GREENHOUSE EVALUATION OF MAIZE PERFORMANCE AND CHANGES IN CHEMICAL PROPERTIES OF SOIL FOLLOWING APPLICATION OF WINERY SOLID WASTE COMPOSTS

by

MANARE MAXSON MASOWA

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SUPERVISOR: DR. FMG VANASSCHE

CO-SUPERVISORS: PROF. FR KUTU

Ms. LP SHANGE (ARC)

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DEDICATION

This mini-dissertation is dedicated to my parents and siblings, who supported and encouraged me to continue with my studies.

DECLARATION

I declare that the mini-dissertation hereby submitted to the University of Limpopo, for the degree of Master of Science in Agriculture (Soil Science) has not previously been submitted by me for a degree at this or any other university; that it is my work in design and in execution, and that all material contained herein has been duly acknowledged.

Masowa MM (Mr) **31 March 2015**

Surname, Initials (title) **Date**

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ABSTRACT

Winery solid waste materials namely, wine filter materials (FM), grape marc (berry stalks, skins and seeds) and chopped grapevine pruning canes were composted in heaps through a thermophilic process. The filter materials were mixed with the grape marc and grapevine prunings at five rates (10%, 25%, 50%, 75% and 100%) to produce five composts herein designated as C10FM, C25FM, C50FM, C75FM and C100FM, respectively. A laboratory incubation study was thereafter carried out to determine the nutrient release potential of the composts using two soil types with varying textural characteristics. Each compost was mixed with soil at a rate equivalent to 200 kg N ha^{-1} and the mineral N, available P and exchangeable K content determined over 42 days incubation period. Results revealed that the composts possess high C content and low C:N ratios; and released significantly higher NH_4-N and K concentration relative to un-amended control. The differences in the amount of P mineralised among the five compost treatments were not significant while significantly higher amount of K was mineralised at higher FM mix rates.

The composts were applied to maize cv. SNK2147 on sandy soil in a greenhouse pot study at five rates (5, 10, 20, 40 and 80 t ha^{-1}) to determine their effects on crop growth and yield as well as on selected soil chemical properties. An un-fertilised control and NPK fertiliser treatments were included for comparison. The pots were arranged in a completely randomized design, with each treatment replicated four times. The C50FM, C75FM and C100FM treatments applied at 80 t ha^{-1} gave significantly higher maize dry matter yield than the NPK fertiliser treatment. Quantitative estimates of the optimum compost rate for dry matter production ranged from 450 to 1842 g pot^{-1}. Application of these composts significantly increased dry matter yield, plant height, stem diameter and the number of functional leaves per plant compared to the un-fertilised control. The K content of shoot from composts treatments exceeded the critical nutritional level of 3.3%. Plant tissue Zn content from C10FM, C25FM and C50FM treatments exceeded the critical nutritional level of 15 mg kg^{-1} while the residual soil K, Na and Zn contents after crop harvest were significantly increased following compost application. Similarly, the residual P was significantly increased in C25FM, C75FM and C100FM treatments after harvest. In conclusion, application of these composts exerted beneficial effects on maize performance and soil. Field studies under variable conditions are recommended to validate these findings.

Keywords: wine, compost, nutrient release potential, maize, soil chemical properties

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CHAPTER 1
INTRODUCTION

1.1 Background

Winery solid waste includes grape marc (skins, seeds, pulp and stems) and filter cakes consisting of filter aids (Theron, 2009; Seenappa, 2012). The disposal of winery solid waste without proper treatment may lead to soil, air and water pollution (Van Schoor, 2001a). Therefore, there is a need for an effective winery solid waste management approach. Composting of waste may be used as an alternative waste disposal technique to landfill and incineration (Akhile Consortium, 2010). When the economic returns from agriculture are low, farmers tend to use high inputs such as chemical fertilisers and pesticides in order to improve crop production and thus neglecting soil quality (Hossain, 1988). Therefore, more attention has to be given to possible ways that will improve soil fertility and health without causing detrimental effects on soil and water. Composts from wastes such as sewage sludge and agricultural waste have been reported to improve soil fertility and soil physical conditions (Aslantas *et al.,* 2010; Basri *et al.,* 2013). However, most composts contain harmful contaminants such as heavy metals (Shata *et al.,* 1990) that may potentially raise environmental and human health concerns. Hence, environmental legislation have been put in place to limit their application on soils.

1.2 Problem statement

The process of wine making results in massive generation of solid waste such as grape skins, seeds, and filter cakes. Filter cakes consist of filter aids such as diatomaceous earth (DE) and perlite. The disposal of DE and perlite wastes is a problem for the wine industry world-wide (Casani and Bagger-Jørgensen, 2000; Fillaudeau *et al.,* 2006). In the past, wine producers in South Africa usually dumped winery solid waste in landfills (Dillon, 2011). However, this method now has serious legislative restrictions; hence such waste disposal is now quite expensive due to scarcity of land. Worse still, dumping of DE and perlite without proper treatment may result in soil and water pollution, thus affecting the performance of natural vegetation and human health (Van Schoor, 2001a). Small wineries have attempted to dispose their wastes through waste processing companies but the costs are very high because most waste processing companies are not willing to collect small amounts of waste (Walsdorff *et al.,* 2004). Some wineries use winery solid waste for composting purposes but without the knowledge of its potential impact on soil and the environment.

Furthermore, the introduction of the National Environmental Waste Management Act 59 (2008) compelled industries to manage wastes in a manner that does not endanger health or the environment. The act clearly states that in case where generation of waste cannot be avoided, the holder of waste must reduce, re-use, recycle and recover the wastes. Though the Integrated Production of Wine (IPW) guidelines on management of solid and liquid wastes produced by wine industries in South Africa have been documented (IPW Guidelines, 2012), there is still dearth of information on efficient and cost saving winery solid waste disposal strategies that could be beneficial to the general winery. Currently, the production of winery solid waste compost in the wine industry is driven by the pressing need of waste disposal techniques as the costs of using other options are high.

1.3 Motivation

South Africa ranks as the seventh largest producer of wine in the world (Siphugu and Terry, 2011). Increased wine production in South Africa has led to significant increases in the pressure on natural resources such as soil (Van Schoor, 2005). Composting solid wastes produced at wine cellars may eliminate indiscriminate dumping of wastes that result in negative impacts on the environment (South Australian Wine Industry Association Environment Committee, 2004). Van Schoor (2000) reported that winery solid waste causes bad odors and may contaminate soil and water resources, and consequently affecting the performance of vegetation. Van Schoor (2001b) reported that the national and foreign markets stipulate that all factors that have environmental impacts, such as solid and liquid waste disposal from cellars must be managed by means of an effective Environmental Management System (EMS), such as ISO 14001. This management system encourages industries to eliminate waste through resource recovery practices, such as recycling (BIS, 2012). Therefore, a proper winery solid waste management strategy such as the production of winery solid waste composts is not only to ensure national winery industry legislative compliance but also help the wine industries to maintain ISO 14001 accreditation. Furthermore, composting winery solid waste will among others help address the disposal problems and also benefit resource-poor farmers who cannot afford chemical fertilisers.

1.4 PURPOSE OF THE STUDY

1.4.1 Aim

The aim of the study is to assess the potential suitability of winery solid waste composts for crop production as a management strategy for dealing with the massive solid waste generated during wine production in the wine industry.

1.4.2 Objectives

The objectives of the study are to:

i. study the nutrient release patterns of the different winery solid waste composts produced.

ii. compare the effects of variable application rates of the various winery solid waste composts produced on maize growth and yield with those of inorganic NPK fertiliser.

iii. determine the optimum application rate for the different winery solid waste composts produced.

iv. evaluate the changes in the chemical characteristics of a sandy soil after winery solid waste composts application.

1.5 HYPOTHESES

i. The nutrient release characteristics of the various winery solid waste composts do not differ markedly.

ii. The effects of variable application rates of various winery solid waste composts on maize growth and yield are not comparable to those of inorganic NPK fertiliser application.

iii. Application of variable rates of the winery solid waste composts exerts no significant difference on maize growth and yield parameters.

iv. Application of winery solid waste composts will have no effect on the chemical characteristics of a sandy soil.

CHAPTER 2
LITERATURE REVIEW

2.1 Wine production in South Africa

In South Africa, there are about 3667 grape farmers, 604 wine cellars and 102 bulk wine buyers (SAWIS, 2009). The South African wine industry contributes about R26.2 billion towards the GDP, with about R14.2 billion remaining in the Western Cape to benefit its residents (SAWIS, 2009). The South African wine industry creates about 275000 jobs consisting of 58% unskilled, 29% semi-skilled, and 13% being skilled (SAWIS, 2009; Marco-Thyse, 2012). Wine grapes are produced mainly in the Western Cape districts specifically around Worcester, Paarl, Stellenbosch, Malmesbury, and Robertson; along the Olifants River, the Klein Karoo as well as the Orange River region of Northern Cape (Siphugu and Terry, 2011). White wine grapes are predominately produced in the regions along the Orange and Olifants rivers that are characterized by a hot, dry climate and soils formed from limestone. The Western Cape regions of Stellenbosch, Paarl and Malmesbury are the leading red wine grape production zones on acidic and alluvial soils formed from granite from the mountain slope (Siphugu and Terry, 2011).

