) ratio using a glass-calomel electrode. Ten (10) g of air-dried soil was weighed and 50 cm^3 of de-ionised water was added in a beaker. The solution was stirred rapidly for five seconds with a glass rod and allowed to stand for 30 minutes. After 30 minutes, the solution was stirred again and allowed to stand for 10 minutes. pH was measured by dipping electrodes in the supernatant (Woodruff, 1948).

3.4.5 Available phosphorus (P)

Available P in the soil was determined using Bray-1 method. Each sample was extracted with 50 ml of Bray-1 extracting solution (0.03N NH_4F + 0.025HCL) and the filtrate was stored in extracting bottles. Phosphorus concentration was determined in the filtrate by the reduction of phosphomolybdic acid that yields an intense blue colour using a spectrophotometer at the wavelength of 660 nm (Bray and Kurtz, 1945).

3.4.6 Exchangeable Ca, Mg and K

Extractable cations (Ca, Mg and K) were extracted with 1 mol dm^{-3} ammonium acetate (NH_4OAc, pH 7.0) and filtered through a No. 42 Whatman filter paper. Ca and Mg were determined by atomic absorption spectrometer while K was determined by flame photometry (Peech, 1965).

3.4.7 Total nitrogen (N)

Total nitrogen was determined by micro-Kjeldahl procedure (Bremmer, 1996). A 0.2-gram sample of soil was digested in 4.4 ml of digestion mixture (0.42 g Se + 14 g $Li_2SO_4.H_2O$ + 350 ml of 30 % H_2O_2 + 420 ml conc. H_2SO_4). Hydrogen peroxide (H_2O_2) was added as an additional oxidising agent. Selenium (Se) powder was used in order to raise the boiling point. Free ammonia was liberated from the solution by steam distillation in the presence of excess alkali (NaOH). The distillate was transferred into a conical flask containing boric acid (H_3BO_3) and titrated with 0.0025-mol dm^3 H_2SO_4 in the distillate until the colour changed from green to pink.

3.4.8 Zinc (Zn), manganese (Mn) and aluminium (Al)

About 2.5 g of soil was mixed with 25 ml of EDTA solution. Each sample was stirred for 10 minutes using a magnetic stirrer. After 10 minutes of stirring, soil solution was filtered into extracting bottles (100 ml) with Whatman No 42 filter papers. Zinc, manganese and aluminium were determined directly on the undiluted extract with an atomic absorption spectrophotometer (AA) (Alexander, 1961).

3.4.9 Electrical conductivity (EC)

Electrical conductivity was determined by measuring the electrical resistance of a 1:5 soil: water suspension using a conductivity cell. 1:5 soil water suspension was prepared by weighing 10g air-dry soil (<2 mm) into a bottle. About 50ml of deionised water were added. Each sample was stirred using magnetic stirrer for 1 hour to dissolve soluble salts. The conductivity meter was calibrated according to the manufacturer's instructions using the KCl reference solution to obtain the cell constant. Then the cell was rinsed thoroughly. Electrical conductivity of 0.01M KCl was measured at same temperature as the soil suspension. Conductivity cell was rinsed with soil suspension. The conductivity cell was refiled without disturbing the settled soil and value indicated on the conductivity meter was recorded (Schoonover, 1952).

3.4.10 Soil organic carbon (SOC) and soil organic matter (SOM)

Soil organic carbon (OC) was determined using the Walkley and Black method (Nelson and Sommers, 1982). One gram of soil was digested in 20 ml concentrated sulphuric acid (H_3SO_4) and 10 ml aqueous potassium dichromate ($K_2 Cr_2 O_7$). After complete oxidation, the remaining $K_2 Cr_2 O_7$ was titrated against 0.5 N Ferrous ammonium sulphates. The used $K_2 Cr_2 O_{7,}$ the difference between added and residual $K_2 Cr_2 O_{7,}$ was used as a measure of organic carbon content of soil. Each sample was replicated three times. Soil organic matter content was also analysed using the Walkey and Black method (Jackson, 1973).

3.5 Cultural practices

Chinese cabbage seedlings were planted in trays filled with planting medium on the 12th of March 2018 (season 1) and 8th of April 2019 (season 2). Healthy and uniformed sized seedlings were uprooted carefully to avoid any damage to the root system and were transplanted on each individual plot. Each treatment consisted of 6 rows with 12 plants each making a total of 72 plants per plot with inter-row spacing of 40 cm and intra-row spacing of 40 cm. Plants were planted at 15 cm depth hole prepared by a hand hoe. An overhead irrigation system using the micro irrigation jets was used to supply water to the plants. Uniform irrigation schedule was followed in all plots to maintain similar amount of water throughout the growing period. The emitter system was used to irrigate three times in a week for 2 hours. The plots were kept weed-free throughout the experiments. MALASOL was applied at the rate of 12.5 ml per 10L of water once every two weeks in order to control pests such as locust, crickets, ants and snails.

3.6 Harvesting and yield determination

Plants in the outer rows and extreme end of middle rows were excluded from sampled plants to avoid border effect. Six plants from two inner rows from an area measuring 0.12 m^2 were tagged and used for yield determination (number of leaves, leaf fresh biomass and leaf dry biomass) and leaf area. Harvesting of leaves was done manually using a sharp knife at 28, 47 and 74 DAT (days after transplanting). Number of leaves was determined by counting the number of leaves found in each plot. A weighing balance was used to measure fresh leaf biomass. The leaves harvested from the sample area were oven-dried in 65˚C for 48 hours to determine dry leaf biomass. The weighing balance was used to measure dry leaf biomass. Dried samples were ground in a Willey mill with 1.0mm mesh. All the ground materials were stored in glass bottles for nutrient content analysis (N, P, K, Ca, Mg, Fe, B and Mn). After the final harvest, sampled plants were carefully uprooted using hands and the roots washed with tap water. Roots were uprooted to determine fresh root biomass and root length. The roots were oven dried for 48 hours at 65˚C and dry root biomass was measured using a weighing balance. Leaf area was measured using LI-COR LI-300 area metre.

3.7 Leaf sample analysis

After drying, a composite sample from each treatment were taken and stored in well labelled plastic bags. The sample were then sent to the ARC’s laboratory in Nelspruit for nutrient concentration analysis. The leaves were analyzed for total nitrogen, total phosphorus, calcium, magnesium, zinc and manganese. Similar procedures that were used to analyze leaf samples were used to analyze the compost. The mineral elements were analyzed as described in 3.7.1 and 3.7.2.

3.7.1 Nitrogen

Total nitrogen was determined by the micro-Kjeldahl procedure outlined by Okalebo *et al*., (1993). This procedure involves digesting the ground leaf samples with concentrated sulfuric acid (H_2SO_4). The distillate was collected in saturated boric acid (H_3BO_3) and then titrated with dilute H_2SO_4 until the colour changed from green through grey to a definite pink.

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

The total phosphorus, calcium, magnesium, zinc and manganese in the leaf tissues were determined by the perchloric acid digestion procedure. Samples were heated by the oscillating electromagnetic field and digested by acid oxidation (Nitric acid, concentrated 70% HNO_3, Hydrogen peroxide, 30% H_2O, Hydrochloric acid: concentrated, 37%). Total phosphorus and boron were determined using a spectrophotometer at a wavelength of 660 nm whereas K, Ca, Mg, Zn, and Mn were determined on the Atomic Absorption Spectrometer (Motsara and Roy, 2008).

3.8 Weather

Daily weather data for experiment I and II were obtained from an automatic weather station located approximately 100m from experimental site. Rainfall (mm), relative humidity (%) maximum and minimum temperatures (˚C) were recorded each day during the experiments.

Table 3.1 Summary of weather during 2018 and 2019 cropping season in Levubu

Month	Max temp (˚C)	Min temp (˚C)	Rainfall (mm)	Humidity (%)
2018				
April	26	16	25.32	68
May	24	12	9.92	58
June	24	12	3.14	50
July	21	11	6.41	61
August	27	15	2.23	49
Mean/ Total	24.4	13.2	47.02	57.2
2019				
April	29	18	34.1	69
May	28	16	6.3	56
June	25	13	15.4	58
July	27	14	1.9	40
August	28	16	7.4	48
Mean/ Total	27.4	15.4	65.1	54.2

3.9 Data analysis

Analyses of variance (ANOVA) were conducted on all the data using Genstat 18th edition package where mean comparisons were performed using Least Significant Different (LSD) test at 5% level of significant. Correlation analysis was determined using Parson’s simple correlation coefficients.

4. MACADAMIA HUSK COMPOST EFFECT ON SELECTED SOIL PHYSICAL AND CHEMICAL PROPERTIES

ABSTRACT

Poor soil fertility caused by decline of soil organic carbon is considered as one of major constraints limiting crop productivity in tropical and subtropical regions of South Africa. This study evaluated the effect of macadamia husk compost on selected physicochemical properties in sandy loam soil in Levubu, Limpopo, South Africa. The experiment was a complete block design (RCBD) with four treatments and four replications; control (zero), inorganic fertilizer (100:60:60 NPK Kg ha^{-1}), macadamia husk compost at 15 t ha^{-1} and 30 t ha^{-1}. Soil bulk density, water holding capacity, soil pH, EC, organic carbon, organic matter, N, available P, K, Ca, Mg, Ca, Al, Zn, Cu and Mn were determined. Macadamia husk compost application decreased bulk density and increased water holding capacity at 0-15 cm soil. Macadamia husk compost and NPK fertilizer increased soil pH, total N, organic carbon, C:N ratio, organic matter, available P, exchangeable cations, and micronutrients but the effect was more pronounced under compost treatments especially at 30 t ha^{-1}. It was concluded that the improvement of these properties was attributed to high organic carbon from macadamia husk compost matter and the increase of soil organic matter.

Key words: *Soil fertility, macadamia husk compost, organic carbon*

4.1 Introduction

In Limpopo, South Africa, yields are not only limited by inadequate rainfall but also by poor soil fertility. Poor soil fertility inhibits farmers especially smallholder farmers to prepare large portion of land to plant crops due to high crop failure associated with arid and semi-arid environments (Kundhlande *et al.,* 2004). Majority of these farmers experience low yields that continue to decline with time. This can be explained by inherently low soil fertility and declining of soil fertility. Poor soil fertility is aggravated by poor soil management such as continuous monoculture, excessive burning of veld, uncontrolled grazing and low organic matter application (Ramaru *et al.,* 2000). This can result in destruction of ecological soil processes, depletion of soil quality, biodiversity and direct loss of soil (Brogan *et al.,* 2002). These conditions are inappropriate for crop production as it requires a well-balanced soil minerals, water, moisture and organic matter which allows water drainage & retention, nutrients movements and provision of physical support to plants (Parikh and James, 2012). Greater organic input into the soil has been associated with high soil nutrient concentration, high water retention and high crop yield (Bouajila and Sanna, 2011; Barus, 2016; Golabi *et al*., 2004). Soil organic matter, referred as to all organic material that are found in soil including litter, microbial biomass, water soluble organics, light fraction and humus (Stevenson, 1994), is a key attribute of soil quality (Gregorich *et al.,* 1994). Soil organic matter influences vast soil characteristics such as pH, bulk density, aggregate stability and cation exchange capacity (Aslantas *et al*., 2010; Basri *et al*., 2013).

Poor climate conditions such as low rainfall and high temperatures could affect crop production because such parameters govern choice of crop to be grown and crop yield. Therefore, application of organic fertilizers such as compost are one of the key practices for soil fertility management and have a great potential for long term sequestration of carbon and is suitable for assimilation into current agronomic regimes (Adugna, 2016). However, the effect of compost on soil and crop productivity varies with environment and chemical composition of the compost type (Bernal *et al.,* 2009). Compost has the potential to improve soil structure, increase soil organic matter and establish patterns of nutrient cycling (Bernal *et al.,* 2009; Abubaker, 2013). For example, various compost materials (rice straw, spent mushroom, household waste and plant waste) improved soil physicochemical properties such as water holding capacity, bulk density, aggregate formation, soil structural stability, total porosity and chemical properties such as soil pH, carbon exchange capacity, organic matter, N, P, K and micronutrients (Soheil *et al*, 2012; Golabi *et al.,* 2004; Albaladejo *et al.,* 2009).

In the of above, some smallholder farmers in the Vhembe District Municipality (VDM) use macadamia husk compost to improve soil fertility and thus crop yield. However, there is limited scientific evidence on the effect of macadamia husk compost on soil fertility and other soil related properties. The objective of the study reported in this chapter was to quantify the effect of macadamia husk compost on physicochemical properties of a sandy soil. The hypothesis tested was that soil physicochemical properties are improved by application of macadamia husk compost.

4.2 Materials and method

Full experimental details are given in chapter 3, but a brief summary is described below. The experiment was carried in 2018 winter season at the Agricultural Research Council-Institute for Tropical and Subtropical Crops (ARC-ITSC) farm, Levubu in Limpopo Province, South Africa. Compost was incorporated into the soil a month before planting and NPK fertilizer was applied two weeks after planting. Soil samples were collected at 0-15 cm depth using soil auger to determine selected soil physical properties (soil bulk density and soil water holding capacity) before planting and after harvest. Soil bulk density and water holding capacity were calculated using formulas described in section 3.4.2 and 3.4.3 respectively. Soil samples were dried and sieved through 2mm sieve before analysis of the following soil chemical properties: (pH, total C, total N, EC, OM, available P, K, Ca, Mg, Na, Al, Zn and Mn). Data was analysed using analyses of variance (ANOVA) for randomized complete block design (RCBD) using Gentant 18th edition package. The means among the treatments were compared using the LSD test at 5% significant level and correlation analysis was determined using Parson's simple correlation coefficients for soil physicochemical properties.

4.3 Results

Chemical composition of macadamia husk compost used in the experiments is presented in Table 4.1. The pH of macadamia husk compost was moderately acidic, with high level of total C, low N and C:N ratio of 17.51:1. The compost had moderate P, K, Na, Mg, Ca, Mn, Al and very low Zn & Cu.

Table 4.1. Chemical composition of macadamia husk compost

Chemical properties	**Values**
pH (H_20)	6.62
Total N (g kg^{-1})	17.8
Total C (g kg^{-1})	312
Available P (m kg^{-1})	570
K (g kg^{-1})	27.9
Ca (g kg^{-1})	380
Mg (g kg^{-1})	300
Na (mg kg^{-1})	166
Zn (mg kg^{-1})	28
Cu (mg kg^{-1})	22
Mn (mg kg^{-1})	319
Al (mg kg^{-1})	316
C:N ratio	17.5: 1
Moisture (%)	70.72

Results of physicochemical analyses of the soil before planting are shown in Table 4.2. Soil was moderately acidic with a pH of 6.06 with low levels of N, total C, OM, P, Na, Zn, CN ratio and EC. The soil had moderate amount of Mn, Mg and Ca with low bulk density 0.68 g cm^{-3}

Table 4.2. Physicochemical properties of soil before macadamia husk compost application at Levubu

Soil properties	**Values**
pH (H_2O)	6.06
Organic C (%)	1.09
Total N (%)	0.04
C:N ratio	27:1
EC (dsm^{-1})	2.3
OM (%)	1.87
Available P (mg kg^{-1})	6.7
K (mg kg^{-1})	53
Ca (mg kg^{-1})	483
Mg (mg kg^{-1})	132
Na (mg kg^{-1})	7
Al (mg kg^{-1})	8
Zn (mg kg^{-1})	2.88
Mn (mg kg^{-1})	112
Bulk density (g cm^{-3})	0.68
Sand (%)	70
Silt (%)	3
Clay (%)	27
Soil textural class	Sandy loam soil

4.3.1 The effect of macadamia husk compost and NPK fertilizer on physical properties of the soil

Application of 15 and 30 t ha^{-1} macadamia husk compost decreased soil bulk density by 15% and 18%, respectively but the effect of inorganic fertilizer was not significant (Table 4.3). Similarly, application of macadamia husk compost affected soil water holding capacity, but inorganic fertilizer had no effect on water holding capacity of soil; water holding capacity was greater by 26% (15 t ha^{-1}) and 30% (30 t ha^{-1}) of macadamia husk compost compared to inorganic fertilizer, and 20% (15 t ha^{-1}) and 24% (30 t ha^{-1}) greater than the control (Table 4.3).