2.2 Wine making processes

The wine making process is illustrated in Figure 1. Grape harvesting is the most critical stage of the wine making process. The grapes must be harvested when the sugar, acid, phenol and aroma compounds are optimal for the kind of wine desired. The harvesting of the grapes can either be done manually or mechanically, although majority of the wineries harvest grapes manually (Janick and Paull, 2008). The grapes are removed from the stems and gently crushed to break the skins. Sulfur dioxide is added to control oxidation, wild yeasts, and spoilage bacteria (Safriet, 1995) while enzymes are added to break down the cell walls of grape pulps and skins, and thus promoting the release of juice (Sparrow *et al.,* 2006). The juice extraction process depends on the type of wine to be produced but always involves squeezing berries by pressing. The juice is inoculated with live yeast, which then carries out the fermentation reaction (Safriet, 1995). According to Shijina (2009), fermentation takes almost 10 to 30 days but this depends on the quality of the grapes and the climate.

Wine clarification involves filtering and fining of the lees. It is the process by which insoluble matter suspended in the wine is removed before bottling; and it begins once fermentation is completed. Diatomaceous earth (DE) rotary vacuum filters and plate-and-frame filters using 1-1.5 kg of perlite/hl of lees filtered, are the two kinds of filters used for wine lees filtration. After filtration, the waste perlite and DE are obtained. The disposal of waste perlite and DE is problematic (Walsdorff *et al.,* 2004). Sterile filter pads catch large and small solids. Alternatively, wine cellars clarify wine by adding fining agents such as clay and egg whites that create an enzymatic or ionic bond with the suspended particles, thereby producing larger molecules and particles which precipitate out of the wine more readily and rapidly (Ribéreau-Gayon *et al.,* 2000). The clarified wine is then racked into another vessel, where it is ready for bottling or further aging.

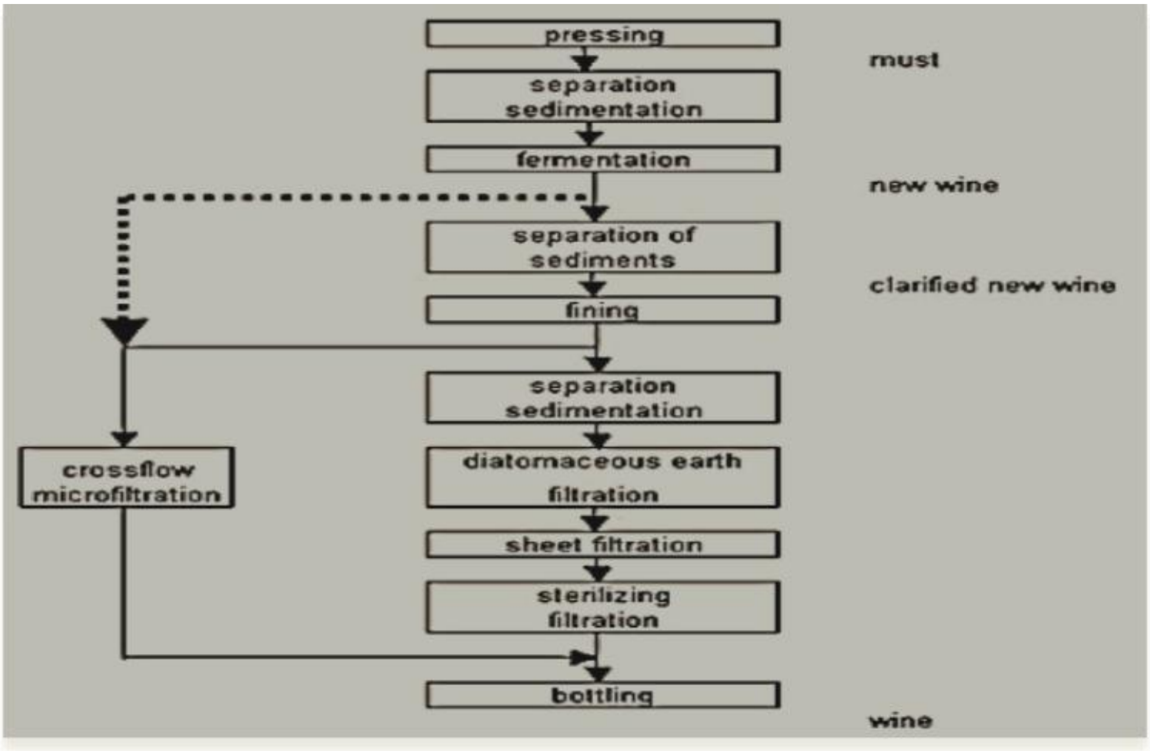

Figure 1. An overview of the wine making process.

Source: http://www.membranafiltration.com/filtrationmodules/beverage-clarification.cfm

2.3 Filter aids used in the wine clarification process

In the wine industry, filter pads are manufactured from cellulose fibers, diatomaceous earth (DE) or perlite in various densities for different degrees of clarification. Diatomaceous earth is often used in depth filtration. It is an amorphous silica mineral of organic origin which is considered to be a variety of opal (Antonides, 1997). After quarrying, drying, and pulverizing, DE is used in filters of drinking water, beverages, wine and beer (Vigliani and Mottura, 1948). It is used in wine filter materials because its commercial products provide fine, irregular-shaped, and porous particles that have large surface area and high liquid absorptivity, and these properties promote filtration (Antonides, 1997). Usually, the chemical composition of oven-dried DE is 80 to 90% silica, 2 to 4% alumina and 0.5 to 2% iron oxide (Antonides, 1997).

Perlite is used as an alternative filter aid for DE in the wine industry (Franson, 2012). It is very light and white, and it is a naturally occurring siliceous rock (Cheremisinoff, 2002). Apart from clarifying wine or beer, it is used as a soil amendment, allowing aeration and moisture retention and also used as a carrier for fertiliser, herbicides and pesticides (Bamforth, 2006). A study by Simal-Gándara *et al.* (2008) revealed that the application of perlite from winery solid waste to *Lolium multiflorum* improved growth, and this improvement was related to the increase in soil fertility following addition of N, P and K from the perlite waste.

2.4 Benefits of using compost on crop land

Soil amendment with compost has been reported to produce a suppressive effect on crop diseases caused by soil-borne plant pathogens (Noble, 2011). Scheuerell *et al*. (2005) related the suppression of diseases to the volatiles released from compost such as ammonia, sulphur containing compounds and organic acid following mineralisation (Scott and Gilead 1995) induced by high temperature. Compost provides beneficial micro-organisms that kill or compete with pathogens in the soil, as a result suppressing diseases such as root rot caused by *Pythium* and *Phytophthora* (Sullivan, 2004). This 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.

Compost applied to sorghum have been reported to improve the dry matter production and grain yield in comparison with no compost application treatment (Abdel-Rahman, 2009). Abdelaziz *et al.* (2007) reported that *Rosmarinus officinalis* treated with a mixture of compost and micro-organisms showed a significant increase in vegetative growth, total N, P and carbohydrate content and essential oil production as compared to chemical NPK fertiliser treatment. Compost contains organic molecules (chelators) that bind metal cations such as Fe, Cu, Zn and Mn, and maintaining them in a soluble state (Van Schoor, 2009). Chelate formation is important in the soil because it reduces the toxicity of plant nutrients and also minimizes unnecessary losses of nutrients through leaching, thereby making them available exactly when needed. Furthermore, it is also an environmentally friendly and cost-effective approach that is important in the reduction of metal contaminants such as lead and chromium; and hence, reduces both their leaching and accumulation by plants (Van Herwijnen *et al.,* 2007).

Amending soil with compost improves soil structure by binding soil particles together forming aggregates (Ethne, 2011). In heavy soils, the formation of aggregates helps to create larger pores, thereby promoting air and water movement. Therefore, amending soil with compost may provide more efficient water utilization and thus reduce the need for frequent irrigation thereby saving on the cost of crop production (US Composting Council, 2001).

2.5 Nutrient release characteristics of composts

The use of incubation and laboratory analyses to elucidate nutrient release patterns of compost has been reported to help in indicating the potential of the compost to supply nutrients to crops (Adediran *et al.,* 2003). Furthermore, the study of nutrient release characteristics of compost is important to estimate the potential leaching of nutrients and to determine the optimum application rates, timing and placement of compost (Adediran *et al.,* 2003). In an earlier study, He *et al.* (2000) revealed that application rates, timing and placements of compost containing a high N concentration should be adjusted for high N release to minimize NO_3-N leaching into groundwater.