Table 4.3. Effect of macadamia husk compost and NPK fertilizer on soil physical properties

Treatments	**Bulk density (g cm^{-3})**	**Water holding capacity (%)**
Control	0.67±0.02a	16.33±2.08b
NPK	0.67±0.01a	15.66±1.53b
MC1	0.57±0.01b	19.67±0.58a
MC2	0.55±0.02b	20.33±0.58a
LSD (0.05)	0.028	2.549
P (*F -ratio*)	*p<0.01*	*p<0.01*
CV %	2.26	7.74

Values are means ± standard deviation; n= 12, Within a column means bearing the same letter are not statistically different, Control = no fertilizer, NPK = 100:60:60 kg NPK ha^{-1}, MC1 = Macadamia husk compost at 15 t ha^{-1}, MC2 = Macadamia husk compost at 30 t ha^{-1}, LSD = Least Significant Difference, CV= Coefficient variance

4.3.2 Effect of macadamia compost and NPK fertilizer on soil chemical properties

4.3.2.1 Soil pH and EC

The application of macadamia husk compost and NPK fertilizer increased soil pH (Table 4.4a). Also, soil pH was greater with application of macadamia husk compost compared with NPK fertilizer (Table 4.4a). In contrast, application of macadamia husk compost and NPK fertilizer did not affect soil EC (Table 4.4a).

4.3.2.2 Soil organic matter, soil organic carbon, total N and C:N ratio

Application of macadamia husk increased soil organic matter but the increase was much greater (about 2.5 times) with 30 t ha^{-1} macadamia husk compost compared with 15 t ha^{-1} of macadamia husk compost with an increase of 45% (Table 4.4a). In contrast, the effect of NPK fertilizer on SOM was not significant (Table 4.4a). Application of 30 t ha^{-1} of macadamia husk compost increased SOC by 62% but the effect of NPK and 15 t ha^{-1} macadamia husk compost was not significant (Table 4.4a). Total N was increased by 50% at both 30 t ha^{-1} & NPK fertilizer and also, by 33% at 15 t ha^{-1} macadamia husk compost (Table 4.4a). C:N ratio was 2.4 times greater at 30 t ha^{-1} compared to the control but NPK fertilizer and 15 t ha^{-1} macadamia husk compost did not affect C:N ratio (Table 4.4a).

4.3.2.3 Available P, exchangeable cations and micronutrients

Application of macadamia husk compost increased soil P by 45% and 130% respectively for 15 and 30 t ha^{-1} macadamia husk compost (Table 4.4a). Similarly, soil P was 64% greater with NPK application compared with unfertilized treatment (control) (Table 4.4a). K was greater by 21% to 113% at 15 and 30 t ha^{-1} of macadamia husk compost, respectively compared to NPK fertilizer (Table 4.4a). Also, application of macadamia husk compost increased soil K content by 102% to 226% over the control. Macadamia husk compost and NPK fertilizer increased Ca in soil (Table 4.4b). Also, Ca was greater with macadamia husk compost compared to NPK fertilizer (Table 4.4b). Similarly, macadamia husk compost and NPK increased Mg but the increase was greater with 30 t ha^{-1} compost compared to 15 t ha^{-1} compost and NPK fertilizer (Table 4.4b). Na was increased by 21%, 43% and 157% at NPK fertilizer, 15 and 30 t ha^{-1} macadamia husk compost, respectively (Table 4.4b). Concentration of micronutrients (Al, Zn and Mn) was significantly increased by application of macadamia husk compost at 15 and 30 t ha^{-1} but the increase was greater at 30 t ha^{-1}. For example, Al was increased by 10%, 235% and 96% compared to 15 t ha^{-1} macadamia husk compost, NPK fertilizer and control respectively (Table 4.4b).

Table 4.4a. Effect of macadamia husk compost and NPK fertilizer on selected soil chemical properties

Treatments	**pH**	**SOM (%)**	**EC (dS m^{-1})**	**SOC (%)**	**Total N (%)**	**C: N**	**P (mg kg^{-1})**	**K (mg kg^{-1})**
Control	6.53±0.00c	1.43±0.08c	0.98±0.21	1.02±0.28b	0.06±0.02b	15.84±2.82b	15.33±0.12d	80.67±2.16d
NPK	6.63±0.04b	1.65±0.21c	1.10±0.16	1.23±0.44b	0.09±0.02a	13.28±3.70b	25.13±0.12b	134.67±1.53c
MC1	6.80±0.06a	2.08±0.15b	1.04±0.15	1.25±0.18b	0.08±0.04a	15.84±2.82b	22.17±0.15c	162.67±2.20b
MC2	6.80±0.02a	3.54±0.15a	1.03±0.21	2.71±0.14a	0.09±0.08a	37.99±8.72a	35.40±0.20a	287.00±1.173a
P (F-ratio)	$p<0.01$	$p<0.01$	ns	$p<0.05$	$p<0.05$	$p<0.05$	$p<0.01$	$p<0.01$
LSD (0.05)	0.076	0.315	0.317	0.539	0.009	10.542	0.282	3.881
CV (%)	0.61	7.43	15.94	18.46	2.9	24.8	0.61	1.24

Values are means ± standard deviation; n= 12, Within a column means bearing the same letter are not statistically different, Control = no fertilizer, NPK = 100:60:60 kg NPK ha^{-1}, MC1 = Macadamia husk compost at 15 t ha^{-1}, MC2 = Macadamia husk compost at 30 t ha^{-1}, LSD = Least Significant Difference, CV= Coefficient variance, ns= non-significant

Table 4.4b. Effect of macadamia husk compost and NPK fertilizer on soil chemical properties

Treatments	**Ca (mg kg^{-1})**	**Mg (mg kg^{-1})**	**Na (mg kg^{-1})**	**Al (mg kg^{-1})**	**Zn (mg kg^{-1})**	**Mn (mg kg^{-1})**
Control	685.00±3.00d	141.67±2.08d	21.00±2.00d	9.00±0.00c	6.07±0.06d	49.40±o.43c
NPK	763.33±2.00b	159.33±1.53c	25.33±1.15c	5.33±0.57d	3.37±0.06d	48.23±0.32d
MC1	986.00±2.00b	254.67±2.31b	30.33±1.15b	16.00±0.57b	7.60±0.00b	51.96±0.05b
MC2	1270.60±2.08a	274.33±4.04a	54.00±2.00a	17.66±0.00a	9.93±0.06a	65.10±0.10a
P (F-test)	*p<0.01*	*p<0.01*	*p<0.01*	*p<0.01*	*p<0.01*	*p<0.01*
LSD (0.05)	4.579	5.011	3.074	0.768	0.094	0.521
CV (%)	0.26	1.28	4.99	3.40	0.74	0.51

Values are means ± standard deviation; n= 12, Within a column means bearing the same letter are not statistically different, Control = no fertilizer NPK = 100:60:60 kg NPK ha^{-1}, MC1 = Macadamia husk compost at 15 t ha^{-1}, MC2 = Macadamia husk compost at 30 t ha^{-1}, LSD = Least Significant Difference, CV= Coefficient variance, ns= non-significant

4.4 Discussion

Organic matter is regarded as a source of nutrients and microbial activity in soil and it affects water holding capacity, soil structure, infiltration rate, soil aeration and soil porosity (Amlinger *et al.,* 2007; Sarwar *et al.,* 2008; Brown and Cotton, 2011). Macadamia husk compost increased soil organic matter. The increase of organic matter was attributed to more organic matter content in compost and to the increase of soil organic carbon with compost application (Lalfakzuala *et al.,* 2008). A strong positive correlation (r = 0.99***) between soil organic matter and organic carbon was observed (Appendix 1). Similarly, Hossen *et al*. (2015) and Ojobor *et al*. (2017) reported that application of organic fertilizer increased soil organic carbon due to the increase rate of carbon sequestration on treatments that received compost. Greater soil organic matter content at compost treatments over inorganic fertilizer application was not surprising because inorganic fertilizer do not contain organic matter or decaying matter necessary to improve soil structure, as they provide specific nutrients for crop growth as previously reported by (Sarker *et al.,* 2012; Ojobor *et al.,* 2017; Mahmood *et al.,* 2017). The increase of soil organic carbon with compost application can be associated with high C content on macadamia husk compost (Table 4.1). Compost has the ability to increase soil organic matter content (Golabi *et al.,* 2004; Fischer and Glaser, 2012; Adugna, 2016). Similar results have been reported with farm manure compost and municipal waste compost (Bouajila and Sanna, 2011; Soheil *et al.* 2012). Non-significant effect of NPK fertilizer on organic C was expected as inorganic fertilizer application have no influence on organic C (Lusiba *et al*., 2016). Organic fertilizers increase soil organic matter to a greater extent compared to inorganic fertilizers because organic fertilizer increase soil C directly whereas the effect of inorganic fertilizer on soil C is less pronounced since it increases C indirectly by improving crop growth (Antil *et al.,* 2005). Similar results were observed by Joshi *et al*. (2016) who reported that soil amended with compost had higher SOC compared to control and inorganic fertilizer. Atere and Olayinka (2012) also found that SOC at water hyacinth compost treatment was higher than SOC at soil treated with inorganic fertilizer.

Greater soil water holding capacity with application of macadamia husk compost was likely due to similar increase in soil organic matter (Valarini *et al*., 2009; Zemanek, 2011; Askin and Aygun, 2018). Organic matter correlated positively (r =0.97***) with water holding capacity (Appendix 1). Organic matter affects water holding capacity by improving soil structure, soil aggregate stability, particle size, total porosity, water absorption capacity of organic matter and moisture retention capacity by increasing total number of storage pores (Bhattacharyya *et al.,* 2009). Similar results were also reported with other organic wastes (Vengadarama and Joshothan, 2012; Mengistu and Mekonnen, 2012; Malik *et al*., 2014; Jeyamangalam *et al.,* 2012) where the increase in water holding capacity was attributed to increase of SOM.

In this study, application of macadamia husk compost reduced soil bulk density probably due to increase of soil organic carbon after compost application. There was a strong negative correlation (r = -0.89***) between bulk density and soil organic carbon (Appendix 1). Addition of organic amendments to soil reduces soil bulk density by increasing total soil organic carbon which causes an increase in stable soil aggregates and soil porosity (Celik *et al*., 2010; Civeira. 2010; Busscher *et al*., 2011; Brown and Cotton, 2011; Leroy *et al*., 2008; Liu *et al*., 2013; Martinez-Blanco *et al*., 2013; Lee *et al.,* 2015). The findings of this study are comparable to earlier reports by Golabi *et al*. (2004), Brown and Cotton (2011), Leroy *et al.* (2008) who attributed decrease of bulk density to the formation of stable aggregates units with addition of organic matter to the soil. Hemmat *et al*. (2010) and Aranyos *et al*. (2016) also found negative correlations (r = -0.75***) and (r = -0.81***) respectively between bulk density and organic carbon (Appendix 1).

The significant increase in soil available phosphorus as a result of macadamia husk compost application observed was probably due to the increase of SOM and high concentration of P in the compost used (Bustamante *et al*., 2008; Civeira, 2010). A significant positive correlation was found between SOM and available P (r= 0.65**) (Appendix 1). However, it was not quite clear why soil available P was greater with compost application compared to NPK fertilizer but probably the macadamia husk released various organic acids which led to increased solubilization (Mohammadi *et al.,* 2009). Similar results have been reported elsewhere by Hossain and Ryu (2017) and Goyal *et al*. (2009) who attributed greater P from organic fertilizers over NPK fertilizer to inherent P content of organic fertilizers incorporated in soil. Similar increase of total N at compost treatments (15 & 30 t ha^{-1}) to NPK fertilizer could also be attributed to the direct addition of high N from macadamia husk compost and the increase of SOM (Bakayoko *et al*., 2009). Positive correlation (r= 0.58**) between N and SOM was observed (Appendix 1). The increase of exchangeable cations and micronutrients content in soil with compost application was likely due to high content of these nutrients from compost (Table 4.1). The application of compost has been previously reported to increase exchangeable K, Na, Mg, Ca and micronutrients on soil (Zai *et al.,* 2008; Iren *et al.,* 2015; Ogbonna *et al.,* 2012; Hossain and Ryu, 2017) due to high content of exchangeable cations and micronutrients contained in organic fertilizers. Greater exchangeable cations and micronutrients with application of macadamia husk compost compared to NPK fertilizer was expected since, NPK fertilizer only supply nitrogen, phosphorus and potassium to soil (Masarirambi *et al*., 2010). Organic manure supply wide range of nutrients and have high cation exchange capacity which bind more exchangeable cations (Wetterstedt *et al*. 2009). However, the increase in exchangeable cations due to inorganic fertilizer was unexpected since the mineral fertilizer used did not contain exchangeable cations.

Addition of organic matter as compost without including lime can be enough to adjust soil pH downwards because organic matter produces hydrogen ions as it decomposes (Brady and Weil, 2002). However, in this study I observed an increase in soil pH with application of macadamia husk compost which was likely due to high pH in the compost used (Table 4.1). Also, the increase can be associated with the increase of organic matter due to addition of organic materials on soil (Dong *et al*. 2001; Adeniyan *et al*., 2011). A positive correlation (r= 0.50**) was observed between soil organic matter and soil pH (Appendix 1). The application of compost has been previously reported to increase soil pH (Teshome *et al.,* 2017; Frimpong *et al.,* 2016). Greater increase of soil pH at 15 and 30 t ha^{-1} over NPK fertilizer was probably due to the increase of exchangeable cations after macadamia husk compost application. Indeed, there was an increase in all exchangeable cations with application of compost (Table 4.4a and 4.4b). The results are supported by positive correlations between exchangeable K (r= 0.44*), Na (r= 0.46*), Ca (r= 0.49*), Mg (r= 0.71**) and soil pH (Appendix 1). Carbon mineralization and addition of cations such as K, Ca and Mg with application of compost contribute to increased soil pH (Olayinka and Adebayo, 1985; Mkhabela and Warman, 2005; Sarwar *et al.,* 2008). These results are in agreement with a study by Obiamaka (2011) who reported increase of soil pH with application of compost at 20, 40 and 60 t ha^{-1} compared with inorganic fertilizer. Ojobor *et al.* (2017) also found that application of rice husk compost at 2.5, 5 and 10 t ha^{-1} increased soil pH over control and inorganic fertilizer relatively due to exchangeable Ca, Na and K that compost contain.

4.5 Conclusion

Application of macadamia husk compost at 15 and 30 t ha^{-1} served as a good source of organic amendment for improvement of soil physical and chemical properties. This was indicated by significantly higher values of water holding capacity, soil chemical properties and low bulk density. The effect of macadamia husk compost in this study varied with compost application rate, with the effect being greater at 30 t ha^{-1} macadamia husk compost. Moreover, macadamia husk compost was clearly advantageous over NPK fertilizer on physicochemical properties. The improvement of these properties was attributed to high carbon content from compost and the increase of soil organic matter. However, since the study was conducted in one location, more research is needed to assess the effect of macadamia husk compost on physicochemical properties involving different soil type, climate and application rates.

5. MACADAMIA HUSK COMPOST EFFECT ON GROWTH, YIELD AND NUTRIENT CONTENT OF CHINESE CABBAGE (*Brassica rapa L. Chinensis*)

ABSTRACT

Low soil fertility and limited access to fertilizers are considered as major problems affecting crop productivity in arid and semi-arid areas of South Africa. Two field experiments were conducted in winter season of 2018 and 2019 to assess the effect of macadamia husk on growth, yield and nutrient content of Chinese cabbage in Levubu, Limpopo, South Africa. The treatments (Zero control, 100:60:60 kg NPK ha^{-1}, 15 and 30 t ha^{-1} macadamia husk compost) where arranged in a randomized complete block design with three replicates. Harvesting was done three times (28 DAT, 46 DAT and 74 DAT). Yield was determined in terms of number of leaves, fresh mass, dry mass, and leaf area. After each harvest, leaves were dried and analysed for leaf nutrient content (N, P, K, Ca, Mg, Zn, Cu, Mn and B). After final harvest, plants were uprooted to determine root biomass (Fresh root biomass and dry root biomass) and root length. Application of NPK fertilizer and compost increased root biomass and root length. The interaction between fertilizer treatment and harvesting time affected yield; at 28 DAT NPK resulted in higher yield but at 74 DAT the highest yield was recorded in plots that received 30 t ha^{-1} compost. Macadamia husk and NPK fertilizer had no effect on leaf nutrient content of Chinese cabbage.

Key words: Macadamia husk compost, Chinese cabbage, harvesting time, leaf nutrient content

5.1 Introduction

Vegetables are important components in diets of rural families in South Africa as they provide vitamins and minerals. Chinese cabbage (*Brassica rapa L. Chinensis*) is one of the most widely planted leafy vegetables in peri-urban smallholder farms in northern part of South Africa (Mukwirimbaa *et al.,* 2016) and one of the most popular vegetables in South Africa (Van Averbeke and Netshithuthuni, 2010). Smallholder farmers in South Africa grow Chinese cabbage for family consumption and as a means of generating income by marketing through local markets and chain stores (DAFF, 2013). Chinese cabbage provides good source of food as it is rich in dietary vitamins and minerals (Peyvast and Abbassi, 2006). It has a short growing season and it requires NPK nutrients in relatively large quantities to sustain rapid growth as compared to other vegetables (Magnusson, 2002).

In Limpopo, South Africa, farmers continue to experience low yields. This is attributed to water scarcity and deficiency of soil nutrients which are major constraints that limit crop production amongst smallholder farmers in the arid and semi-arid regions of Limpopo Province, South Africa (Kundhlande *et al.,* 2004). Poor soil type, soil erosion, lack of fertilizer due to high cost and lack of manure have been identified as factors that greatly contribute to low fertility (Ramaru *et al.,* 2000; Lusiba *et al.,* 2016). Use of synthetic fertilizers is one option to obtain high yields. However, many smallholder farmers are disadvantaged because of high cost and poor accessibility (Okorogbona *et al.,* 2011). Manures such as cattle manure and chicken manure have been used by smallholder farmers to enhance soil fertility, but the quantity is not usually enough for the available areas. Therefore, there is a need to focus on alternative ways to improve the availability of organic manure. Organic manure such as of macadamia husk compost could be an alternative to enhance soil fertility and improve crop production. Macadamia husks are the outer coating of the net-in-shell and usually accumulate in stockpiles on farms because of de-husking process. Most of these husks end up in landfill while few farmers use it to make compost and feed animals. These husks are known to decompose quickly and release nutrients rapidly (Cox *et al*., 2004).

Compost use as soil amendment has received much attention from farmers because of its benefit on soil and crop growth (Tweib *et al.,* 2011; Nguyen *et al.,* 2013). Compost addition improves root growth and indirectly improve nutrient availability to plants which therefore improve crop yield and leaf area (Walker and Bernal, 2008; Oworu *et al.,* 2010; Adamtey *et al.,* 2010). A number of studies have documented the effect of compost on crop growth and yield (Nguyen et *al.,* 2013; Polat *et al.,* 2009; Togun *et al.,* 2003), nutrient content (Polat *et al.*, 2004; Anwar *et al*., 2017; Adekayode and Ogunkoya, 2011) and leaf area (El-Quesni *et al.* 2013; Gonzales *et al*., 2015; Rady *et al.,* 2016). However, the effects vary with feedstock type, application method, application rate as well as soil type and environment. Moreover, there are some studies in literature which reveal the effect of macadamia husk compost on soil properties (Bittenbender *et al.,* 1998; Cox *et al.,* 2004), there is hardly any evidence of macadamia husk effect on crop production. Therefore, this study evaluated the effect of macadamia husk compost on growth, yield and leaf nutrient content of Chinese cabbage in sandy loam soil.

5.2 Materials and method

Full experimental details are given in chapter 3, but a brief summary is described below. The experiment was conducted in winter 2018 (experiment I) and 2019 (experiment II) at the Agricultural Research Council-ITSC Experimental Farm, in Levubu, Limpopo Province, South Africa. Harvesting was done three times (28 DAT, 46 DAT and 74 DAT). Yield was determined in terms of number of leaves, fresh leaf biomass, dry leaf biomass and leaf area by sampling six plants in the middle inner rows in each experimental plot. Leaf samples from each harvesting date were dried and taken to the laboratory for leaf nutrient content determination. After the final harvest, same plants used for yield determination were uprooted carefully using and washed with tap water. Roots were uprooted to determine fresh root biomass and root length. The roots were oven dried for 48 hours at 65˚C and dry root biomass was measured. The data were subjected to analysis of variance (ANOVA) using Genstat 18th edition package where mean comparisons were performed using Least Significant Difference (LSD) test at 5% level of significance. Correlation analysis was determined using Parson's simple correlation coefficients.

5.3 Results

5.3.1 Yield components, leaf area, root biomass and root length

5.3.1.1 Number of leaves

Application of NPK fertilizer, 15 and 30 t ha^{-1} macadamia husk compost increased number of leaves by 65%, 43% and 77%, respectively compared to control (Table 5.1). Similarly, number of leaves was increased by NPK fertilizer (41%), by 15 t ha^{-1} (39%) and 30 t ha^{-1} (54%) of macadamia husk compost in 2019 season (Table 5.1). Harvesting time significantly affected number of leaves in 2018 (Table 5.1). Number of leaves harvested at 74 DAT was higher compared to number of leaves harvested at both 28 and 68 DAT (Table 5.1 and figure 5.1). In contrast, the effect of harvesting time on number of leaves was not significant in 2019 cropping season (Table 5.1 and figure 5.2). The was an interactive effect of harvest of harvesting time and fertilizer treatment in both cropping seasons (Figure 5.1 and 5.2). Highest number of leaves was recorded at NPK fertilizer during the first harvest while at last day of harvest highest number of leaves was recorded at 30 t ha^{-1} of macadamia husk compost (Figure 5.1 and 5.2). In general, number of leaves at NPK fertilizer decreased with harvesting time while number of leaves at both compost treatments increased with harvesting time (Figure 5.1 and 5.2). Number of leaves was greater during the second cropping season (2019) compared to first cropping season (2018) (Figure 5.9).

5.3.1.2 Fresh and dry leaf biomass

Application of macadamia husk compost and NPK fertilizer increased fresh leaf biomass in 2018 and 2019 (Table 5.1). Also, fresh leaf biomass was greater at 30 t ha^{-1} of macadamia husk compost compared to NPK fertilizer and macadamia husk compost at 15 t ha^{-1} (Table 5.1). Similarly, application of macadamia husk and NPK increased dry leaf biomass but the increase was greater at 30 t ha^{-1} of macadamia husk compost compared to NPK and 15 t ha^{-1} macadamia husk compost (Table 5.1). Fresh leaf biomass harvested at 74 DAT was higher compared to fresh leaf biomass harvested at both 28 and 68 DAT in both seasons (Table 5.1, figure 5.3 and 5.4). Also, higher dry leaf mass was recorded at last date of harvest compared to harvest at first and second date in 2018 (Table 5.1 and figure 5.5). Harvesting time had no effect on leaf dry biomass during the second cropping season (Table 5.1 and figure 5.6). The interaction between fertilizer treatment and time of harvest affected fresh and dry leaf biomass in both seasons (Figure 5.3, 5.4, 5.5 and 5.6). The effect of treatment varied with time such that at first harvest highest fresh leaf biomass was recorded at NPK fertilizer while at the last date of harvest highest fresh leaf biomass was recorded at 30 t ha^{-1} of macadamia husk compost in 2018 and 2019 (Figure 5.3 & 5.4). Similarly, macadamia husk compost application at 30 t ha^{-1} gave the highest dry leaf biomass at 74 DAT but at 28 DAT NPK fertilizer gave the highest dry leaf biomass compared to control, 15 t ha^{-1} and 30 t ha^{-1} macadamia husk compost in both cropping seasons (Figure 5.5 and 5.6). Higher fresh and dry leaf biomass was recorded during the second cropping season compared to first cropping season (Figure 5.10a and 5.10b).

5.3.1.3 Leaf area

Application of macadamia husk compost and inorganic fertilizer increased leaf area but the increase was greater at 30 t ha^{-1} macadamia husk compost in 2018 (Table 5.1). Similarly, in 2019 highest leaf area was recorded at 30 t ha^{-1} macadamia husk compost with 24% and 44% increase compared to NPK fertilizer and macadamia husk compost at 15 t ha$_{-}^{1}$ (Table 5.1). Time of harvest had a significant effect on leaf area in both cropping seasons (Table 5.1). Harvest three had greater leaf area compared to harvest two and one (Table 5.1, figure 5.7 and 5.8). The interaction between fertilizer treatment and harvesting time affected leaf area of Chinese cabbage in 2018 and 2019 cropping season (Figure 5.7 & 5.8). In 2018 season, highest leaf area was recorded during the last date of harvest at 30 t ha^{-1} macadamia husk compost (Figure 5.7). Also, at 28 DAT and 46 DAT macadamia husk compost at 30 t ha^{-1} had higher leaf area but was not significantly different from NPK fertilizer (Figure 5.7). In 2019 cropping season, NPK fertilizer had greater leaf area compared to control and compost (15 & 30 t ha^{-1}) during the first date of harvest but during the second and third harvest 30 t ha^{-1} macadamia husk compost ^{1} had greater leaf area compared to NPK and 15 t ha^{-1} macadamia husk compost (Figure 5.8). Second cropping season had greater leaf area compared to first cropping season (Figure 5.11).

Table 5.1 Effect of macadamia husk compost and NPK fertilizer on number of leaves, fresh leaf biomass, dry leaf biomass and leaf area in 2018 and 2019

Treatment	**No of leaves per m^2**	**Fresh leaf biomass (g/m^2)**	**Dry leaf biomass (g/m^2)**	**Leaf area per m^2**
		Experiment I (2018)		
Fertilizers (F)				
Control	26.00±6.12c	188.00±68.20d	20.00±4.06c	2.10±0.26d
NPK	43.00±8.06a	681.40±78.40b	45.89±7.62b	3.20±0.24b
MC1	37.11±5.88b	588.90±167.9c	46.33±19.82b	2.91±0.49c
MC2	45.89±14.03a	783.80±322.4a	55.44±23.85a	3.81±1.06a
LSD (0.05)	2.932	22.200	2.402	0.101
Harvesting time (T)				
28 DAT	34.83±12.64b	409.11±215.40c	28.75±11.19b	2.90±0.45b
46 DAT	34.00±4.35b	531.70±198.10b	38.83±13.14b	2.71±0.28b
74 DAT	45.50±12.48a	740.82±352.10a	58.17±23.24a	3.50±1.27a
LSD (0.05)	2.540	19.230	2.080	0.088
P (F-test)				
Fertilizers	$P<0.01$	$P<0.01$	$P<0.01$	$P<0.01$
Harvesting time	$P<0.01$	$P<0.01$	$P<0.01$	$P<0.01$
F*T	$P<0.01$	$P<0.01$	$P<0.01$	$P<0.01$
CV%	7.9	4.1	5.9	3.5
		Experiment II (2019)		
Fertilizers (F)				
Control	38.56±11.51b	420.44±150.39c	29,11±8.48d	1.74±0.15d
NPK	51.89±12.23a	986.44±244.32a	52.33±12.62b	2.54±0.49b
MC1	51.00±12.00a	710.22±223.55b	43.16±24.01c	2.19±0.48c
MC2	56.44±7.97a	1079.22±475.11a	64.44±12.62a	3.16±0.78a
LSD (0.05)	11.252	140.420	8.556	7.406
Harvesting time (T)				
28 DAT	53.00±10.80	748.58±319.98b	46.83±28.01	2.30±0.56b
46 DAT	51.50±10.54	716.64±263.23b	46.09±12.53	2.32±0.49b
74 DAT	43.92±14.85	925.50±523.12a	50.00±16.11	2.64±1.06a
LSD (0.05)	9.744	121.621	7.406	0.254
P (F-test)				
Fertilizers	$p<0.05$	$p<0.01$	$p<0.01$	$p<0.01$
Harvesting time	ns	$p<0.05$	ns	$p<0.05$
F*T	$p<0.05$	$p<0.01$	$p<0.01$	$p<0.01$
CS	$p<0.01$	$p<0.01$	$p<0.01$	$p<0.01$
CV%	16.71	21.53	11.92	6.61

Values are means ± standard deviation; n= 12, means bearing same letter within a column are not statistically different, NPK= 100:60:60 kg NPK ha^{-1}, MC1= compost at 15 t ha^{-1}, MC2= compost at 30 t ha^{-1}, LSD= Leaf significant difference, CS= Cropping season, CV= Coefficient variance, ns= non significant

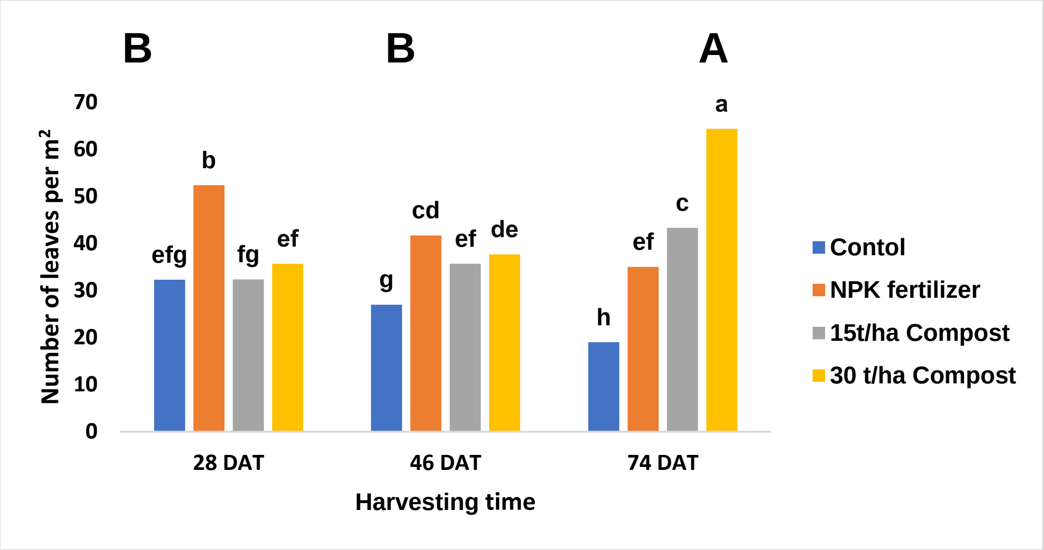


Figure 5.1. Effect of macadamia husk compost and NPK fertilizer on number of leaves during three harvest period in 2018, 28 DAT= Harvest 1, 46 DAT= Harvest 2, Harvest 3= 74 DAT

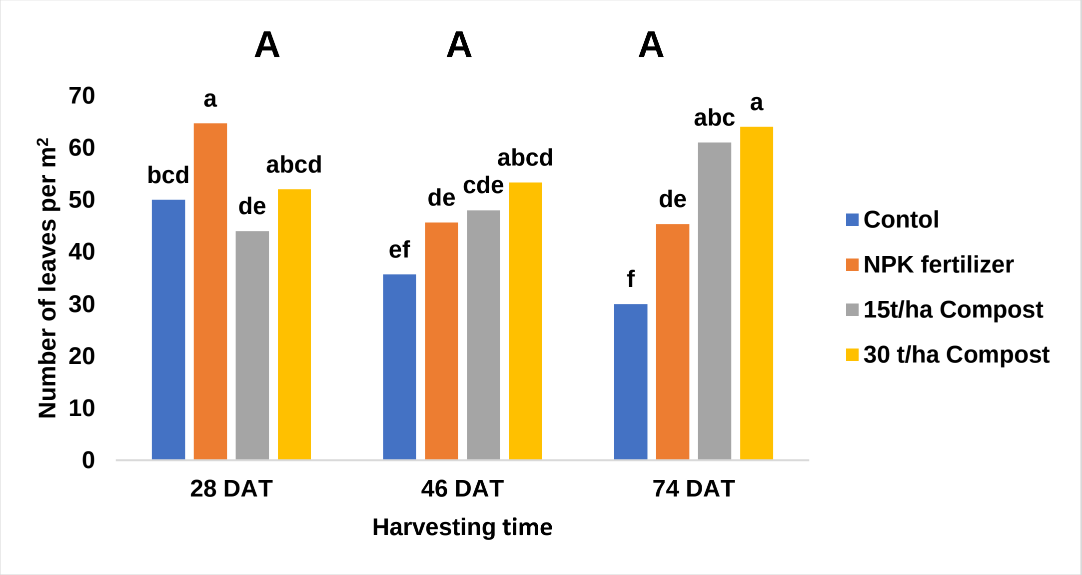


Figure 5.2. Effect of macadamia husk compost and NPK fertilizer on number of leaves during three harvest period in 2019, 28 DAT= Harvest 1, 46 DAT= Harvest 2, Harvest 3= 74 DAT

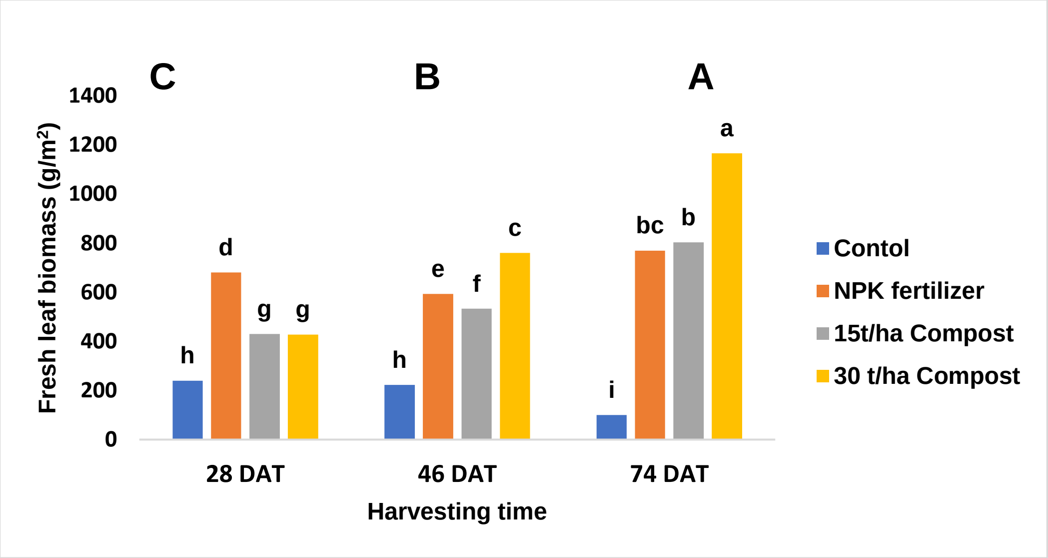


Figure 5.3. Effect of macadamia husk compost and NPK fertilizer on fresh leaf biomass during three harvest period in 2018, 28 DAT= Harvest 1, 46 DAT= Harvest 2, Harvest 3= 74 DAT