2.6 Maize production in South Africa and its growth requirements

Maize (*Zea mays* L.) is a valuable source of carbohydrates and it is the most important grain crop in South Africa for animal and human consumption. White maize is used for human consumption while yellow maize is mostly used as animal feed (Europa Publications, 2003). The maize production sector ensures food security in South Africa and in the Southern African Development Community (DAFF, 2011). Maize is a warm weather crop that is often not grown in areas where the mean daily temperature is less than 19°C or where the mean daily temperature in summer is less than 23°C (Du Plessis *et al.,* 2003). Flowering in maize occurs best at temperatures ranging from 19-25°C (DAFF, 2008). In Africa, temperatures above 30°C are critical for maize and may affect yield (Lobell *et al.,* 2011). Maize requires soils with a good effective depth, an optimal moisture regime and balanced quantities of plant nutrients (Du Plessis *et al.,* 2003). Current maize cultivars require 600-700 mm of water for optimum growth and yield (Hammad *et al.,* 2011).

Assimilation of N, P and K reaches peak during flowering while the total N, P and K uptake of a single maize plant at maturity could be 8.7 g, 5.1 g and 4.0 g, respectively (Du Plessis *et al.,* 2003). Maize requires relatively high amounts of Zn and consequently, Zn is likely to be deficient (Bundy, 1998) particularly in sandy soils, which inherently have low total Zn levels (Schulte, 2004). Sandy to sandy loam soils are more likely to be Zn deficient than either silty or clay soils (Schulte, 2004). Zinc deficiency is mostly induced by high levels of P which precipitates Zn in the soil (Sadeghzadeh, 2013). This is not likely to occur when high soil P is a result of heavy manure application because the manure will also add Zn to the soil (Schulte, 2004). Mousavi (2011) reported that Zn uptake by maize increases with an increase in organic matter level in the soil.

2.7 Impact of compost application on maize productivity

The intergrated use of compost and inorganic fertiliser has been reported to increase maize productivity and production (Friesen and Palmer, 2002; Laekemariam and Gidago, 2012). Lima *et al.* (2004) observed composts made from organic waste significantly increasing maize plant height, stem diameter, biomass root and biomass aerial part compared with the control. The N uptake by maize increased following compost application (Lehrsch and Kincaid, 2007). Compost application increased ear length and marketable yield in comparison with no compost treatment (Jackson *et al.,* 2013). The improvement in maize growth and yield has been attributed to the beneficial effects of composts to improve soil physical properties and fertility (Singh and Agrawal, 2008; Farhad *et al.,* 2011).

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Description of the study sites

The study consisted of three different phases namely: (i) winery solid waste compost production, (ii) laboratory incubation study for nutrient release characterization of the composts, and (iii) a greenhouse pot study for agronomic evaluation of the produced composts. The winery solid waste composts were produced in heaps through thermophilic process at the ARC-Infruitec/Nietvoorbij farm, Stellenbosch, Western Cape. The laboratory incubation and greenhouse studies were conducted in the Soil Science Laboratory and at the Plant Protection Skills Centre, respectively at the University of Limpopo.

3.2 Production of winery solid waste composts

The materials used for the production of winery solid waste composts consisted of a mixture of waste perlite and DE collectively described as wine filter materials (FM), and grape marc that comprised of berry stalks, skins and seeds, and chopped grapevine prunings. The spent wine FM were mixed with grape marc and chopped grapevine prunings at five rates of 10%, 25%, 50%, 75% and 100% per compost heap to produce five composts herein designated as C10FM, C25FM, C50FM, C75FM and C100FM, respectively. In order to comply with the environmental safety regulations, each compost heap was produced on a hardened soil surface, with each heap measuring 2 m x 1.5 m x 1 m. The compost heaps were turned once weekly with moderate amounts of water added to allow for optimal microbial activities. The thermophilic composting process was continued for a period of 13 weeks for the composts to be properly cured.

Samples of the waste materials and of the resulting composts were air-dried, milled and passed through a 2 mm sieve and thereafter, subjected to a detailed chemical analysis following standard procedures. Total carbon content was determined by a dry-combustion method (Nelson and Sommers, 1982). The pH and electrical conductivity (EC) were measured in a 1:5 sample/1 M KCl and a 1:5 compost/water suspension, respectively and read on a Crison GLP-21 pH meter and a conductivity meter, respectively. The pH was measured in 1 M KCl solution in order to eliminate the interference from suspension effects and from variable salts contents (Morocomp, 2008). The determination of total N, P, K, Na, Ca, Mg, Fe, Cu, Zn, Mn and B contents in ashed compost samples was as described by Okalebo *et al.* (2002). Total N in the ashed compost solution was determined by micro-Kjeldahl distillation method. Phosphorus was measured colorimetrically following the Bray-2 method (Bray and Kurtz, 1945) while total K, Na, Ca, Mg, Fe, Cu, Zn and Mn contents in the ash solution were determined using an atomic absorption spectrophotometer. Boron was determined colorimetrically by spectrophotometry.

3.3 Laboratory incubation and greenhouse studies of winery solid waste composts

A 42-day laboratory incubation study was carried out to assess the nutrient release characteristics of the different composts using two soil types with variable textural characteristics. Both soils were collected from 0 to 15 cm depth, air-dried and sieved (2 mm) in order to remove stones and plant debris. Physical and chemical properties of these soils were determined (Table 1). Each compost was weighed and thoroughly mixed with 1.2 kg of soil at a calculated rate of 200 kg N ha^{-1}; and transferred into 15 cm diameter plastic pots for incubation. An un-amended control of each soil type was also included for the purpose of comparison. The holes at the bottom of each pot were blocked with a cotton wool in order to prevent soil losses. About 150 ml of deionised water was added to the soil to maintain a moist state for microbial activity before placing the pots into an Electro Thermal Incubator (ETI-9082) at a controlled temperature of 25°C. The moist soil condition was checked and maintained at weekly interval. Approximately 100 g of soil was scooped from each pot at 7, 14, 21, 28, 35 and 42 days after incubation for the determination of mineral N (NH_4-N and NO_3-N), available P and exchangeable K content. Nitrate and NH_4-N were extracted with 0.5 M K_2SO_4 solution and their concentrations determined colorimetrically as described by Okalebo *et al.* (2002). Phosphorus was determined colorimetrically following the Bray-1 extraction method described by Bray and Kurtz (1945). Potassium was extracted using a 1 M ammonium acetate solution and the concentration determined by an atomic absorption spectrophotometer.

Table 1. Physical and chemical properties of soils used in the compost incubation study

Soil characteristics	Sandy soil	Sandy loam soil
Clay (%)	2	10
Silt (%)	4	20
Sand (%)	94	70
Textural class	Sandy	Sandy loam
pH (H_2O)	7.18	7.62
pH (KCl)	5.36	5.72
OC (%)	0.46	0.72
NH_4-N (mg kg^{-1})	11.23	15.88
NO_3-N (mg kg^{-1})	28.64	20.07
Bray-1 P (mg kg^{-1})	4.56	3.30
K (mg kg^{-1})	546	1088

A greenhouse study using the winery solid waste composts produced was conducted to assess their effects on maize performance and on soil chemical characteristics. The treatments consisted of five winery solid waste composts, each applied at five rates (5, 10, 20, 40 and 80 t ha^{-1}). Un-fertilised control and a compounded NPK fertiliser treatments were included as negative and positive controls, respectively. The inorganic NPK fertiliser treatment consisted of a mixture of 100 kg N ha^{-1}, 60 kg P ha^{-1} and 40 kg K ha^{-1} obtained from limestone ammonium nitrate (LAN), single super phosphate (SSP) and muriate of potash (MOP), respectively. Each treatment was replicated four times and the trial laid out in a completely randomized design (CRD). A well characterized surface (0-20 cm) soil obtained from a field in Ga-Matsea village was used for this study (Table 2). The soil was sieved (6 mm) in order to remove stones and plant roots, and then filled in a 30 cm diameter plastic pot. Each pot was filled with 12 kg of soil. The holes at the bottom of each pot were blocked with a cotton wool in order to prevent soil losses. Prior to planting, the composts and inorganic NPK fertiliser treatment were thoroughly mixed with the soil and transferred into clearly labelled pot based on the specified treatment. The pots were watered (750 ml of tap water) and allowed to equilibrate for 5 hours, after which four seeds of maize (*Zea mays* L.) cv. SNK2147 were sown in each pot. Thinning was done at one week after seedling emergence; with two healthy seedlings per pot maintained. Irrigation was kept uniform for all treatments throughout the period of plant growth. The study was terminated 63 days after planting with the harvesting of maize shoots from the soil surface.