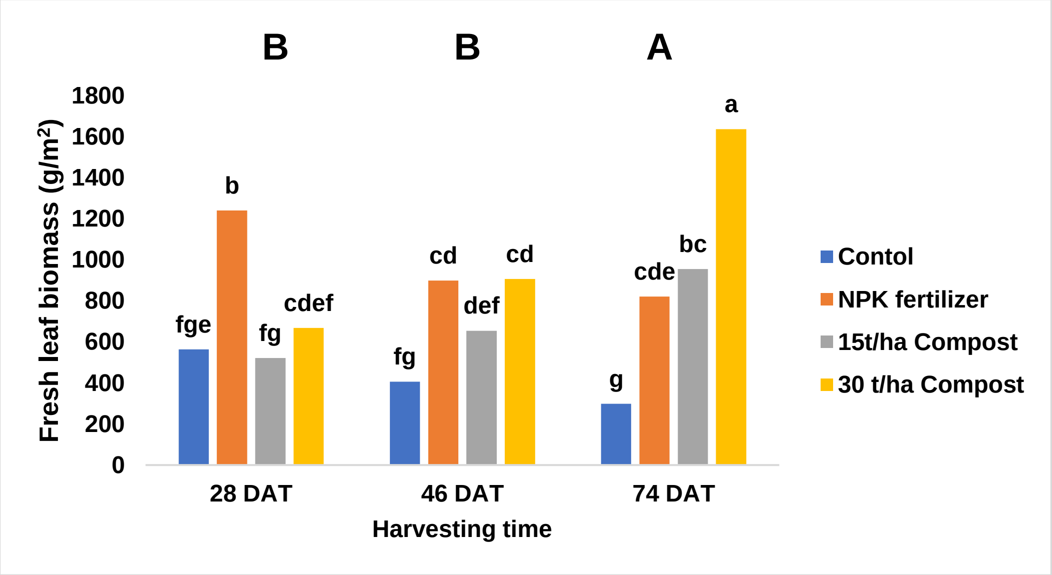


Figure 5.4. Effect of macadamia husk compost and NPK fertilizer on fresh leaf biomass during three harvest period in 2019, 28 DAT= Harvest 1, 46 DAT= Harvest 2, Harvest 3= 74 DAT

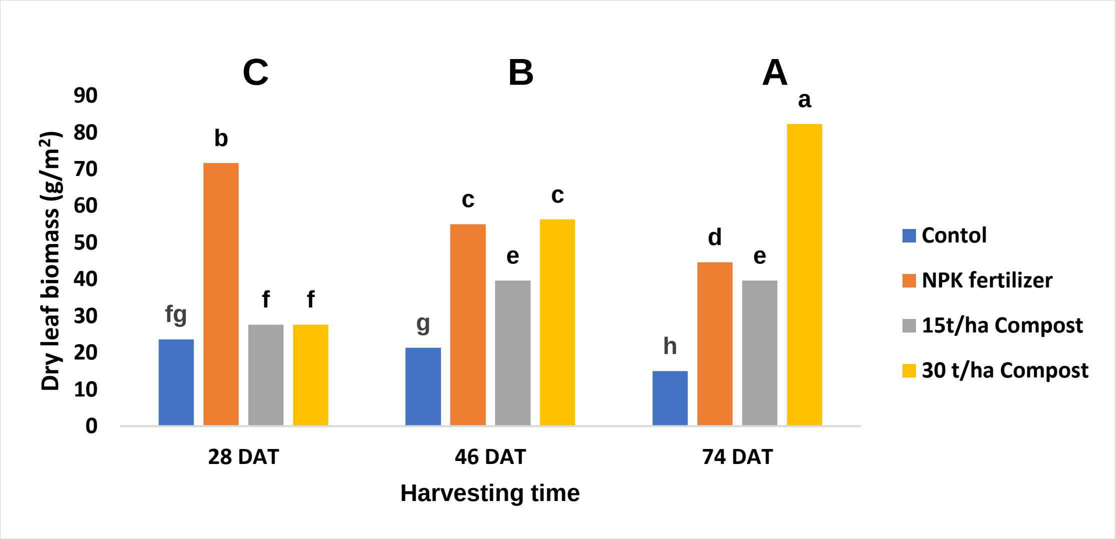


Figure 5.5. Effect of macadamia husk compost and NPK fertilizer on dry leaf biomass during three harvest period in 2018, 28 DAT= Harvest 1, 46 DAT= Harvest 2, Harvest 3= 74 DAT

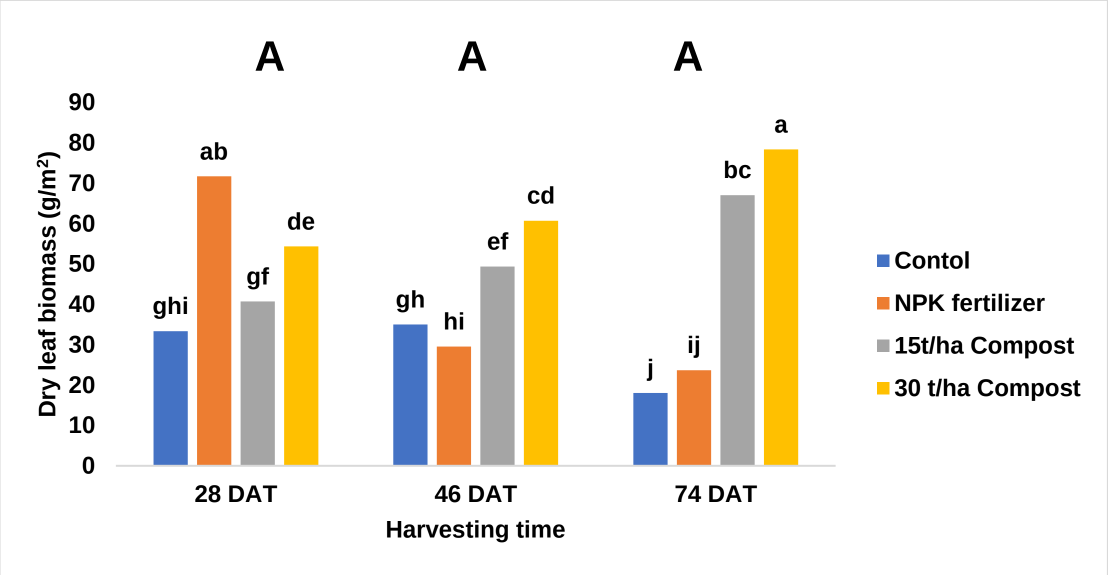


Figure 5.6. Effect of macadamia husk compost and NPK fertilizer on dry leaf biomass during three harvest period in 2019, 28 DAT= Harvest 1, 46 DAT= Harvest 2, Harvest 3= 74 DAT

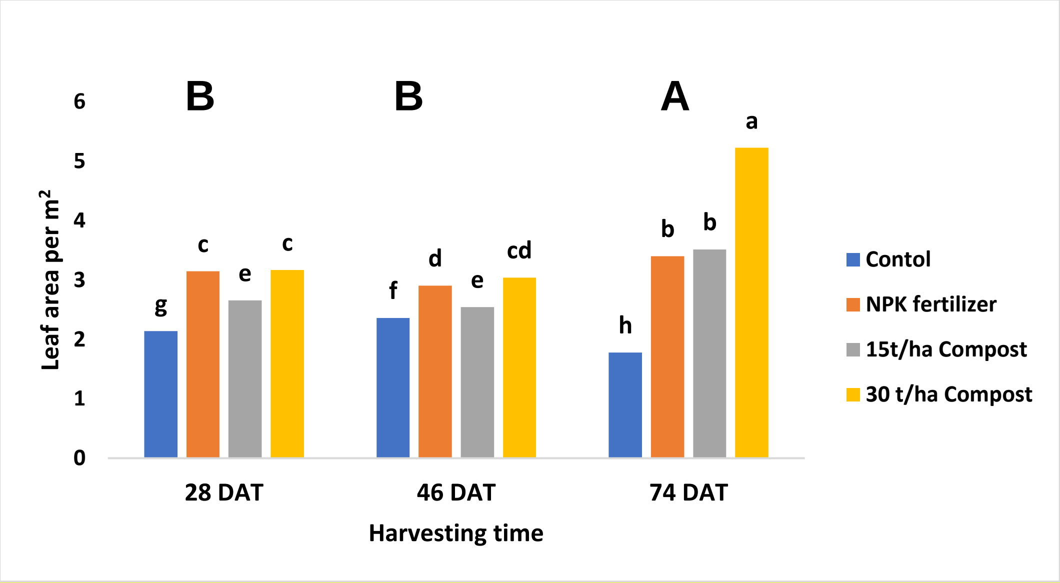


Figure 5.7. Effect of macadamia husk compost and NPK fertilizer on leaf area during three harvest period in 2018, 28 DAT= Harvest 1, 46 DAT= Harvest 2, Harvest 3= 74 DAT

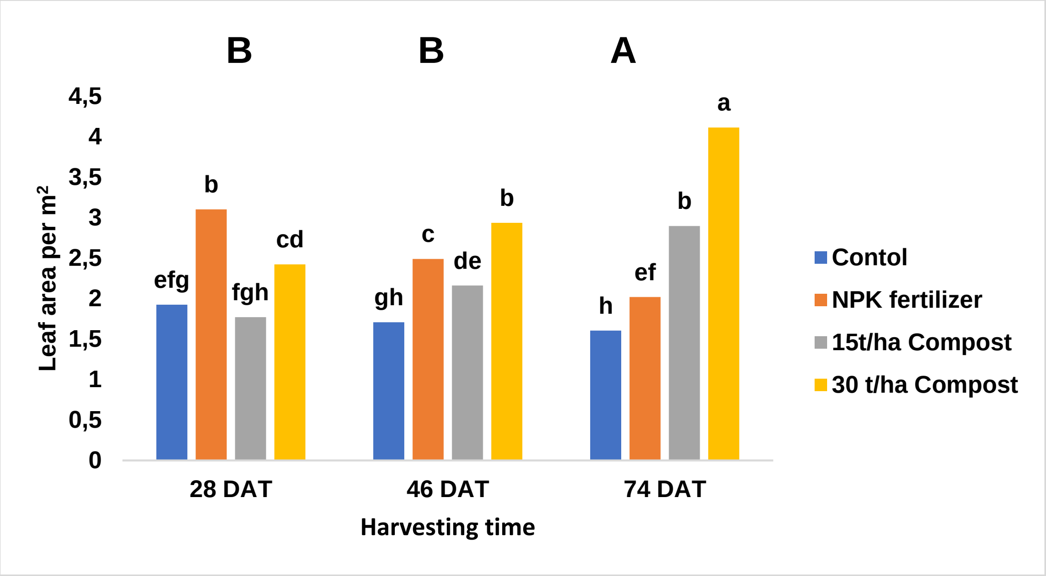


Figure 5.8 Effect of macadamia husk compost and NPK fertilizer on leaf area during three harvest period in 2019, 28 DAT= Harvest 1, 46 DAT= Harvest 2, Harvest 3= 74 DAT

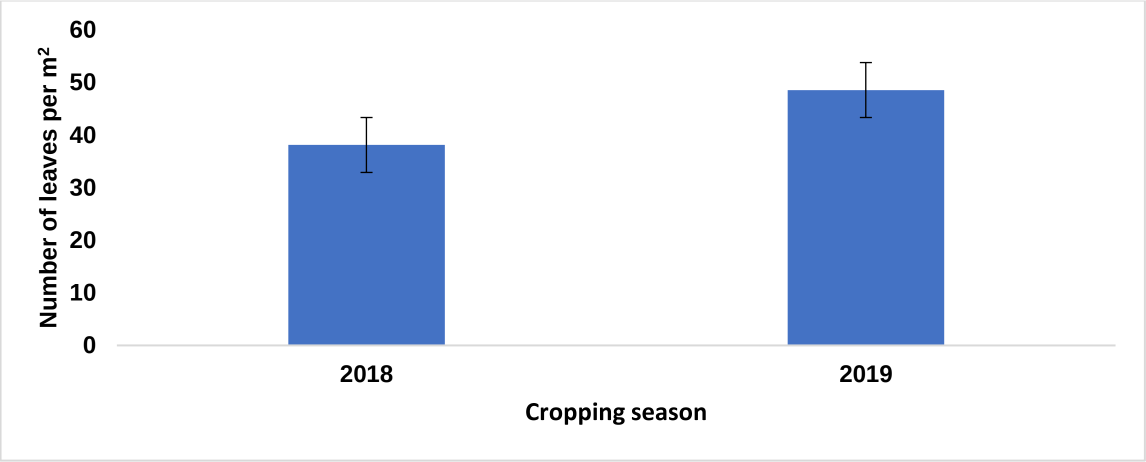
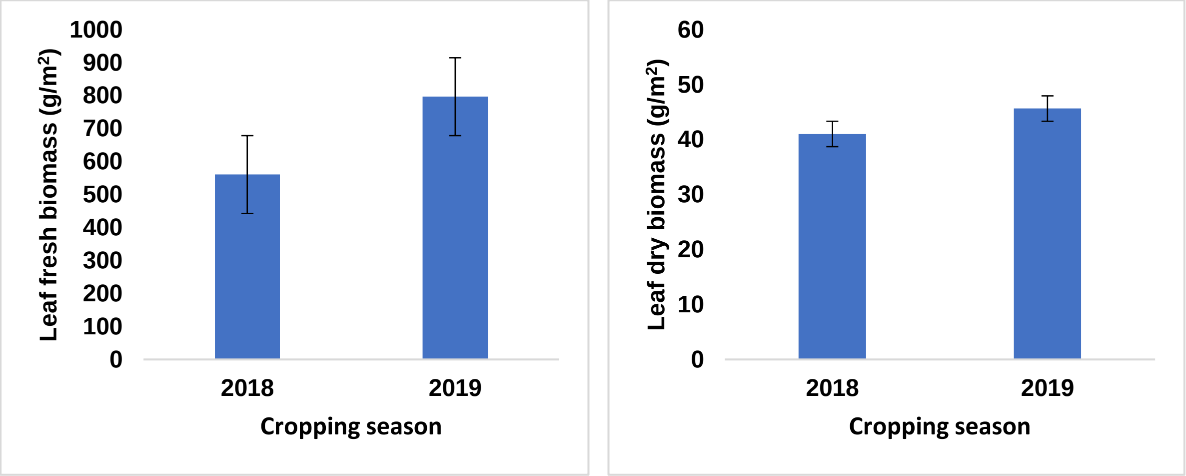


Figure 5.9. Effect of cropping season on number of leaves



(a) (b)

Figure 5.10. Effect of cropping season on (a) fresh leaf and (b) dry leaf biomass

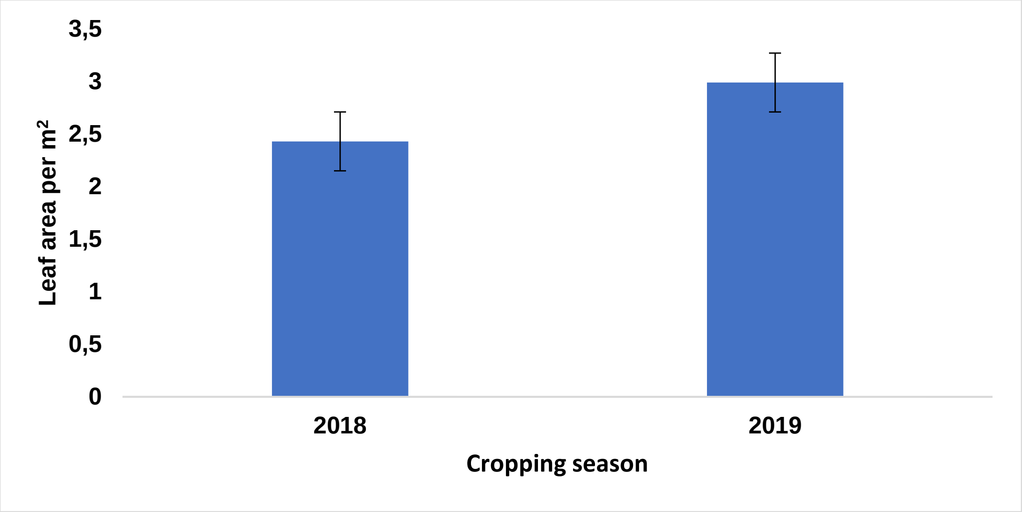


Figure 5.11. Effect of cropping season on leaf area

5.3.1.4 Root biomass and length

Application of macadamia husk compost and NPK fertilizer affected root biomass in both cropping seasons (Table 5.2). Also, in 2018, fresh root biomass of Chinese cabbage was greater by 159% (NPK), 160% (15 t ha^{-1}) and 179% (30 t ha^{-1}) compared to control (Table 5.2). Similarly, in 2019 fresh root biomass increased by 135%, 148% and 179% at NPK fertilizer, 15 t ha^{-1} and 30 t ha^{-1} of macadamia husk compost, respectively (Table 5.2). Dry root biomass was increased by the application of macadamia husk compost at both rates and NPK fertilizer, but greater increase was recorded at 30 t ha^{-1} of macadamia husk compost in 2018 and 2019 (Table 5.2). Root length was increased by 31.8%, 32% and 47.9% at NPK, compost at 15 t ha^{-1} and 30 t ha^{-1}, respectively in 2018 cropping season (Table 5.2). In 2019 root length was also increased by the application of macadamia husk compost and NPK fertilizer with the increase being greater at 30 t ha^{-1} compared to NPK fertilizer and 30 t ha^{-1} with increases of 30 & 21%, respectively (Table 5.2).

Table 5.2 Effect of macadamia husk compost and NPK fertilizer on root biomass and length of Chinese cabbage in 2018 and 2019 cropping season

Treatments	**Fresh root biomass (g/ m^2)**	**Dry fresh biomass (g/ m^2)**	**Total root length (cm^2)**
	Experiment I (2018)		
Control	3.40±0.50b	0.30±0.10c	11.20±1.20b
NPK	8.48±1.34a	0.80±0.36bc	14.77±1.02a
MC1	8.83±1.10a	1.08±0.37b	14.80±0.45a
MC2	9.50±1.92a	1.36±0.15a	16.57±1.15a
P (F-test)	$P < 0.05$	$P < 0.05$	$P < 0.05$
LSD (0.05)	2.179	0.538	2.168
CV%	18.0	20.4	7.6
	Experiment II (2019)		
Control	3,30±0.78b	0,29±0.06c	11.46±1.14c
NPK	7.78±0.71a	0.82±0.17b	14.87±0.79ab
MC1	8.50±0.25a	1.03±0.12b	13.98±0.50b
MC2	9.22±0.01a	1.30±0.16a	16.22±1.17a
P (F-test)	$P<0.05$	$P<0.05$	$P<0.05$
LSD (0.05)	1.692	0.266	2.041
CV%	11.76	15.40	7.23

Values are means ± standard deviation; n= 12, means bearing the same letter within a column are not statistically different at p<0.01 and p<0.05, NPK = 100:60:60 kg NPK ha^{-1}, MC1 = Macadamia husk compost at 15 t ha^{-1}, MC2 = Macadamia husk compost at 30 t ha^{-1}, LSD = Least Significant Difference, CV= Coefficient variance, ns= non-significant

5.3.2 Leaf nutrient content

Macadamia husk compost and NPK fertilizer had no effect on leaf N, P, K, Ca, Mg, Zn, Cu, Mn and B content in 2018 and 2019 (Table 5.3 & 5.4). In 2018, harvest time affected leaf N, P, K, Cu and Mn (Table 5.3). Content of N, P, K, Mn and B on leaf of Chinese cabbage was greater during the third harvest compared to harvest one and harvest two (Table 5.3). Leaf Cu content was lower at 28 DAT compared to 46 DAT and 74 DAT (Table 5.3). In second cropping season harvesting time affected K, Ca and Mn with greater content being at 74 DAT compared to 28 DAT and 46 DAT (Table 5.4).

Table 5.3 Effect of macadamia husk compost and NPK fertilizer on leaf nutrient content of Chinese cabbage in 2018

Treatments	**N**	**P**	**K**	**Ca**	**Mg**	**Zn**	**Cu**	**Mn**	**B**
	(%)	**(%)**	**(%)**	**(%)**	**(%)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Fertilizers (F)									
Control	4.03±0.53	0.45±0.17	4.85±0.99	2.63±0.49	0.55±0.09	38.22±2.95	11.11±2.14	52.11±20.70a	68.64±32.70
NPK	4.19±0.34	0.49±0.16	5.13±1.19	2.54±0.44	0.49±0.11	36.89±4.51	10.56±1.94	47.33±17.07ab	62.32±28.45
MC1	4.20±0.50	0.57±0.15	5.15±1.14	2.75±0.59	0.50±0.16	38.00±2.50	10.78±2.58	45.89±23.37ab	61.45±29.10
MC2	4.16±0.57	0.54±0.12	5.31±0.85	2.72±0.42	0.55±0.14	36.33±4.09	10.00±3.24	40.78±10.17b	60.11±40.75
LSD (0.05)	0.300	0.076	0.507	0.324	0.100	2.845	1.906	9.953	5.99
Harvesting frequency (H)									
H1	3.99±0.46b	0.39±0.07b	3.94±0.47c	2.58±0.47	0.47±0.09	35.92±3.48	8.50±1.44b	29.17±9.97c	39.90±6.04c
H2	3.82±0.29b	0.45±0.14b	5.53±0.33b	2.32±0.24	0.56±0.12	36.42±2.81	11.50±1.78a	45.75±4.43b	59.18±21.0b
H3	4.63±0.17a	0.66±0.04a	6.05±0.33a	2.71±0.42	0.52±0.15	39.75±3.22	11.83±2.85a	64.67±15.55a	90.15±21.2a
LSD (0.05)	0.088	0.065	0.439	0.280	0.086	2.464	1.651	8.626	5.18
P(*F-test*)									
Fertilizers	ns	ns	ns	ns	ns	ns	ns	ns	ns
H frequency (H)	*P< 0.01*	*P<0.01*	*P<0.01*	ns	ns	ns	*P<0.01*	*P<0.01*	*P<0.01*
F *H	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV%	7.4	15.4	10.4	12.5	19.6	7.8	18.4	21.9	28.5

Values are means ± standard deviation; n= 12, Within a column means bearing the same letter are not statistically different at p<0.01 and p<0.05, NPK = 100:60:60 kg NPK ha^{-1}, MC1 = Macadamia husk compost at 15 t ha^{-1}, MC2 = Macadamia husk compost at 30 t ha^{-1}, H1 = 28 DAT, H2 = 46 DAT, H3 = 74 DAT LSD = Least Significant Difference, CV= Coefficient variance, ns= non-significant

Table 5.4 Effect of macadamia husk compost and NPK fertilizer on leaf nutrient content of Chinese cabbage in 2019

Treatments	**N**	**P**	**K**	**Ca**	**Mg**	**Zn**	**Cu**	**Mn**	**B**
	(%)	**(%)**	**(%)**	**(%)**	**(%)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Fertilizers (F)									
Control	4.16±0.21	0.43±0.05	4.02±0.33	2.00±0.29	0.40±1.09	37.78±3.52	9.75±2.37	51.33±5.39	41.73±5.92
NPK	4.36±0.36	0.39±0.05	4.20±0.49	2.12±0.45	0.49±0.09	38.67±3.43	10.44±2.40	60.87±14.52	47.45±10.16
MC1	4.38±0.28	0.48±0.07	4.30±0.57	2.40±0.26	0.42±1.14	38.11±2.57	10.56±1.94	46.33±6.20	50.26±5.00
MC2	4.38±0.30	0.49±0.15	4.58±0.63	2.90±0.60	0.49±0.08	40.33±2.91	10.56±1.84	47.00±4.30	51.30±8.51
LSD (0.05)	0.456	0.122	0.477	0.335	0.146	4.079	1.372	5.84	7.11
Harvesting frequency (H)									
H1	4.49±0.24	0.41±0.06	4.06±0.51b	2.12±0.29	0.43±0.12	38.75±3.04	10±2.26	47.00±5.14b	49.79±9.06
H2	4.31±0.29	0.44±0.09	4.21±0.33ab	2.39±0.60b	0.42±0.11	37.75±3.44	10.18±2.63	49.33±7.84ab	48.23±8.76
H3	4.15±0.26	0.46±0.12	4.56±0.49a	2.66±0.60a	0.49±0.11	39.67±2.93	10.83±1.19	56.67±12.73a	50.79±6.69
LSD (0.05)	0.204	0.106	0.413	0.334	0.126	3.529	1.186	5.847	8.43
P(*F-test*)									
Fertilizers	ns	ns	ns	ns	ns	ns	ns	ns	ns
H frequency (H)	ns	ns	*P<0.01*	*P<0.01*	ns	ns	ns	*P<0.05*	*ns*
F *H	ns	ns	ns	ns	ns	ns	ns	ns	ns
CS	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV%	5.40	22.46	13.11	12.17	23.66	5.63	13.12	11.32	14.71

Values are means ± standard deviation; n= 12, Within a column means bearing the same letter are not statistically different at p<0.01 and p<0.05, NPK = 100:60:60 kg NPK ha^{-1}, MC1 = Macadamia husk compost at 15 t ha^{-1}, MC2 = Macadamia husk compost at 30 t ha^{-1}, H1 = 28 DAT, H2 = 46 DAT, H3 = 74 DAT LSD = Least Significant Difference, CS= Cropping season, CV= Coefficient variance, ns= non-significant

5.4 Discussion

Soil physical properties are indicator of quality of soil and they determine how well roots of plants grow (Malik *et al*., 2014). Plants roots grow well in soil that has good infiltration, drainage, water holding capacity, aggregate stability, porosity, and bulk density. Therefore, any management practice that improves soil physical properties is likely to enhance root growth and development. In the current study application of macadamia husk increased root biomass and root length of Chinese cabbage. This was attributed to improvement of soil productivity (Ayeni *et al.,* 2016). Positive correlations were observed between root biomass, root length and some of soil properties (Appendix 2). For example, there was a positive correlation (r= 0.61**), (r= 0.36*), (r= 0,74***), (r= 0.62**), (r= 0.40*), (r=0.87***), (r= 0.48*), (r= 0.47*), (0.56**) between fresh root biomass and Ca, Mg, K, Na, Al, Zn, SOC & SOM, respectively. Also, a negative correlation between root biomass and bulk density was observed (Appendix 2). Similar results were observed by Jagadeesh *et al.* (2018) who found positive effects of organic manures application on root length of beetroot. Such increases were reported by other authors on other field crops (Kiran *et al*., 2016; Agbede *et al.,* 2017; Riyana *et al.,* 2018; Chinthapalli *et al.*, 2015; Rady *et al.,* 2016). However, they reported several mechanisms as an explanation for organic manures and chemical fertilizers maintaining high root biomass. According to Yuksek *et al.* (2009) and Duong *et al*. (2011), compost improves soil physical properties by reducing soil compaction while promoting water infiltration and root penetration. On the other hand, NPK fertilizer also increased root biomass due to supply of readily available nutrients which create favourable conditions for root development (Kapourchal *et al*. (2009). Similarly, Liu *et al*. (2013), reported that root length of pineapples was increased due to improvement of bulk density, organic matter and available K, P and N after composted pineapples was applied. Islam *et al.* (2011) indicated that root length of radish and Amaranthus were more pronounced at compost treatments compared to control due to proper supply of nutrients from inorganic fertilizer and organic manure which create favourable conditions for better root growth and development.

Total yield was determined in terms of number of leaves, fresh mass, dry mass and leaf area. The increase of yield after application of NPK and macadamia husk compost was expected since both fertilizers supply nutrients that are required for crop growth (Mrabet *et al.,* 2012; Ayeni *et al.*, 2016). Moreover, the increase in yield could be associated a similar increase in root biomass with NPK and compost fertilizer application (Islam *et al*., 2011; Priyadarshani *et al.*, 2013; Chinthapalli *et al*., 2015). Positive correlations were observed between yield components and root biomass at all harvests (Appendix 3). However, during the first harvest higher number of leaves, fresh mass, dry mass and leaf area were observed from NPK fertilizer probably due to readily available nutrients that were added from NPK fertilizer.

Inorganic fertilizers are manufactured with all necessary available nutrients and are ready to be utilized by the plants with no further processing as it is in the case of organic fertilizers. In addition, if supplied judiciously, inorganic fertilizers can outperform organic fertilizers in terms of improving the growth and yield of plant crops (Adeniyan *et al.,* 2011). The only shortfall of inorganic fertilizers is that it cannot sustain soil fertility and it is harmful to most of the soil organisms that are responsible for soil transformation and nutrient cycling (Adeniyan *et al.,* 2011).These findings are corroborated with the previous results of Islam *et al.* (2011), Kiran *et al.* (2016) and Rady *et al*. (2016) who associated the increase of yield, yield components and leaf area by inorganic fertilizers over organic manures to readily available and mineralized nutrients from inorganic fertilizers. In contrast, yield components at NPK fertilizer plots decreased with time of harvest. This was attributed to low sustainability of nutrients for longer period (Masarirambi *et al*., 2010; Adeniyan *et al.,* 2011).

It was observed that at 46 and 74 DAT, number of leaves, fresh mass, dry mass and leaf area were greater at compost treatments especially at 30 t ha^{-1} compared to inorganic fertilizer. Increase of yield components with time of harvest in plots supplied with compost was possibly due to slow release of nutrients from compost. Unlike inorganic fertilizers, organic fertilizers are known as the slow release of nutrient elements and it requires time for all nutrient to become available for plant uptake (Masarirambi *et al.,* 2010; Mbatha *et al.,* 2014). Moreover, the increase of yield with compost application could also be attributed to improved soil properties compared to inorganic fertilizer treatments. Macadamia husk compost application improved both physical and chemical properties such as water holding capacity, organic matter, N, P, soil pH which thereby increased root biomass, root length and thus number of leaves, fresh leaf biomass, dry leaf biomass and leaf area. Strong positive and weak positive correlations were observed between soil properties and Chinese cabbage yield components (Appendix 4). Unlike inorganic fertilizers, compost improves water holding capacity, bulk density and helps to hold more nutrients which therefore enhances crop production (Golabi *et al*., 2004). These results comparable to the findings of Hossain and Ryu (2017), Setyowati *et al.* (2014) and Nguyen *et al.* (2013) who attributed higher yield at compost treatments compared with inorganic fertilizer due to improvement of soil physical, chemical and biological properties. Higher fresh leaf biomass, dry leaf biomass, number of leaves and leaf area in the second cropping season compared to first cropping season could be due to amount of rainfall received, in which the second cropping season crops received more rainfall compared to the first cropping season (Table 3.1).

The effect of macadamia husk compost and NPK fertilizer on leaf nutrient content was not significant but leaf N, P, K, Ca, Mn, B increased with harvesting time. The increase of N, P, K, Ca, Mn, B at 76 DAT was associated with longer period of uptake and accumulation of nutrients by plants due possibly due to moisture level, soil temperatures and microorganism activity (Viera *et al.,* 2017).

5.5 Conclusion

The study showed that application of macadamia husk compost (15 & 30 t ha^{-1}) and NPK fertilizer improved root biomass and increased number of leaves, fresh leaf biomass, dry leaf biomass, leaf area but greater effect was observed at 30 t ha^{-1}. It can be concluded that macadamia husk compost can be an alternative source of nutrients for suitable crop growth. However, to derive maximum yield, large quantity of compost must be used as greater yields were archived at higher compost rate. Moreover, since effect of compost vary with environment, further studies from different areas, different soil type and application rates on different crops should be done before a definite conclusion can be drawn.

6. GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATION

6.1 General discussion

Agriculture in arid and semi-arid areas such as Vhembe District Municipality is characterized by low productivity due to declining soil fertility. Farmers in this region cannot afford adequate amounts of synthetic fertilizers to supply their fields because they are expensive. It is suggested that organic manure such as compost can be alternate to synthetic fertilizer as it is less costly, environmentally friendly and readily available. Compost can play an important role in improving soil productivity by influencing structural stability to improve water movement in the soil, nutrient retention, increase water holding capacity and facilitate root growth and crop development. Compost from different sources have been reported to improve soil properties and plant production (Adeniyan, 2011; Adugna, 2016). This study assessed the use of macadamia husk compost on soil physicochemical properties and growth, yield and nutrient content of Chinese cabbage. The hypothesis tested was that the macadamia husk compost affects selected physicochemical properties of soil, growth, yield and nutrient content of Chinese cabbage.