Table 2. Physical and chemical properties of the soil used in the greenhouse study

Soil properties	
Clay	1.5%
Silt	3.3%
Sand	95.2%
Textural class	Sandy
pH (H_2O)	8.7
EC	198 µS/cm
Organic C	0.25%
Total N	27 mg kg^{-1}
Bray-1 P	6.42 mg kg^{-1}
Zn	0.48 mg kg^{-1}
Ca	0.79 mg kg^{-1}
Mg	43 mg kg^{-1}
Na	82 mg kg^{-1}
K	192 mg kg^{-1}

3.4 Agronomic data collection and post-harvest soil analysis

Prior to maize shoots harvesting and trial termination, the number of functional leaves per plant was recorded. Plant height and stem diameter were also measured using a measuring tape and vernier calliper, respectively. The maize shoots were harvested from the surface using a sharp knife, put into brown paper bags, dried in an oven at 65°C to constant weight, and the dry weight recorded for the determination of dry matter yield (g pot^{-1}). The dried milled maize shoots from each pot were ashed at 500°C for 2 hours in a furnace and the total contents of P, K, Na, Fe, Cu, Zn, Mn and B were determined according to procedures described by Okalebo *et al.* (2002). One gram of milled maize shoots was digested on a heating block using a mixture of H_2O_2, H_2SO_4, salicylic acid and selenium for N determination. Nitrogen was subsequently determined titrimetrically following a micro-Kjeldahl digestion procedure (Bremmer and Mulvaney, 1982). Phosphorus and B were measured colorimetrically by spectrophotometry. Potassium, Na, Fe, Cu, Zn and Mn in the ash solution were measured using an atomic absorption spectrophotometer. The nutrient uptake was estimated using the equation shown below.

$$\text{Nutrient uptake} = \%\ \text{Nutrient content x dry matter yield (g pot}^{-1}\text{)}$$

Approximately 300 g of soil from each pot was scooped, air-dried, sieved and analysed for pH, EC, organic C and the contents of NH_4-N, NO_3-N, P, K, Na, Fe, Cu, Zn and Mn. Soil pH was measured in a soil-water suspension (1:2.5) using a pH meter (McLean, 1982). Nitrate and NH_4-N were determined colorimetrically following extraction with 0.1 N K_2SO_4 solution (Okalebo *et al.,* 2002). Soil extractable P was determined colorimetrically as described by Bray and Kurtz (1945). Organic C was determined by dichromate oxidation and titration with ammonium ferrous sulphate (Walkley-Black, 1934). Iron, Cu, Zn and Mn were extracted with 0.1 M HCl and their concentrations were quantified by atomic absorption spectrophotometry. Extractable Na and K were extracted using 1 M ammonium acetate and their concentrations were quantified by atomic absorption spectrophotometry.

3.5 Data analysis

Soil data generated from the compost incubation study were subjected to analysis of variance (ANOVA) using Statistix 8.1 package and the treatment means were separated by the Tukey test at alpha level of 0.05. Plant growth and tissue analysis as well as soil data from the greenhouse pot experiment were subjected to analysis of variance using statistical analysis system (SAS) computer program. The significant differences among treatment means were tested using Duncan's Multiple Range Test (DMRT) at an alpha level of 0.05 (Duncan, 1955). The separation of main treatment means (compost types, NPK fertiliser and control) for nutrient uptake data with the DMRT was not sufficiently clear, consequently, the Tukey test at alpha level of 0.05 was applied using Statistix 8.1 package. Regression analysis based on the quadratic polynomial model $Y = a + b_1X +$

b_2X^2 was used to determine the optimum application rate and dry matter yield (Mahdy, 2011).

CHAPTER 4
RESULTS

4.1 Characterization of winery solid waste materials and composts

The chemical characteristics of the winery solid waste materials and the resulting composts produced are shown in Tables 3 and 4, respectively. The pH (KCl) values of all waste materials revealed that they are alkaline in nature except the grapevine prunings, which is slightly acidic. These waste materials constituted good sources of C, P, K, Ca, Mg and micronutrients for possible recycling except the waste DE which has low concentration of P, Ca and Mg. The pH values of the resulting composts ranged from 7.10 in C25FM to 9.0 in C100FM, while the electrical conductivity (EC) varied between 10.8 (C10FM) and 26.9 dS/m (C100FM). The total Na content ranged from 0.11% in C10FM to 0.22% in C100FM. The EC and total Na content of composts tend to increase with increasing percent content of FM in the composts. The total organic C content ranged between 11.1% in C50FM and 22.6% in C10FM while the total N content varied from 1.71% in C75FM to 1.80% in C10FM. The C:N ratios of the composts were generally below 20 and it ranged between 6.5 (C50FM) and 13.8 (C25FM). The total P content of composts varied between 0.13% (C10FM) and 0.21% (C75FM).

The K content of the composts was relatively high; and it varied from 1.11% (C10FM) to 1.71% (C50FM). The Ca content of the composts ranged between 0.66% (C75FM) and 1.16% (C100FM). The Mg content decreased with increasing percent composition of FM in composts and it ranged from 0.05% (C100FM) to 0.20% (C10FM). The Ca:Mg ratios of the composts varied from 4.2 (C10%FM) to 23.2 (C100%FM). The levels of micronutrients in composts varied from 1646 to 2130 mg kg^{-1} for Fe, 16 to 25 mg kg^{-1} for Cu, 24 to 47 mg kg^{-1} for Zn, 31 to 53 mg kg^{-1} for Mn and 28 to 35 mg kg^{-1} for B. The Mn content seemed to decrease with an increasing percent content of FM in composts.

Table 3. Chemical characteristics of winery solid waste materials used in compost production

Waste Material	pH (KCl)	Total elemental composition										
		C	P	K	Na	Ca	Mg	Fe	Cu	Zn	Mn	B
		← (%) →						← (mg kg^{-1}) →				
Waste perlite	9.9	11.3	0.14	6.44	0.02	0.32	0.03	228	15.6	13	17	16
Waste DE*	10	2.86	0.01	1.52	0.02	0.05	0.02	280	4.28	6	6	6
Grape stalks	7.1	31.5	0.09	0.52	0.07	0.52	0.19	80	7.62	32	46	10
Grape skins and seeds	8.2	9.17	0.07	2.46	0.01	0.34	0.10	384	8.54	18	18	17
Grapevine prunings	6.5	14	0.05	0.55	0.03	0.44	0.17	131	4.75	40	45	5

**Diatomaceous earth*

Table 4. Chemical characteristics of winery solid waste composts

Compost Types	pH (KCl)	EC	Total nutrients contents												C:N ratio	Ca:Mg ratio
			C	N	P	K	Na	Ca	Mg	Fe	Cu	Zn	Mn	B		
		(dS/m)	(%)							(mg kg^{-1})						
C10FM	7.20	10.8	22.6	1.80	0.13	1.11	0.11	0.84	0.20	2130	16	47	53	32	12.5	4.2
C25FM	7.10	11.5	19.3	1.40	0.14	1.30	0.12	0.86	0.16	2086	22	38	46	35	13.8	5.3
C50FM	7.60	17.4	11.1	1.71	0.17	1.71	0.18	0.76	0.11	2001	25	41	42	33	6.5	6.9
C75FM	8.30	23.0	12.2	1.70	0.21	1.57	0.21	0.66	0.09	1646	20	30	32	30	7.2	7.3
C100FM	9.0	26.9	11.9	1.23	0.20	1.56	0.22	1.16	0.05	1812	25	24	31	28	9.7	23.2

C10FM, C25FM, C50FM, C75FM and C100FM connote compost with 10%, 25%, 50%, 75% and 100% filter materials, respectively

4.2 Laboratory incubation study of winery solid waste composts

4.2.1 Effect of compost types on mean concentration of N, P and K mineralised across sampling dates and soil types

Figure 2 shows the mean concentration of ammonium N measured in the incubated soils across the various sampling dates and soil types. The different compost types had significant ($P \leq 0.05$) effects on the amount of NH_4-N released in comparison with the control. Except for C75FM, all other composts released significantly more NH_4-N than the control, suggesting that these composts have the potential to supply NH_4-N into the soil.

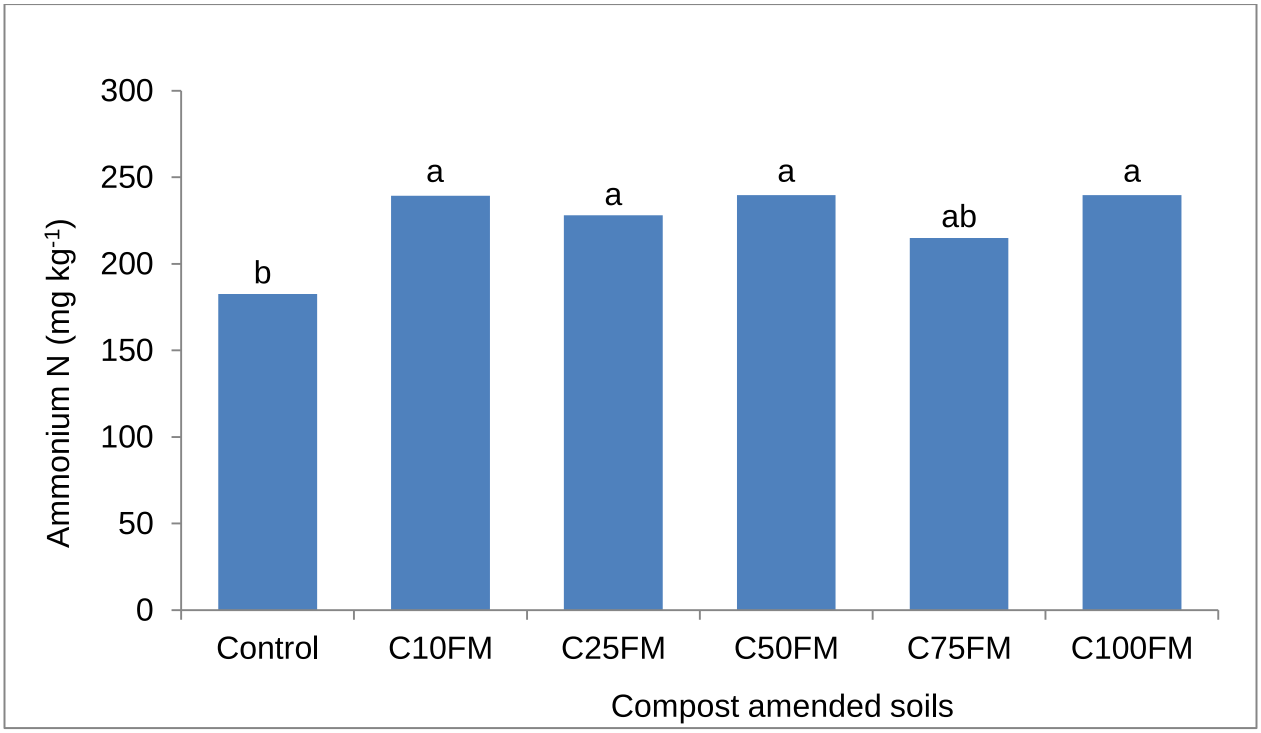

Figure 2. The effect of compost types on NH_4-N released. Columns with the same letter(s) are not significantly different ($P \leq 0.05$). *(C10FM, C25FM, C50FM, C75FM and C100FM connote compost with 10%, 25%, 50%, 75% and 100% filter materials, respectively)*

The different compost types similarly had significant ($P \leq 0.05$) effects on the mean amount of NO_3-N mineralised (Figure 3). The C100FM gave a significantly higher NO_3-N concentration than the control and C10FM, while the mean amount of NO_3-N released from the remaining composts did not differ significantly from each other. Therefore, C100FM constitutes a better source of NO_3-N.

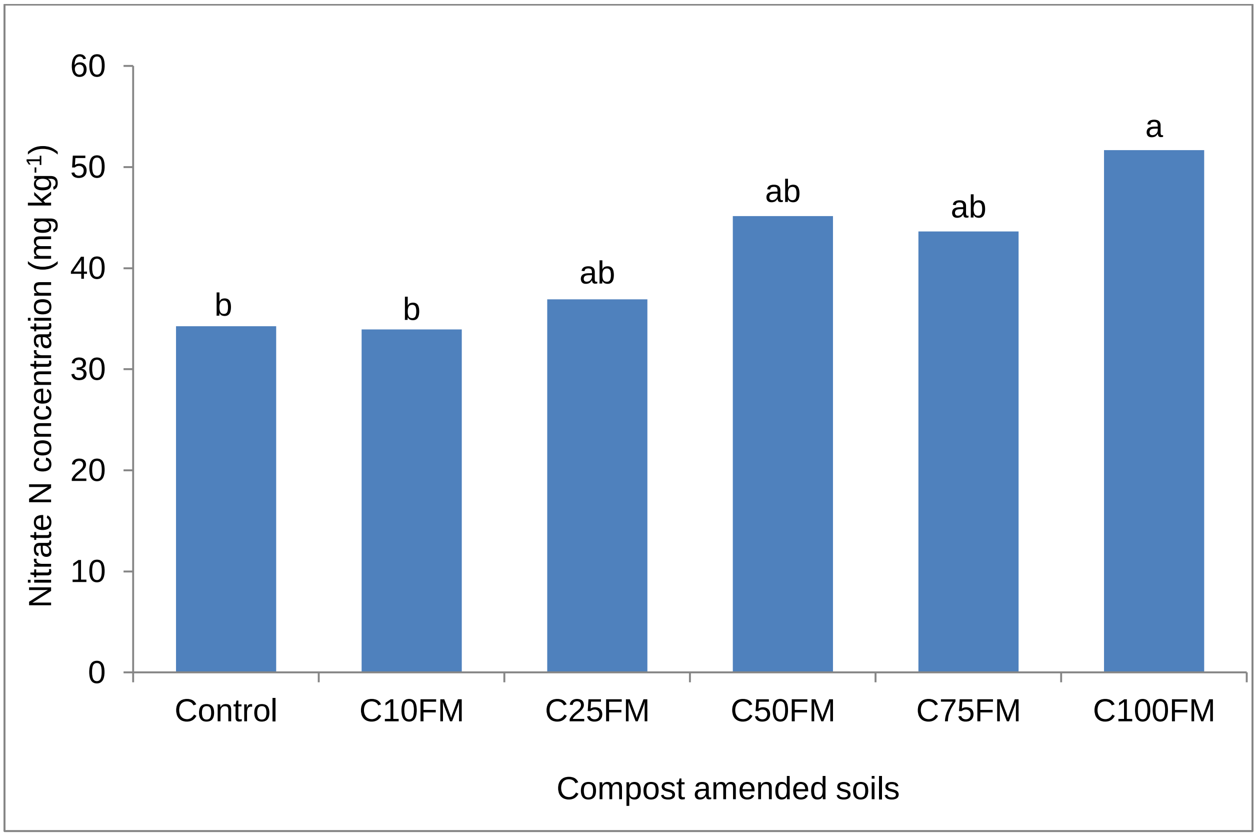

Figure 3. The effect of compost types on NO_3-N released. Columns with the same letter(s) are not significantly different ($P \leq 0.05$). *(C10FM, C25FM, C50FM, C75FM and C100FM connote compost with 10%, 25%, 50%, 75% and 100% filter materials, respectively)*

The mean amount of P mineralised from the different composts did not differ significantly. There was a significant ($P \leq 0.05$) difference in the mineralised K among the treatments regardless of the soil type and the incubation period (Figure 4). The concentration of exchangeable K mineralised was in the order of C100FM > C75FM > C50FM > C25FM > C10FM > control suggesting that FM constitutes a K sink for the composts and thus resulted in increased K release potential at higher percent FM composition.

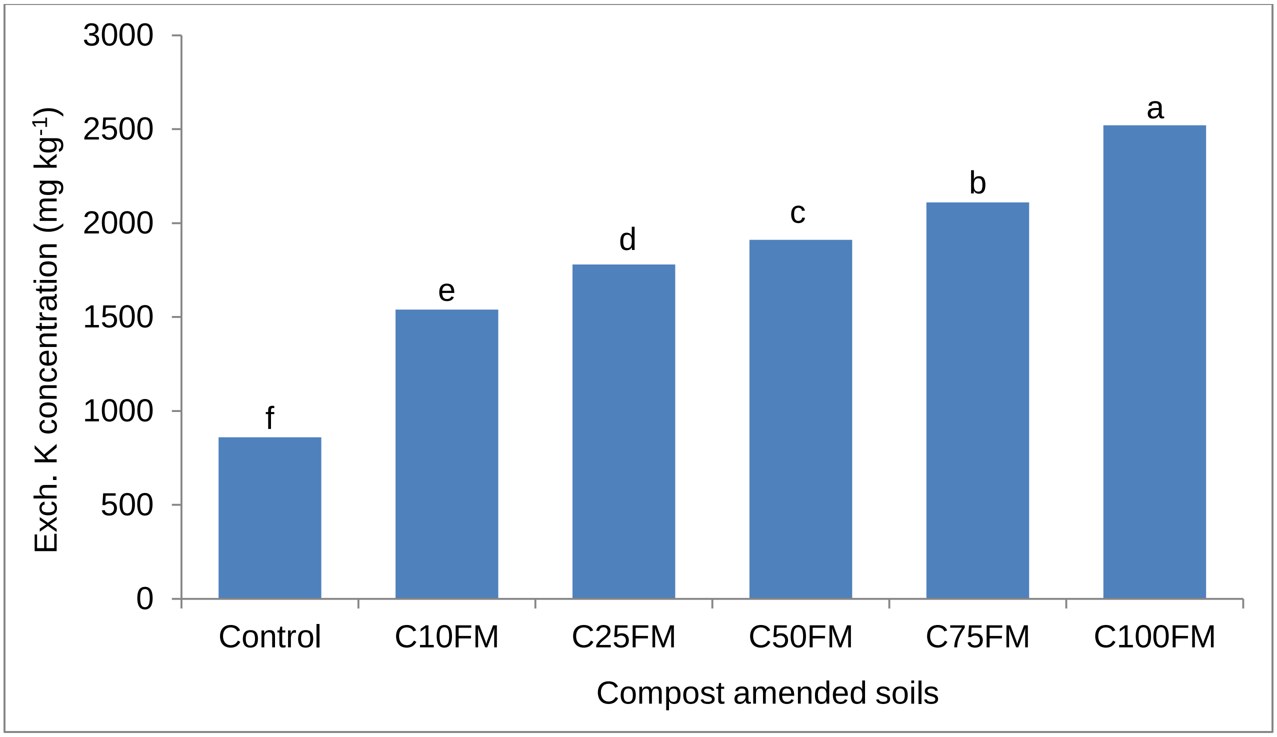

Figure 4. The effect of compost types on K released. The means are significantly different ($P \leq 0.05$). *(C10FM, C25FM, C50FM, C75FM and C100FM connote compost with 10%, 25%, 50%, 75% and 100% filter materials, respectively)*