Macadamia husk compost affected bulk density, water holding capacity, soil organic matter, soil organic carbon, soil pH, N, P, K, Na, Mg, Ca, yield components and root biomass of Chinese cabbage. The results of this study showed that the application of macadamia husk compost increased soil organic matter in sandy loam soil. The increase of soil organic matter was associated with the increase of organic carbon in soil (Sarker *et al.,* 2012; Ojobor *et al.,* 2017). Indeed, the organic carbon in soil was increased with the application of macadamia husk compost at 15 and 30 t ha^{-1}. Soil organic matter and organic carbon increased with rate of macadamia husk compost. Therefore, if macadamia husk compost maybe used primarily for increasing soil organic matter and organic carbon, then higher compost rate must be used. The increase of soil organic carbon was associated with the high C content on the compost used in this study (Table 4.1). Similar observations were made by Soheil *et al.* (2012) who reported the increase in soil organic carbon with compost rates which was associated with the municipal waste compost content.

Organic matter and organic carbon are important factors that influence water holding capacity and bulk density. In the current study the increase of soil organic matter led to lower bulk density and increase in water holding capacity at 15 and 30 t ha^{-1} macadamia husk compost. These findings concur with the results by Amlinger *et al.* (2007) and Askin & Aygun (2018) who reported decrease of bulk density and increase of water holding capacity with addition of compost which was attributed to high carbon content on compost used. The increase and decrease of soil water holding capacity and bulk density, respectively from this experiment suggest that macadamia husk compost maybe necessary to retain water on soil in arid and semi-arid regions. Lower soil holding capacity and high bulk density in these areas maybe one of the reasons why crop productivity in very low (Sally and Kamara, 2003). Indeed, water holding capacity at control (zero) and inorganic fertilizer treatments was very low (Table 4.3).

Macadamia husk compost had a positive effect on soil chemical properties. The increase in soil exchangeable cations (K, Na, Mg and Ca), available phosphorus and micronutrients (Al, Zn and Mn) was associated with the high contents of these nutrients of the compost used in this study (Table 4.1). The increase of exchangeable cations and micronutrients on soil after compost application have been reported (Gamal, 2009; Bustamante *et al*., 2008; Civeira, 2010; Dikinya and Mufwanzala (2010). Also, the results of the study showed that the application of macadamia husk compost at 15 and 30 t ha^{-1} increased soil pH. However, there was no difference between 15 and 30 t ha^{-1}. Therefore, if macadamia husk compost may be used to primarily for increasing soil pH then 15 t ha^{-1} may be applied on sandy loam soil. The increase of soil pH with macadamia husk compost application was attributed to increase of exchangeable cations in the soil and higher pH value of the compost used (Table 4.1).

The effect of macadamia husk compost on fresh root biomass, dry root biomass and root length was significant in both cropping seasons. The response of fresh root biomass, dry root biomass and root length to macadamia husk compost application could be due to reduced soil bulk density and increased soil water holding capacity (Kapourchal *et al.,* 2009 Chinthapalli *et al.,* 2015). The increase of root length, fresh and dry root biomass led to higher number of leaves, fresh leaf mass, dry leaf mass and leaf area. The increase in root biomass favours promotion of photosynthetic production in above ground parts which ultimately increase crop yield (Qi *et al.,* 2012). Moreover, larger root system contributes to more nitrogen and water uptake from soil to crops. Also, the increase of number of leaves, fresh leaf mass, dry leaf mass and leaf area was associated with improvement of soil physical properties and supply of soil nutrients. Compost contains important minerals which are important for crop growth and development. Increase in availability of nutrients such as N, P, K and organic carbon has been reported on compost amended soils (Iren *et al.,* 2015; Angelova *et al.,* 2013 Hossain and Ryu, 2017). These results are comparable with the results reported by Tayebeh *et al.* (2010) who observed increase in grain yield with compost application which was associated with increase improvement of soil properties.

6.2 General conclusion

Macadamia husk compost application had a positive effect on physical and chemical properties of sandy loam soil. The improvement of soil physical (Bulk density and water holding capacity) and chemical properties (Soil pH, SOM, SOC, N, P, K, Ca, Mg, Al, Zn and

Mn) led to improved fresh root biomass, dry root biomass, root length, number of leaves, fresh leaf biomass, dry leaf biomass and leaf area. It is evident from the results that the effect of macadamia husk as a soil amendment depend on application rate as greater soil improvement and yield was realised at 30 t ha^{-1} macadamia husk compost compared to 15 t ha^{-1} macadamia husk compost. Moreover, application of compost had greater effect on soil and yield compared to NPK fertilizer, more especially at 30 t ha^{-1}. Application of macadamia husk did not have a significant effect on leaf nutrient content of Chinese cabbage. Despite non-significant difference on leaf nutrient content within the treatments, harvesting time affected leaf nutrient content. The results of this study showed that macadamia husk compost can be used to improve soil properties thus enhance crop yield and could have a potential to be used as an alternative option to synthetic fertilizers.

6.3 Recommendations

The results of this study indicated that macadamia husk compost is clearly advantageous over NPK fertilizer and could improve bulk density, water holding capacity, soil pH, phosphorus, Total N, exchangeable cations and yield components. Macadamia husk compost at 30 t ha^{-1} maybe recommended for soil and crop improvement especially for soils with low pH, phosphorus and nitrogen. However, the study was conducted for less than three seasons which maybe not be long enough to make conclusive recommendations especially on physical properties. Also, another limitation for this study is that only one location was used. Therefore, more research is required to assess the effects of macadamia husk compost on in different locations under different field conditions over long period of time because compost effects on soil and crop yield vary widely with application methods, application rates, crop type and soil type.

REFERENCES

Abubaker, S. (2013). Effect of different types of mulch on performance of tomato (*Lycopersicon esculentum M.*) under plastic house conditions. *Journal of Food, Agriculture and Environment*. **11(2)**: 132-134.

Adamtey, N., Cofie, O., Ofosu-Budu, K.G., Ofusu-Anim, J., Laryea, K.B. and Forster, D. (2010). Effect of N-enriched co-compost on transpiration efficiency and water-use efficiency of maize (*Zea mays L.*) under controlled irrigation. *Agricultural water Management*. **97**: 995-1005.

Adekayode, F.O. and Ogunkoya, M.O. (2011). Comparative effects of organic compost and NPK fertilizer on soil fertility, yield and quality of amaranths in southwest Nigeria. *The International Journal of Biological and Chemical Sciences*. **5(2)**: 490-499.

Adeniyan, O.A., Ojo, A.O., Akinbode, O.A. and Adediran, J.A. (2011). Comparative study of different organic manures and NPK fertilizer for improvement of soil chemical properties and dry matter yield of maize in two different soils. *Journal of Soil Science and Environmental Management*. **2(1)**: 9-13.

Adugna, G. (2016). A review on impact of compost on soil properties, water use and crop productivity. *Academic Research Journal of Agricultural Science and Research*. **4(3)**: 2360-7874.

Agbede, T.M., Adekiya, A.O. and Eifediyi, E.K. (2017). Impact of poultry manure and NPK fertilizer on soil physical properties and growth and yield of carrot. *Journal of Horticultural Research*. **25(1)**: 81-88.

Albaladejo, J., Garcia, C., Ruiz-Navarro, A., Garcia-Franco, N. and Barbera. G.G. (2009). Effects of organic composts on soil properties: Comparative evaluation of source-separated and non-source-separated composts. 1st Spanish National conference on Advances in Materials Recycling and Eco. Energy Madrid.

(https://digital.csic.es/bitstream/10261/1849/1/S02.10.pdf.) Accessed 29 June 2017.

Alexander, M. (1961). Introduction to soil microbiology. John Wiley and Sons, Inc. New York, pp.2.

Amlinger, F., Peyr, S., Geszti, J., Dreher, P., Karlheinz, W. and Northcliff, S. (2007). Beneficial effects of compost application on fertility and productivity of soils. *Environment and Water Management*. (https://umweltnet.at/filemanager/download/20558/) Accessed 27 June 2018.

Angelova, V.R., Akova, V.I., Artinova, N.S. and Ivanov, K.I. (2013). The effects of organic amendments on soil chemical characteristics. *Bulgarian Journal of Agricultural Science*. **19(5)**: 958-971.

Antil, R.S., Gerzabek, M.H., Haberhauer, G. and Eder, G. (2005). Long-term effects of cropped vs fallow and fertilizer amendments on soil organic matter. *Journal of Plant Science and Plant Nutrition*. **168**: 212-218.

Anwar, Z., Irshad, M., Mahmood, Q., Hafeex, F. and Bilal, M. (2017). Nutrient uptake and growth of spinach as affected by cow manure co-composted with poplar leaf litter. *The International Journal of Recycling of Organic Waste in Agriculture*. **6**: 79-88.

Aranyos, J.T., Tomocsik, A., Makadi, M., Meszaros, J. and Blasko, L. (2016). Changes in physical properties of sandy soil after long-term compost treatment. *International Agrophysics*. **30:** 269-274.

Arthur, E., Cornelis, W.M. and Razzaghi, F. (2012). Compost amendment of sandy soil affects soil properties and greenhouse tomato productivity. *Compost Science and Utilization.* **4**: 215-221.

Askin, T. and Aygun, S. (2018). Does hazelnut husk compost (HHC) effect on soil water holding capacity (WHC)? An environmental approach. *Eurasian Journal of Soil Science*. **7(1)** 87-92.

Aslantas, R., Angin, I., Karakurt, H. and Kose, M. (2010). Vegetative and pomological changes of sour cherry as affected by sewage sludge application. *Bulgarian Journal of Agricultural Science*. **16**: 740-747.

Atere, C.T. and Olayinka, A. (2012). Effect of organo-mineral fertilizer on soil chemical properties, growth and yield of soybean. *African Journal of Agricultural Research*. **7(37)**: 5208-5216.

Ayeni, M.J., Ademiluyi, B.O. and Shittu, R.A. (2016). Effects of organic and inorganic fertilizers on the growth performance of *Solanum nigrum L*. *Journal of Agriculture and Ecology Research*. **5(4)**: 1-6.

Bakayoko, S., Soro, D., Nindji, C., Dao, D., Tschannen, A., Girardin, O. and Assa, A. (2009). Effects of cattle and poultry manures on organic matter content and adsorption complex of a sandy soil under cassava cultivation (*Manihot esculenta, Crantz*). *African Journal of Environmental Science and Technology*. **3(8)**: 190-197.

Barus, J. (2016). Utilization of crops residues as compost and biochar for improving soil physical properties and upland rice productivity. *Journal of Degraded and Mining Lands Management*. **4**: 631- 637.

Basri, M.H., Junejo, N., Abdu, A., Hamid, H.A. and Kusno, M.A. (2013). Elevation and variability of acidic sandy pH: Amended with conditioner, activator, organic and inorganic fertilisers. *African Journal of Agricultural Research*. **8**: 4020-4024.

Basak, N., Murmu, S. and Tamang, A. (2017). Impact of inorganic fertilizers on soil biological health. *Fertilizers and Environmental News*. **3(2)**: 13-16.

Bastida, F., Hernandez, T., Garcia, C. (2010). Soil degradation and rehabilitation: Microorganisms and functionality. In: Insam, H., Franke-Whittle, I., Goberna, M., (Eds.), Microbes at work. Springer Heidelberg Dordrecht London, New York.

Bernal, M.P., Alburquerque, J.A., and Moral, R. (2009). Composting of animal manures and chemical criteria for compost maturity assessment. *Bioresource Technology*. **100 (22)**: 5444-5453.

Bhattacharyya, R., Prakash, V., Kundu, S., Srivastva, A.K. and Gupta, H.S. (2009). Soil aggregation and organic matter in a sandy clay loam soil of the Indian Himalayas under different tillage and crop regimes. *Agriculture, Ecosystems and Environment*. **132**: 126 –134.

Bittenbender, H.C., Hue, N.V., Fleming, K. and Brown, H. (1998). Sustainability of organic fertilization of macadamia with macadamia husk-manure compost. *Communications in Soil Science and Plant Analysis*. **29:** 409-419.

Blake, G.R., and K.H. Hartge. (1986). Bulk density. In: A. Klute (ed.). *Methods of soil analysis*. Agronomy1, 2nd ed. American Society of Agronomy, Madison, WI, pp 149 -157.

Bouajila, K. and Sanaa, M. (2011). Effects of organic amendments on soil physico-chemical and biological properties. *Journal of Material and Environmental Science*. **2.** 485-490.

Bulluck, L.R., Brosius, M., Evanylo, G.K. and Ristain, J.B. (2002). Organic and synthetic fertility amendments influence soil microbial, physical and chemical properties on organic and conventional farms. *Applied Soil Ecology*. **19**: 147–160.

Brady, N.C. and Weil, R.R. (2002). The nature and properties of soils, 13th edition. Pearson Educ. Pub, New Delhi: India.

Bray, E.M., and Kurtz, L.T. (1945). Determination of total organic and available forms of phosphorus in soils. *Soil Science.* **59**:39-45.

Bremmer, J.M. (1996). Nitrogen-Total. In: Sparks, D.L. (Ed). Methods of analysis. Part 3. Chemical methods. Soil Science Society of America Book Series Number 5. *American Society of Agronomy*, Madison, WI, pp. 1085 -1121.

Brogan, J., Crowe, M and Carty, G. (2002). Towards setting Environmental Quality Objectives for Soil –Developing a Soil Protection Strategy for Ireland. EPA, Wexford.

Brown, S. and Cotton, M. (2011). Changes in soil properties and carbon content following compost application results of on-farm sampling. *Compost Science and Utilization*. **19(2**): 87-96.

Busscher, W. J., Novak, J. and Ahmedna, M. (2011). Physical effects of organic matter amendments of a south eastern US coastal loamy sand. *Soil Science*. **176 (12)**: 661-667.

Bustamante, M.A., Moral, R., Paredes, C., Perez-Espinosa, A., Moreno-Caselles, J. and Perez-Murcia, M.D. (2008). Agrochemical characterization of the solid by-products and residues from the winery and distillery industry. *Waste Management*. **28** :372–380.

Butler, T.J., Han, K.J., Muir, J.P., Weindorf, D.C. and Lastly, L. (2008). Dairy manure compost effects on corn silage production and soil properties. *Agronomy Journal*. **100**: 1541-1545.

Campell, A. and Sharma, G. (2007). Composted mulch for sustainable and productive viticulture. Recycled Organics Unit, The University of New South Wales, Sydney. (https://www.citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.621.3979&rep=rep1&type=pdf.) Accessed 30 August 2017.

Carter, M. R., Sanderson, J. B. and MacLeod, J. A. (2004). Influence of compost on the physical properties and organic matter fractions of a fine sandy loam throughout the cycle of a potato rotation. *Canadian Journal of Soil Science*. **84**: 211–218.

Celik, I., Gunal, H., Budak, M. and Akpinar, C. (2010). Effect of long term organic and mineral fertilizers on bulk density and penetration resistance in semi-arid Mediterranean soil conditions. *Geoderma.* **23(2)**: 51 -67.

Chinthapalli, B., Dibar, D.T., Chitra, D.S.V. and Leta, M.B. (2015). A comparative study on effect of organic and inorganic fertilizers on agronomic performance of faba bean (*Vicia faba L.*.) and Pea (*Pisum sativum L.*). *Agriculture, Forestry and Fisheries*. **4(6)**: 263-268.

Civeira, G. (2010). Influence of municipal solid waste compost on soil properties and plant reestablishment in peri-urban environments. *Chilean Journal of Agricultural Research.* **70(3)**: *446-453.*

Cox, J., Van-Zwieten, L., Ayres, M. and Morris, S. (2004). Macadamia husk compost improves soil health in sub-tropical horticulture. In 'SuperSoil 2004'. Proceedings of the 3rd Australian and New Zealand soils conference, University of Sydney, Australia, 5-9 December 2004. (https://www.regional.org.au/au.asssi/supersoil2004/s12oral/140.coxj.htm.) Accessed 29 August 2017.

Curtis, M.J. and Claassen, V.P. (2005). Compost incorporation increases plant available water in a drastically disturbed serpentine soil. *Soil Science*. **170**:939–953.

Dalzell, H.W., Bidlestone, A.J., Gray, K.R. and Thurairrajan, K. (1987). Soil management, compost production and use in tropical and subtropical Environments. FAO, 56. (https://www.fao.org/3/s8930e/s893e.pdf.) Accessed 17 June 2019.

Demelash, D., Bayu, W., Tesfaye, S., Ziadat, F. and Sommer R. (2014). Current and residual effects of compost and inorganic fertilizer on wheat and soil chemical properties. *Nutrient Cycling in Agroecosystems*. **100**: 357-367.