4.2.2 Compost type x days after incubation interaction effects on the concentration of N, P and K mineralised

The effect of compost type x days after incubation (DAI) interaction on NH_4-N released was significant at $P \leq 0.05$ (Table 5). On the 7th day after incubation, only C50FM and C75FM released less NH_4-N than the control. The above-mentioned composts as well as C100FM released less NH_4-N than the control at 14 DAI. On the 21st day after incubation, all composts except C75FM produced significantly more NH_4-N than the control. The C100FM released significantly more NH_4-N than the control on the 28th day after incubation. The C10FM and C25FM released less NH_4-N than the control at 28 DAI. Except C100FM, all composts released significantly more NH_4-N than the control at 35 DAI. Neither NO_3-N nor Bray-1 extractable P concentration released during the incubation period was significantly affected by compost type x incubation period interaction effect. There was a significant ($P \leq 0.05$) compost type x days after incubation interaction effect on the mean concentration of K mineralised across the two soil types relative to the control (Table 6).

Table 5. Effect of compost type x days after incubation interaction on NH_4-N released (mg kg^{-1})

Composts	Days after incubation					
	7	14	21	28	35	42
C10FM	52hij	263ef	391abc	272de	404a	52hij
C25FM	43ij	195efg	404a	265ef	403a	54hij
C50FM	24j	149fghi	405a	392ab	407a	58hij
C75FM	34ij	150fghi	251efg	398ab	403a	51hij
C100FM	51hij	134ghij	407a	402a	384abcd	57hij
Control	37ij	166efgh	268de	282bcde	275cde	64hij

Means with the same letter(s) are not significantly different at P ≤ 0.05 according to Tukey test; C10FM, C25FM, C50FM, C75FM and C100FM connote compost with 10%, 25%, 50%, 75% and 100% filter materials, respectively

Table 6. Effect of compost type x days after incubation interaction on K released (mg kg^{-1})

Composts	Days after incubation					
	7	14	21	28	35	42
C10FM	1520ghi	1510ghi	1640efghi	1480hi	1610efghi	1470i
C25FM	1890def	1830defgh	1850defg	1790defghi	1740defghi	1570fghi
C50FM	1730defghi	1850defg	2080bcd	1880def	1950de	1970cde
C75FM	2020bcd	2340ab	2310abc	2060bcd	2030bcd	1840defg
C100FM	2460a	2580a	2480a	2450a	2500a	2590a
Control	900j	930j	850j	820j	790j	810j

Means with the same letter(s) are not significantly different at P ≤ 0.05 according to Tukey test; C10FM, C25FM, C50FM, C75FM and C100FM connote compost with 10%, 25%, 50%, 75% and 100% filter materials, respectively

4.2.3 Compost type x soil type interaction effects on the concentration of N, P and K mineralised

The effect of compost type x soil type interaction on released NH_4-N and mineralised K was found to be significant at $P \leq 0.05$ (Table 7). The concentration of NH_4-N released into the soil solution was significant except for the application of C75FM under sandy soil conditions. The interaction effect of compost type x soil type on the concentration of NO_3-N and P was not significant (Table 7). The concentration of NO_3-N measured in compost amended soil was quantitatively higher than in the control under sandy loam soil conditions while only C50FM, C75FM and C100FM composts released higher NO_3-N concentration than the control under sandy soil conditions. The mean concentration of P measured in compost amended soil was quantitatively higher than that of un-amended control only under sandy loam soil but lower in sandy soil. The concentration of K mineralised in C100FM amended soil was significantly higher than in any other composts in both soil types.

Table 7. Effect of compost type x soil type interaction on NH_4-N, NO_3-N, P and K released

Soil type	Composts	NH_4-N	NO_3-N	Bray-1 P	Exch. K
		(mg kg^{-1})			
Sandy loam	C10FM	242abc	36ab	3.84ab	1900d
	C25FM	185cd	42ab	3.91ab	2150c
	C50FM	247ab	49ab	3.85ab	2410b
	C75FM	224abc	49ab	4.00ab	2400b
	C100FM	232abc	59a	5.27a	2890a
	Control	202bcd	35ab	3.60b	1190f
Sandy	C10FM	235abc	31b	3.52b	1170f
	C25FM	270a	31b	3.48b	1400e
	C50FM	231abc	40ab	3.44b	1410e
	C75FM	205bcd	37ab	3.48b	1800d
	C100FM	246ab	43ab	3.58b	2140c
	Control	162d	32b	3.89ab	510g

Means with the same letter(s) in the same column are not significantly different at $P \leq 0.05$ according to Tukey test; C10FM, C25FM, C50FM, C75FM and C100FM connote compost with 10%, 25%, 50%, 75% and 100% filter materials, respectively

4.2.4 Soil type x days after incubation interaction effects on the concentration of N, P and K mineralised

A significant ($P \leq 0.05$) soil type x days after incubation interaction effect was observed only on the mean concentration of NH_4-N across the compost types (Table 8). Under sandy loam soil conditions, the mean concentration of NH_4-N mineralised was highest on the 21st day after incubation, which was not significantly higher than the amount of released NH_4-N on the 35th day after incubation. On the other hand, the concentration of NH_4-N released increased up to the 28th day after incubation beyond which it decreased under sandy soil conditions. The mean concentration of K mineralised on the 21st day after incubation was highest in the sandy loam soil.

Table 8. Effect of soil type x days after incubation interaction on NH_4-N, NO_3-N, P and K released

Soil type	DAI	NH_4-N	NO_3-N	Bray-1 P	K
		(mg kg^{-1})			
Sandy loam	7	39d	43ab	3.88a	2150ab
	14	184c	41ab	4.55a	2200ab
	21	382a	57a	3.75a	2270a
	28	291b	35ab	3.98a	2110ab
	35	382a	47ab	4.73a	2150ab
	42	55d	47ab	3.62a	2060b
Sandy	7	41d	30b	3.76a	1360c
	14	169c	28b	3.33a	1480c
	21	326ab	46ab	3.57a	1470c
	28	380a	44ab	3.40a	1380c
	35	377a	36ab	3.67a	1390c
	42	58d	30b	3.65a	1350c

Means with the same letter(s) in the same column are not significantly different at $P \leq 0.05$ according to Tukey test; DAI = days after incubation

4.3 Greenhouse evaluation of maize performance and changes in chemical properties of soil following application of winery solid waste composts

4.3.1 Main treatment effects on selected maize growth parameters and dry matter yield

Application of the different compost types and NPK fertiliser had significant effects ($P<0.001$) on maize plant height, plant stem diameter, mean number of functional leaves per plant and the dry matter yield (Table 9). The increase in plant height following compost application ranged from 21% (C10FM) to 45% (C100FM) over the un-fertilised control. Maize plant height in pots treated with the NPK fertiliser was significantly higher than in pots treated with the composts. The increase in plant stem diameter following compost application varied between 30% (C10FM) and 84% (C100FM), with no significant difference between the C75FM and C100FM applied plants.

Table 9. Effect of different winery solid waste composts on maize plant growth and dry matter yield

Treatments	Plant height (cm)	Stem diameter (cm)	No. of functional leaves per plant	Dry matter yield (g pot^{-1})
C10FM	71.40d	0.48d	7.3d	7.15c
C25FM	74.90cd	0.56c	7.5d	8.85c
C50FM	80.02bc	0.62bc	7.9cd	11.64b
C75FM	82.90b	0.67ab	8.2bc	13.20b
C100FM	85.45b	0.68ab	8.6ab	13.23b
NPK fertiliser	92.25a	0.73a	9.1a	16.22a
Control	59.12e	0.37e	6.1e	3.45d

Means with the same letter(s) in the same column are not significantly different at P ≤ 0.05 according to Duncan's Multiple Range Test; Number of observations for composts treatments is 20 while for both control and NPK fertiliser treatments is 4; C10FM, C25FM, C50FM, C75FM and C100FM connote compost with 10%, 25%, 50%, 75% and 100% filter materials, respectively

The increase in the mean number of functional leaves per plant for the different compost types ranged from 20% (C10FM) to 41% (C100FM) over the un-fertilised control. The mean number of functional leaves per plant obtained from C100FM applied pot was comparable to that of NPK fertiliser applied pot. NPK fertiliser application gave the highest dry matter yield of 16.22 g pot^{-1}, while values obtained in pots amended with C50FM, C75FM and C100FM though did not differ significantly from one another.

Figures 5 to 9 show the response curves of mean maize dry matter yield to the application of variable levels of the five winery solid waste composts produced. The letters Y and X in the equations represent the predicted dry matter yield and the rate of compost, respectively. The regression equations relating dry matter yield to compost application rates had R^2 values ranging from 0.92 to 0.99 (Table 10). The highest stationary point of the response curve to achieve an estimated optimum dry matter yield of 11 g pot^{-1} was at 450 g pot^{-1} for C10FM application while the highest estimated optimum dry matter yield of 17 g pot^{-1} was achieved at 648 g pot^{-1} application rate for

C25FM. The highest stationary point of the response curve to achieve 50 g pot^{-1} and 31 g pot^{-1} dry matter yield for C50FM and C75FM application were at 1842 and 714 g pot^{-1} respectively, while the estimated optimum dry matter yield of 21 g pot^{-1} for C100FM was achieved at 522 g pot^{-1}.

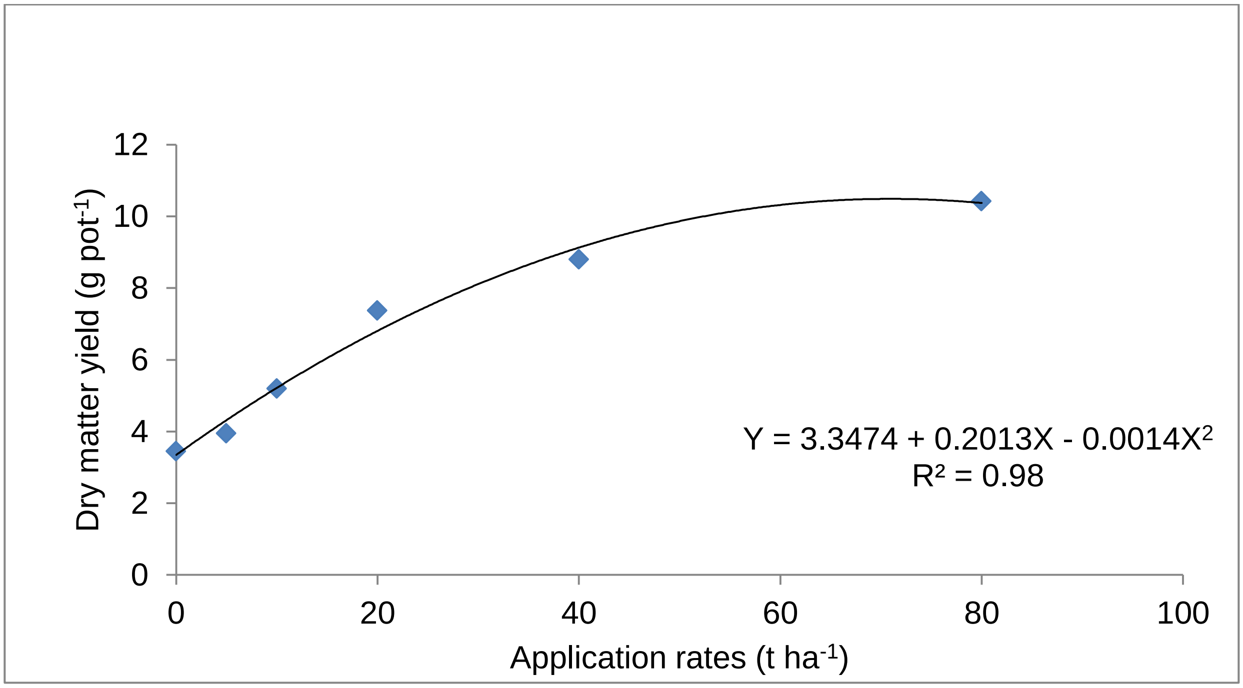

Figure 5. Response curve for dry matter yield as influenced by application rates of C10FM.

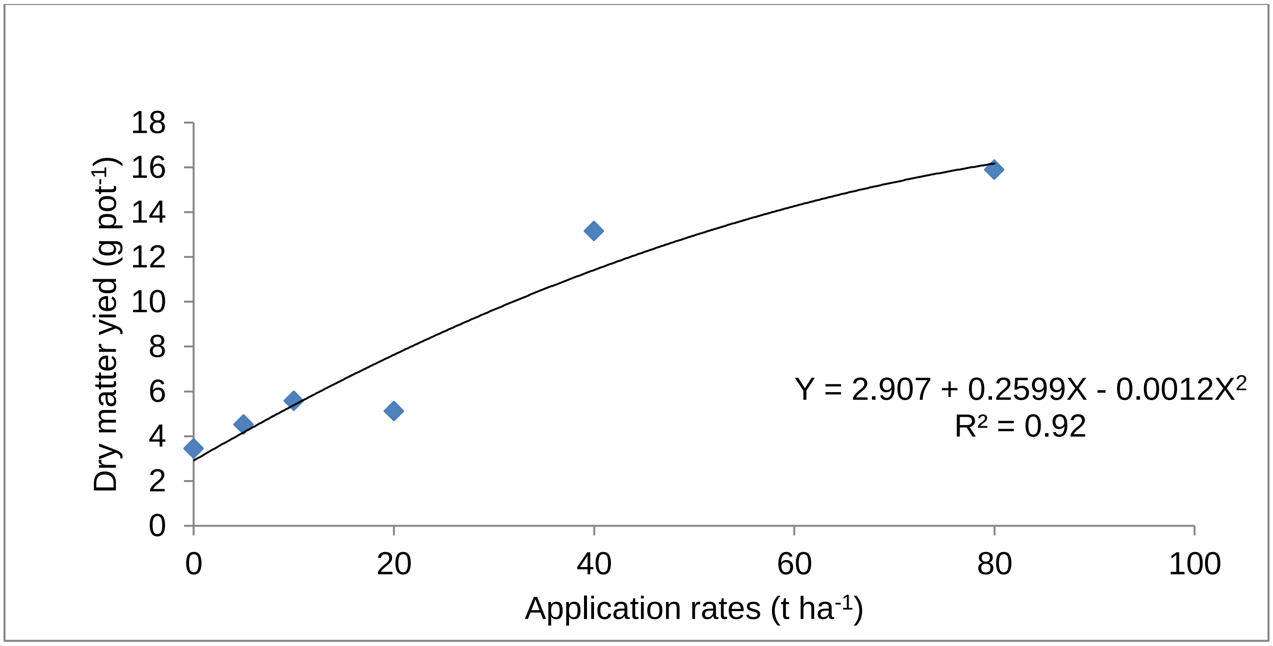

Figure 6. Response curve for dry matter yield as influenced by application rates of C25FM.

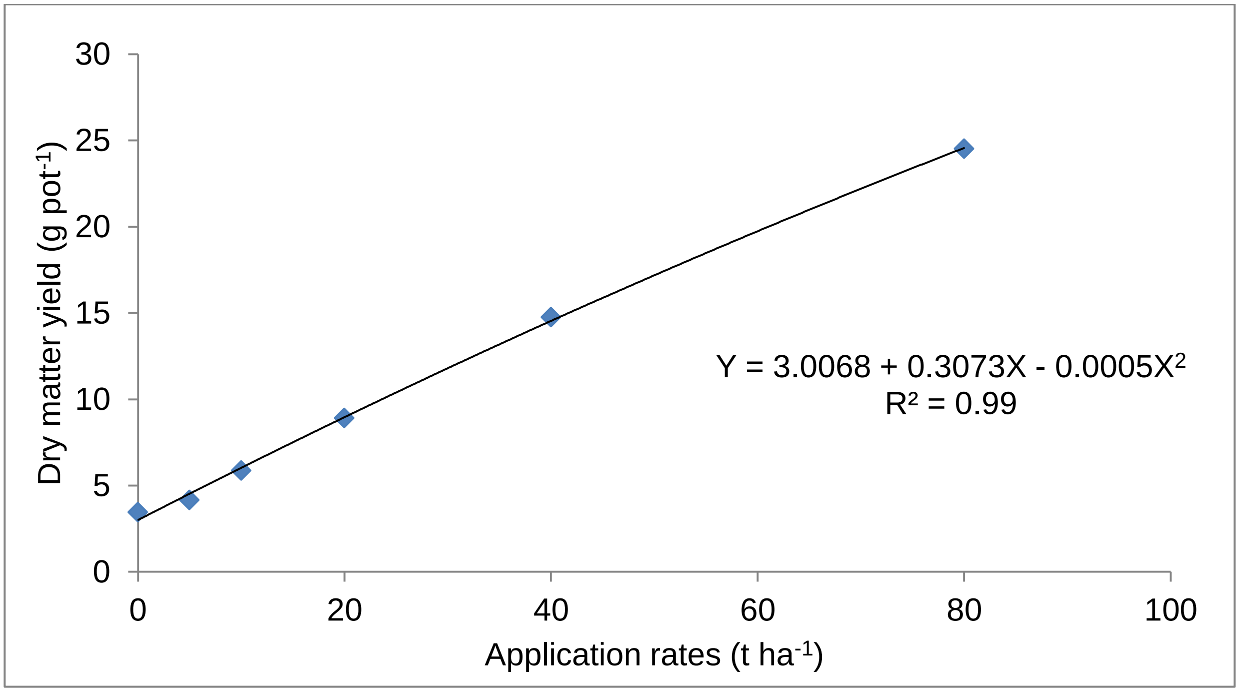

Figure 7. Response curve for dry matter yield as influenced by application rates of C50FM.