Department of Agriculture, Forestry and Fisheries. (2013). Chinese cabbage (*Brassica rapa L. chinensis*) (https://www.nda.agric.za/docs/Brochures/chinese.pdf). Accessed 11 August 2018.

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

Dong, J., Yao, L., Zhang, J., Feng J. and Sa, R. (2001). Feed addictive manual. Beijing: China Agr U Press. pp289.

Duong, T.T.T., Penfold, C. and Marschner, P. (2011). Amending soils of different texture with six compost types: impact on soil nutrient availability, plant growth and nutrient uptake. *Plant Soil*. **354**: 197-209.

Elfeel, A.A. and Abohassan, R.A. (2016). Compost effects on leaf area index and seed production enhancement in an important arid land leguminous tree (*Acacia tortilis subsp. Raddiana*). *An International Journal*. **36(5)**: 748-754.

ElNour, M.E.M., Elfadil, A.G., Manal, F.A. and Saeed B.A.E. (2015). Effects of banana compost on growth, development and productivity of sorghum biocolor cultivar (Tabat). *Journal of Advances in Biology*. **8(2)**: 1555-1561.

El-Quesni, F.E.M., Hashish, K.I., Kandil, M.M. and Mazher, A.A.M. (2013). Impact of some biofertilizers and compost on growth and chemical composition of *Jatropha curcas L. World Applied Sciences Journal*. **21(6)**: 927-932.

Epstein, E. (1997). The science of composting. CRC press LCC, Florida, 504 p.

Farrell, M. and Jones, D.L. (2009). Critical evaluation of municipal solid waste composting and potential compost markets. *Bioresource Technology*. **100:** 4301-4310.

Fischer, D. and Glaser, B. (2012). Synergisms between compost and biochar for sustainable soil amelioration. In: Kumar S (ed). Management of organic waste. InTech, pp 167-198. (https://pdfs.semanticsscholar.org/f846/2d0fb67225b376654f2b8370cb0f91695488.pdf.). Accessed 29 October 2018.

Frimpong, K.A., Amoakwah, E., Osei, B.A. and Arthur, E. (2016). Changes in soil chemical properties and lettuce yield response following incorporation of biochar and cow dung to highly weathered acid soils. *Journal of Organic Agriculture and Environment*. **4(1)**: 28-39.

Gamal, A.R. (2009). Impacts of compost on soil properties and crop productivity in the Sahel North Burkina Faso. *American-Eurasian Journal of Agricultural and Environmental Sciences*. **6(2)**: 220-226.

Golabi, M.H, Denney, M.J. and Iyekar, C. (2004). Use of composted organic wastes as alternative to synthetic fertilizers for enhancing crop productivity and agricultural sustainability on the tropical Island of Guam. 13th International Soil Conservation Organization Conference. Brisbane. (https://www.tucson.ars.ag.gov/isco/isco13/PAPERS%20F-L/GOLABI.pdf). Accessed 17 August 2017.

Gonzales, L.M.R., Caralde, R.A. and Aban, M.L. (2015). Response of pechay (*Brassica napus L.*) to different level of compost fertilizer. *International Journal of Scientific and Research Publication*. **5(2)**: 2250-3153.

Goyal, S., Sigh, D., Suneja, S. and Kapoor, K.K. (2009) Effect of rice straw compost on soil microbiological properties and yield of rice. *Indian Journal Agriculture*. **43(4):** 263-268.

Gregorich, E.G., Carter, M.R., Angers, D.A., Monreal, C.M., Ellert, B.H. (1994). Towars a minimum dataset to assess soil organic matter quality in agricultural soils. *Canadian Journal of Soil Science*. **74**: 367- 385.

Hargreaves J.C., Adl, M.S. and Warman P.R. (2008). A review of the use of composted municipal solid waste in agriculture*. Agriculture, Ecosystems and Environment*. **123**:1-14.

Hemmat, A., Aghilinategh, N., Rezainejad, Y. and Sadeghi, M. (2010). Long-term impacts of municipal solid waste compost, sewage sludge and farmyard manure application on organic carbon, bulk density and consistency limits of a calcareous soil in central Iran. *Soil and Tillage Research*. **108**: 43-50.

Hernandez, A., Castillo, H., Ojeda, D., Arras, A., Lopez, J. and Sanchez, E. (2010). Effect of vermicompost and compost on lettuce production. *Chilean Journal of Agricultural Research*. **70(4)**: 583-589.

Hill, De. (1990). Chinese cabbage and pak choi trials 1988-1989. Bulletin 879. The Connecticut Agricultural Experiment Station, New Haven, USA. 12 pp.

Hossain, M.B. and Ryu, K.S. (2017). Effects of organic and inorganic fertilizers on lettuce (*Lactuca sativa L.*) and soil properties. *The Journal of Agricultural Science*. **15(2)**:93-102.

Hossen, S., Islam, N., Alam, R. and Baten, A. (2015). Effects of different rates of compost application on methane emission and crop yield in Aman rice. *The Journal of Agriculture and Natural Resources Sciences*. **2(3)**: 530-536.

Ibrahim, K.H.M. and Fadni, O.A.S. (2013). Effect of organic fertilizers application on growth, yield and quality of tomatoes in North Kordofan (sandy soil) western Sudan. *Greener Journal of Agricultural Sciences*. **3(4)**: 299-304.

Iren, O.B., Akpan, J.F., Ediene, V.F. and Asanga, E.E. (2015). Influence of cassava peels and poultry manure-based compost on soil properties, growth and yield of waterleaf (*Talinum triangulare Jacq*) in an ultisol of south-eastern Nigeria. *Journal of Soil Science and Environmental Management*. **6(7)**: 187-194.

Islam, M.M., Karim, A.J.M.S., Jahiruddin, M., Majid, N.K., Miah, M.G. Ahmed, M.M. and Hakim, M.A. (2011). Effect of organic manure and chemical fertilizers on crops in radish-stem amaranth-Indian spinach cropping pattern in homestead area. *Australian Journal of Crop Science.* **5(11)**: 1370-1378.

Jackson, M.L. (1973). Soil chemical analysis. Prentice Hall of India Private Ltd., New Delhi. p134-182.

Jagadeesh, C., Madhavi, M., Prasad, M.S. and Padmaja, V.V. (2018). Effect of organic manures on yield and growth attributes of beet root. *International Journal of current Microbiology and Applied Sciences*. **7(11)**: 3538-3553.

Jeyamangalam, F., Annadurai, B. and Arunachalam, N. (2012). Effect of tank silt as organic amendment on physical properties of their soil using groundnut. *Journal of Soils and Crops*. **22(1)**: 10-14.

Joshi, D., Gediya, K.M., Gupta, S. and Birari, M.M. (2016). Effect of organic manures on soil and quality parameters of cowpea (*Vigna unguiculata L.*). *Agricultural Science Digest.* **36(3)**: 216-219.

Kapourchal, A., Pazira, E. and Homaee, M. (2009). Assessing radish (Raphanus sativus L.) potential for phytoremediation of lead polluted soils resulting from air pollution. *Plant, Soil Environment*. **5**: 202-206.

Kiran, M., Jilani, M.S., Waseem, K. and Sohail, M. (2016). Effect of organic manures and inorganic fertilizers on growth and yield of radish (*Raphanus sativus L.*). *Pakistan Journal of Agricultural Research*. **29(4)**: 363-372.

Kundhlande, G., Groenewald, D.C., Baiphethi, M.N., Viljoen, M.N., Botha, J.J., van Rensburg, L.D. and Anderson, J.J. (2004). Socio-economic study on water conservation techniques in semi-arid areas. *Water Research Commusion Report*, WRC Report No. 1267/1/04. (https.www.fwr.org/wrcsa/1267104.htm). Accessed 13 August 2017.

Lakhdar, A., Rabbi, M., Ghnaya T., Montemurro, F., Jedidi, N. and Abdelly, C. (2009). Effectiveness of compost use in salt- affected soil. *Journal of Hazardous Materials*. **171,** 29-37.

Lalfakzuala, R., Kayang, H. and MS, D. (2008). The effect of fertilizers on soil microbial components and chemical properties under leguminous cultivation. *American Eurasian Journal of Agricultural and Environmental Science*. **3**: 314-324.

Larney, F.J., Olson, AF., Miller, J.J., DeMaere, P.R., Zvomuya, F. and McAllister, T.A. (2008). Physical and chemical changes during composting of wood chip-bedded and straw-bedded beef cattle feedlot manure. *Journal of Environmental Quality*. **37**: 725-735.

Laxminarayana, K. (2006). Effect of organic manures on soil properties, yield and nutrient uptake of rice in Ultisols of Mizoram. *Journal of the Indian Society of Soil Science*. **54(1)**:120 -123.

Lee, S.E., Park, J.M., Park, Y.M., Lim, T.J. (2015). Effect of chemical fertilizer and compost on soil physicochemical properties, leaf nutrient content, Yield and quality of red pepper (*Capsicum annuum L*.) in open field. *Horticulture and Herbal Crop Environment Division*. **48(6)**: 683 – 688.

Leroy, B.L.M., Herath, M.S.K., De Neve, S., Grabriels, D., Bommele, L., Reheul, D. and Moens, M. (2008). Effect of vegetable, fruit and garden (VFG) waste compost on soil physical properties. *Compost Science and Utilization*. **16(1)**: 43-51.

Liu, C.H., Liu, Y., Fan, C. and Kuang, S.Z. (2013). The effect of composted pineapple residue return on soil properties and the growth and yield of pineapple. *Journal of Soil Science and plant nutrition*. **13(2)**: 433-444.

Lusiba, S., Odhiambo, J. and Ogola, J. (2016). Effect of biochar and phosphorus fertilizer application on soil fertility: Soil physical and chemical properties. *Achieves of Agronomy and Soil Science*. **63**: 477-490.

Magnusson, M. (2002). Mineral fertilizers and green mulch in Chinese cabbage (*Brassica pekinsensis (Lour.) Rupr*): effect on nutrient uptake, yield and internal tipburn. *Acta Agriculturae Scandinavica, Section B- Soil and Plant Science*. **52**: 25-35.

Mahmood, F., Khan, I., Ashraf, U., Shahzad, T., Hussain, S., Shahid, M., Abid, M. and Ullah, S. (2017). Effects of organic and inorganic manures on maize and their residual impact on soil physico-chemical properties. *Journal of Soil Science and Plant Nutrition*. **17(1)**: 22-32.

Malik, S.S., Chauhan, R.C., Laura, J.S., Kapoor, T., Abhilashi, R. and Sharma, N. (2014). Influence of organic and synthetic fertilizers on soil physical properties. *International Journal of Current Microbiology and Applied Sciences.* **3(8)**: 802-810.

Mandal, M., Chandran, R.S. and Sencindiver J.C. (2013). Amending subsoil with composted poultry litter-I: Effects on soil physical and chemical properties. *Agronomy*. **3**: 657-669.

Manivannan, S., Balamurugan, M., Parthasarathi, K., Gunasekaran, G. and Ranganathan, L.S. (2009). Effect of vermicompost on soil fertility and crop productivity- beans (*Phaselous vulgaris*). *Journal of Environmental Biology*. **30(2)**: 275-281.

Manrique, L.A. (1993). Greenhouse crops: A review. *Journal of Plant Nutrition*.**16 (22)**: 2411-2477.

Manyelo, K.W., Van Averbeke, W. and Hebinck, P. (2015). Smallholder irrigators and fresh produce street traders in Thohoyandou, Limpopo province, South Africa. In: Hebinck P, van der Ploeg J-D, Schneider S (eds), *Rural development and the construction of new markets*. London: Routledge. pp 131–148.

Martinez-Blanco, J., Lazcano, C., Christensen, T.H., Muñoz, P., Rieradevall, J., Møller, J., Antón, A. and Boldrin, A. (2013). Compost benefits for agriculture evaluated by life cycle assessment. *Agronomy for Sustainable Development*. **33(4)**: 721-732.

Masarirambi, M.T., Hlawe, M.M., Oseni, O.T. and Thokhozile E.S. (2010). Effects of organic fertilizers on growth, yield, quality and sensory evaluation of red lettuce (*Lactuca sativa L*.) 'Veneza Roxa'. *Agriculture and Biology Journal of North America*. **1(6)**: 1319-1324.

Mbatha, A.N., Engelbretcht, G.M. and Ceronio, C.M. (2014). Response of carrot (*Daucus carota L*.) yield and quality to organic fertilizer. *South African Journal of Plant and Soil.* **31:** 1-6.

Mkhabela, M.S. and Warman, P.R. (2005). The influence of municipal solid waste compost on yield, soil phosphorus availability and uptake by two vegetable crops grown in a Pugwash sandy loam soil in Nova Scotia. *Agriculture, Ecosystem and Environment*. **106(1)**: 57-67.

Mengistu, D.K. and Mekonnen, L.S. (2012). Integrated agronomic crop management to improve tef productivity under terminal drought. (https://www.researchgate.net/publication/221923107). Accessed 24 April 2009.

Mohammadi, S., Kalbasi, M. and Shariatmadari, H. (2009). Cumulative and residual effectsof organic fertilizer application on selected soil properties, water soluble P, Olsen-P and P sorption index. *Journal of Agricultural Science and Technology*. **11**: 487-497.

Morlat, R. (2008). Long term additions of organic amendments in a Loire Valley vineyard on a calcareous sandy soil. *American Journal of Ecology and Viticulture*. **59**: 364-374.

Motsara, M.R. and Roy, R.N. (2008). Guide to laboratory establishment for plant nutrients analysis. FAO fertilizer and plant nutrition bulletin. Food and Agriculture Organization, Rome. 219pp.

Mrabet, L., Belghyti, D., Loukili, A. and Attarassi, B. (2012). Effect of household waste compost on the productivity of maize and lettuce. *Agricultural Science Research Journals*. **2(8)**: 462-496.

Mukwirimbaa, G.M., Kritzinger, Q. and Aveling, T. (2016). A survey of brassica vegetable smallholder farmers in the Gauteng and Limpopo provinces of South Africa. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*. **117(1)**: 35-44.

Mylavarapu, R.S. and Zinati, G.M. (2009). Improvement of soil properties using compost for optimum parsley production in sandy soils. *Scientia Horticulture.* **120**: 426 – 430.

Nambiar, K.K.M., and Ambrol I.P. (1989). Long term fertilizer experiments in India: An overview. *Fertilizer News*. **1**: 1-22.

Nelson, D.W and Sommers, L.E. (1982). Total carbon, organic carbon and organic matter. In: Page, Al, Miller, R.H., Keeney, D.R., editors. Methods of soil analysis: chemical and microbiological properties. 2nd ed Madison, WI: Agronomy Society of America; p. 553-597.

Nguyen, T.T., Fuentes, S. and Marschner, P. (2013) Effect of incorporated or mulched compost on leaf nutrient concentrations and performance of *Vitis vinifera cv. Merlot*. *Journal of Soil Science and Plant Nutrition*, **13 (2)**, 485-497.

Obiamaka, O.C. (2011). Effects of household compost on the chemical properties of typic paleudult in Nigeria. *Malaysian Journal of Soil Science*. **15**: 35-48.

Odhiambo, J.J.O. and Magandini, V.N. (2008). An assessment of the use of mineral and organic fertilizers by smallholder farmers in Vhembe district, Limpopo province. *South Africa. African Journal of Agricultural Research*. **3(5):** 357-362.

Ogbonna, D.N., Isirimah, N.O. and Princewill, E. (2012). Effect of organic waste compost and microbial activity on growth of maize in the utisols in Port Harcourt Nigeria. *African Journal of Biotechnology*. **11(62)**: 12546-12554.

Odlare, M. and Pell, M. (2009). Effects of fly ash and compost on nitrification and denitrification in agricultural soil. *Applied Energy*. **86**: 74-80.

Okalebo, J.R., Gathua, K.W. and Woomer, P.L. (1993). Fraction of organic matter by particle size. Laboratory method of soil and plant analysis: A working manual. TSBF-KARI UNESCO Nairobi, Kenya. pp. 66-68.

Okorogbona, A.O.M., Van Averbeke, W. and Ramusandiwa, T.D. (2011). Growth and yield response of Chinese cabbage (*Brassica rapa L. subsp. chinensis*) as affected by nutrient availability in air-dried and pulverized different type of animal manure using low biological activity soil. *World Journal of Agricultural science*. **7 (1)**: 1–12

Ojobor, S.A., Obiazi, C.C. and Egbuchua, C.N. (2017). Effects of different levels of compost manure on upland rice and soil chemical properties in Asaba, Delta State, *Nigeria. Golbal Journal of Agricultural Research.* **4 (27):** 276-283.

Olabode, O.S., Sola, O., Akanbi, W.B., Adesina, G.O. and Babajide, P.A. (2007). Evaluation of *Tithonia diversifolia* (Hemsl.) A Gray for Soil Improvement. *World Journal of Agricultural Sciences*. **3 (4)**: 503-507.

Olayinka, A. and Adebayo, A. (1985). The effect of method of application of sawdust on plant growth, plant nutrient uptake and soil chemical properties. *Plant and Soil*. **86**: 47-56.

Or, D. and Wraith, J.M. (2002). Soil water content and ware potential relationships. In: Warrick AW. (ed) Soil physics companion. Boca Raton, Florida, USA: CRC Press LLC. p49-84.

Ouedraogo, E., Mandob, A. and Zombré, N.P (2001). Use of compost to improve soil properties and crop productivity under low input agricultural system in West Africa. *Agriculture, Ecosystems and Environment***. 84**: 259–266.

Oworu, O.O., Dada, O.A. and Majekodunmi, O.E (2010). Influence of compost on growth, nutrient uptake and dry matter partitioning of grain Amaranths (*Amaranthus hypochondriacus L.*). *Libyan Agriculture Research Canter Journal International*. **1**: 375-383.

Parikh, S.J and James, B.R. (2012). Soil: The Foundation of Agriculture. Nature Education Knowledge. **3(10)**: 2.

Paulin, B. and O'Malley, P. (2008). Compost production and use in horticulture. Vol. Bulletin 4746, Western Australian Agriculture Authority. Bulletin 4746.

Peech, M. (1965). Lime requirements. In: Black, CA, editor. Methods of soil analysis. Madison, WI: American Society of Agronomy; p927-932.

Peyvast, G. and Abbassi, M. (2006). Effect of commercial compost on yield and nitrate content of Chinese cabbage. Horticulture, *Environment and Biology*. **47(3)**: 123-125.

Polat, E., Onus, A.N. and Demir, H. (2009). The effects of spent mushroom compost on quality and productivity of cucumber (*Cucumis sativas L.)* grown in greenhouses. *African Journal of Biotechnology*. **8(2):** 176-180.

Polat, E., Onus, A.N. and Demir, H. (2004). The effects of spent mushroom compost on yield and quality in Lettuce growing. *Journal of Faculty of Agriculture of the Akdeniz University*. **17(2)**: 149-154.

Priyadarshani, N.D.N., Amarasinghe, M.K.T.K., Subasinghe, S., Palihakkara, L.R. and Kumarasinghe, H.K.M.S. (2013). Effect of organic and inorganic fertilizers on biomass production, oil yield and quality of Vetiver (*Vetiveria zizanioides L*.). *The Journal of Agricultural sciences*. **8(1)**: 25-38.

Qi, W.Z., Liu, H.H., Liu, P., Dong, S.T., Zhao, B.Q. and Zhao, B. (2012). Morphological and physiological characteristics on corn (*Zea mays L*.) roots from cultivars with different yield potentials. *European Journal of Agronomy*. **38**: 54-63.

Rady, M.M., Semida, W.M., Hemida, K.A. and Abdelhamid, M.T. (2016). The effect of compost on growth and yield of Phaseolus vulgaris plants grown under saline. *International Journal of Recycling of Organic Waste in Agriculture*. **5**: 311-321.

Ramaru, J., Mamabolo, Z. and Lekgoro, J. (2000). Improving soil fertility management in South Africa: Learning through participatory extension approaches. Managing Africa's Soils No.19. Russell Press, Nottingham, UK.

Riyana, D., Widiyastutu, Y., Widodo, H., Purwanto, E. and Samanhudi. (2018). Effect of manure and plants spacing on yield and flavonoid content of *Elepahantopus scaber L*. *Earth and Environmental Science*. **142:** 12-38.

Rubatzky, V. E and Yamaguchi, M. (1997). World vegetables: Principles and nutritive values (2nd edition). Chapman and Hall, New York, USA. 843 pp.

Sally, H. and Kamara, A. (2003). Water for food, livelihoods and nature: simulations for policy dialogue in South Africa. *Physics and Chemistry of Earth*. **28**: 1085-109.

Sanni, K.O. (2016). Effect of compost, cow dung and NPK 15-15-15 fertilizer on growth and yield performance of Amaranth (*Amaranthus hybridus*). *International Journal of advances in Scientific Research.* **2(03)**: 076-082.

Sarker, A., Kashem, M.A. and Osman, K.T. (2012). Comparative effect of city finished compost and NPK fertilizer on growth and availability of phosphorus to radish (*Raphanus sativus L.*). *Open Journal of Soil Science*. **40**: 275-282.

Sarwar, G., Hussain, N., Schmeisky, H. and Muhamad, S. (2008). Use of compost an environment friendly technology for enhancing rice-wheat production in Pakistan*.* *Pakistan Journal of Botany.* **39(5)**: 1553-1558.

Schippers, R.R. (2000). African indigenous vegetables. An overview of the cultivated species. Natural resources institute/ACP-EU technical centre for agricultural and rural cooperation, Chatham, UK. 214 pp. (https://www.scirp.org). Accessed 23 June 2019

Schoonover, W.R. (1952). *Examination of soils for alkali*. Berkeley, USA, University of California Extension Services.

Schulze, R.E. and Maharaj, M. (2003). Development of a database of gridded daily temperatures of Southern Africa, ACRUcons Report 41, University of Natal, Pietermaritzburg, South Africa. 81pp.

Setyowati, N., Muktamar, Z., Suriyanti, B. and Simarmata M. (2014). Growth and yield of chili pepper as affected by weed based organic compost and nitrogen fertilizer. *International Journal on Advanced Science Engineering Information Technology.* **4(2):** 2088-5334.

Shyamala, D. C. and Belagali, S. L. (2012). Studies on variations in physicochemical and biological characteristics at different maturity stages of municipal solid waste compost. *International Journal of Environmental Science and Technology*. **2(4)**:1984-1994.

Smith, K.A. and Mullins, C.E. (1996). Soil analysis: Physical methods. Marcel Dekker, New York, USA.

Soheil, R., Hossien, M. H., Gholamreza, S., Leila, H., Mozhdeh, J. and Hassan, E. (2012). Effects of composted municipal waste and its leachate on some soil chemical properties and corn plant responses. *Journal of Agriculture*. **2(6)**: 801-814

Sonmez, I. and Kaplan, M. (2011). The effects of some agricultural waste composts on carnation cultivation. African Journal of Agricultural Research. **6(16)**: 3936-3942.

Statistics South Africa. (2016). Quality labour force survey. (https://www.statssa.gov.za/publications/P02111stQuarter20116.pdf). Retrieved 12 August 2017.

Stevenson, J.F. (1994). *Humus chemistry*. New York, USA. (https://www.wiley.com/en-us/Humus+Chemistry). Accessed 29 August 2019

Stone, D. M. and Elioff, J. D. (1998). Soil properties and Aspen development five years after compaction and forest floor removal. *Canadian Journal of Soil Science*. **78(1)**: 51-58.

Subrop constitution. (2008). (http://www.subtrop.co.za/docrep/012/ojss/3288i) Accessed 23 August 2017.

Sullivan, D. M., Nartea, T. J., Bary, A. I., Cogger, C. G. and Myhre, E. A. (2004). Nitrogen availability and decomposition of urban yard trimmings in soil. *Soil Science*. **169**: 697-707.

Tadesse, T., Dechassa, N., Bayu, W. and Gebeyehu, S. (2013). Effects of farmyard manure and inorganic fertilizer application on soil physico-chemical properties and nutrient balance in rain-fed lowland rice ecosystem. *American Journal of Plant Sciences*. **4**: 309-316.

Tayebeh, A., Abass, A. and Seyed, A.K. (2010). Effect of organic and inorganic fertilizers on grain yield and protein banding pattern of wheat. *Australian Journal of Crop Science*. **4(6)**: 384-389.

Teshome, B., Tana, T., Dechassa, N. and Singh, T.N. (2017). Application of compost, lime and Pfertilizer on selected soil properties and P use efficiency of maize in acidic soil of Assosa, Western Ethiopia. *Journal of Experimental Agriculture International*. **18(6)**: 1-14.

Togun, A.O., Akanbi, W.B. and Dris, R. (2003). Influence of compost and nitrogen fertilizer on growth, nutrient uptake and fruit yield of tomato (*Lycopersiocon esculentum*). *Field Crops Research.* **26(1)**: 98-105.

Tripathi, K.M., Dhakal, D.D., Sab, S.C., Baral, D.R. and Sharma, M.D. (2015). Evaluation of vermicompost and chemical fertilizers on performance of Pak choi (*Brassic rapa C.v. Hong Tae*) and soil biological process. *Journal of the Institute of Agriculture and Animal Science*.**33(34)**: 243 -250.

Tweib, S.A., Rahman, R.A and Kalil, M.S. (2011). A Literature Review on the Composting. 2011. *International Conference on Environment and Industrial Innovation*.**12**: 26- 32.

Valarini, P.J., Curaqueo, G., Seguel, A., Manzano, K., Rubio, R., Cornejo, P. and Borie, F. (2009). Effect of compost application on some properties of volcanic soil from central south Chile. *Chilean Journal of Agricultural Research*. **69(3**):416-425.

Van Averbeke, W. and Netshithuthuni, C. (2010). Effect of irrigation scheduling on leaf yield of non-heading Chinese cabbage (*Brassica rapa L. subsp.chinensis*). South African Journal of Plant and Soil. **27(4)**: 322-327.

Van Averbeke, W., Tshikalange, T.E. and Juma, K.A. (2007). The commodity systems of *Brassica rapa L.* subsp. chinensis and *Solanum retroflexum* Dun. in Vhembe, Limpopo province, South Africa. Water SA. **33**: 349–353.

Van Rensburg, W.S.J., Van Averbeke, W., Slabbert, R., Faber, M., Van Jaarsveld, P., Van Heerden, I., Wenhold, F. and Oelofse, A. (2007). African leafy vegetables in South Africa. *Water South Africa*.**33**: 317-326.

Vengadaramana, A. and Jashothan, P.T.J. (2012). Effect of organic ferilizers on the water holding capacity of soil in different terrains of Jaffna peninsula in Sri Lanka. *Journal of Natural Product and Plant Resources*. **2(4):** 500-503.

Viera, J.L.V., Nardi, K.T., Silva, G.R.A., Moreira, L.A., Zavaschi, E., Moura, T.A. and Otto, R. (2017). Nutrient uptake by high-yielding cotton crop in Brazil. *Soil Fertility and Plant Nutrition.* https://doi.org/10.1590/18069657rbcs2017003. Accessed 13 December 2019.

Walker, D.J. and Bernal, M.P. (2008). The effects of olive mill waste compost and poultry manure on the availability and plant uptake of nutrients in highly saline soil. *Bioresource Technology*. **99(2)**: 396-403.

Wetterstedt, J.A.M., Persson, T. and Agren, G.I. (2009). Temperature sensitivity and substrate quality in soil organic matter decomposition – results of an incubation study with three substrates. Global Change. In: Reeves, D.W. (1997). The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil Tillage Research*. **43**: 131-167.

Woodruff, C.M. (1948). Testing soils for lime requirements by means of buffered solution and the glass electrode. *Soil Science*. **66**: 53-64.

Yuksek, T., Gol, C., Yuksek, F. and Yuksek, F.F. (2009). Effects of land-use changes on soil properties: The conversion of alder coppice to tea plantation in the Humid Northern Blacksea Region. *African Journal of Agricultural Research*. **4**: 655-674.

Zai, A.K.E., Horiuchi, T. and Matsui, T. (2008). Effects of compost and green manure of pea and their combinations with chicken manure and rapeseed oil residue on soil fertility and nutrient uptake in wheat-rice cropping system. *African Journal of Agricultural Research*. **3(9)**: 633-639.

Zemanek, P. (2011). Evaluation of compost influence on soil water retention. *Acta Universitastis Agricultura*. **3**: 227-232.

APPENDICES

Appendix 1. Correlation coefficients between soil physicochemical properties

Variables	pH	EC	OM	SOC	BD	WHC	N	P	K	Ca	Mg	Na	Al	Zn	Mn
pH	1														
EC	0.58*	1													
OM	0.50*	0.09ns	1												
SOC	0.50*	0.09ns	0.99***	1											
BD	0.58**	-0.17ns	-0.89***	-0.47*	1										
WHC	0.03ns	-0.23*	0.97***	0.56*	-0.35*	1									
N	0.60**	0.89***	0.58**	-0.16ns	-0.52*	-0.03ns	1								
P	0.60**	0.00ns	0.65**	-0.34*	-0.10ns	0.15ns	0.16ns	1							
K	0.44*	-0.12ns	0.74**	0.58**	-0.84*	0.42*	0.24ns	0.68*	1						
Ca	0.49*	0.04ns	0.76**	0.14ns	-0.72**	-0.15ns	0.24ns	-0.50*	0.47*	1					
Mg	0.71**	0.25*	0.89***	-0.18ns	-0.81***	-0.13ns	0.51*	-0.30*	0.09ns	0.92**	1				
Na	0.36*	0.23ns	0.80***	-0.06ns	-0.77**	-0.15ns	0.51*	-0.73**	0.98***	0.34*	-0.05ns	1			
Al	-0.37*	0.51*	0.30*	-0.73**	-0.12ns	-0.48*	0.53*	-0.94**	0.75**	0.76**	0.52*	0.73***	1		
Zn	0.24ns	0.54*	0.45*	-0.29*	-0.34*	0.05ns	0.74**	-0.59**	-0.96***	0.66**	0.32*	0.89***	0.75**	1	
Mn	0.73**	0.12ns	0.48*	0.40	-0.76**	0.35*	0.36*	0.36*	0.14ns	0.93***	0.99***	0.01ns	0.60**	0.35*	1
C:N ratio	0.54*	-0.48	-0.13ns	0.95***	-0.10ns	0.46*	-0.41*	-0.42*	0.48*	0.12ns	-0.27*	-0.16ns	-0.80***	-0.45	0.22*

*= P<0.05, **=P<0.01, ***P<0.001 ns= Not significant

Appendix 2. correlation coefficients between root biomass, root length and soil physicochemical properties

Variables	pH	EC	OM	SOC	BD	WHC	N	P	K	Ca	Mg	Na	Al	Zn	Mn
Fresh root biomass	0.36*	-0.50*	0.47*	0.47*	-0.51*	0.40*	0.35*	-0.15ns	0.74***	0.61**	0.35*	0.62*	0.40*	0.87**	0.34*
Dry root biomass	-0.03ns	-0.62	0.68**	0.68**	-0.66**	0.18ns	0.39*	0.14ns	0.26*	0.74***	0.70**	0.09ns	0.20*	0.52*	0.66**
Root length	0.44*	-0.46	0.69**	0.69**	-0.46*	0.29*	0.46*	-0.37*	0.88***	0.55*	0.29*	0.80**	0.59*	0.95**	0.23ns

*= P<0.05, **=P<0.01, ***= P<0.001, ns= Not significant

Appendix 3 Correlation coefficients between root biomass, root length and yield components

Variables	Number of leaves	Fresh leaf biomass	Dry leaf biomass	Leaf area
Fresh root biomass	0.62**	0.84***	0.61**	0.61**
Dry root biomass	0.59*	0.61*	0.50*	0.60**
Root length	0.61**	0.49*	0.65**	0.61**

*= P<0.05, **=P<0.01, ***= P<0.001, ns= Not significant

Appendix 4 Correlation coefficients between yield components and soil physicochemical properties

Variables	pH	EC	OM	SOC	BD	WHC	N	P	K	Ca	Mg	Na	Al	Zn	Mn
Number of leaves	0.61**	0.06ns	0.24ns	0.24ns	0.18ns	0.52**	0.95***	0.58**	0.43*	0.79***	0.62**	0.46*	0.46*	0.80**	0.60**
Fresh leaf biomass	0.63**	-0.04ns	0.14ns	0.14ns	-0.08ns	0.61**	0.89***	0.42**	0.33*	0.81***	0.73**	0.26ns	0.51*	0.65**	0.83***
Dry leaf biomass	0.66**	0.13ms	0.07ns	0.07ns	0.09ns	0.54**	0.67**	0.58**	0.42**	0.97***	0.85***	0.26ns	0.34*	0.64**	0.70**
Leaf area	0.16ns	-0.43**	-0.34*	-0.34*	-0.55**	0.34*	0.93**	0.34*	0.40*	0.92***	0.86***	0.27ns	0.50**	0.84**	0.84***

Appendix 5 Correlation coefficient between yield components

Variables	Number of leaves	Fresh leaf biomass	Dry leaf biomass	Leaf area
Number of leaves	1	0.88***	0.82***	0.86***
Fresh leaf biomass	0.88**	1	0.96***	0.90***
Dry leaf biomass	0.83**	0.95***	1	0.86***
Leaf area	0.85**	0.90**	0.86***	1

*= P<0.05, **=P<0.01, ***= P<0.001, ns= Not significant