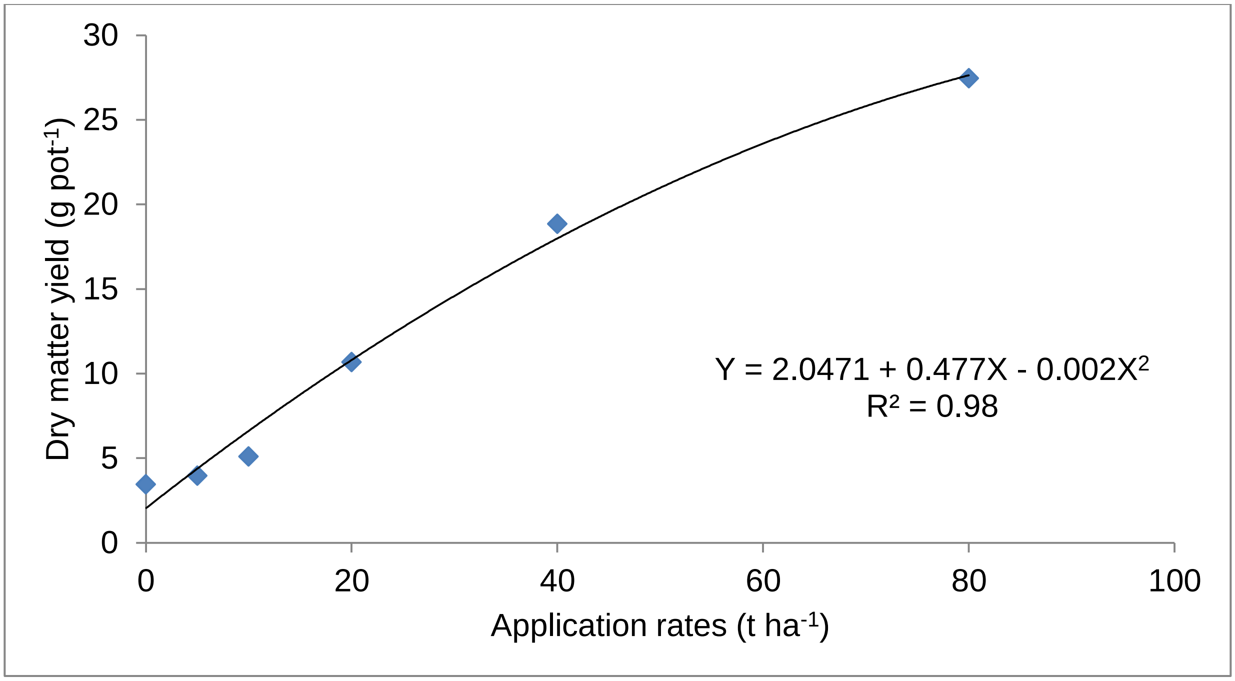

Figure 8. Response curve for dry matter yield as influenced by application rates of C75FM.

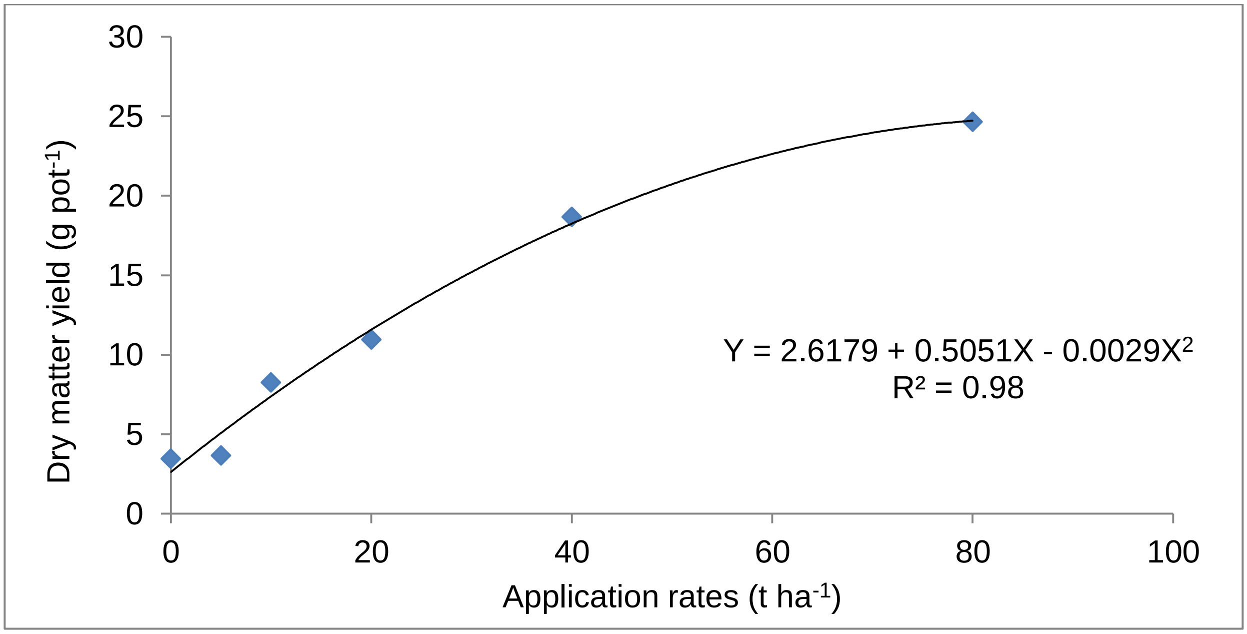

Figure 9. Response curve for dry matter yield as influenced by application rates of C100FM.

Table 10. Regression equations, predicted dry matter yield and compost application rate

Compost type	Regression Equation	R^2	Y (g pot^{-1})	X (g pot^{-1})
C10FM	$Y = 3.3474 + 0.2013X - 0.0014X^2$	0.98	11	450
C25FM	$Y = 2.907 + 0.2599X - 0.0012X^2$	0.92	17	648
C50FM	$Y = 3.0068 + 0.3073X - 0.0005X^2$	0.99	50	1842
C75FM	$Y = 2.0471 + 0.477 - 0.002X^2$	0.98	31	714
C100FM	$Y = 2.6179 + 0.5051X - 0.0029X^2$	0.98	21	522

Y and X represent predicted dry matter yield and compost application rate, respectively; C10FM, C25FM, C50FM, C75FM and C100FM connote compost with 10%, 25%, 50%, 75% and 100% filter materials, respectively

4.3.2 Treatment interaction effects on selected maize growth parameters and dry matter yield

There was a significant ($P<0.001$) compost type x application rate interaction effect on plant height, mean number of functional leaves per plant, plant stem diameter and dry matter yield (Table 11). The height of plants in pots treated with C100FM at 80 t ha^{-1} was highest and statistically comparable to that of plants in pots treated with C50FM and C75FM both at 80 t ha^{-1}. Plants in pots treated with 80 t ha^{-1} of C75FM had the highest stem diameter (1.02 cm) which differed non-significantly only with that of plants in pots treated with C50FM and C100FM both at 80 t ha^{-1}. The mean number of functional leaves per plant was highest in pots treated with C100FM at 80 t ha^{-1} and was statistically not different with that in pots treated with C50FM and C75FM both at 80 t ha^{-1}. The dry matter yield ranged between 3.45 g pot^{-1} in the un-fertilised control treatment and 27.45 g pot^{-1} in the C75FM treatment at 80 t ha^{-1}. The 80 t ha^{-1} application rate for C50FM, C75FM and C100FM gave the highest values of stem diameter, number of functional leaves per plant and dry matter yield; and were all significantly higher than those observed in the NPK fertiliser treatment. Only C100FM treatment at 80 t ha^{-1} significantly improved plant height than the NPK fertiliser treatment.

Table 11. Compost type x application rate interaction effects on maize plant growth and dry matter yield

Treatments	Rates*	Plant height (cm)	Stem diameter (cm)	No. of functional leaves per plant	Dry matter yield (g pot^{-1})
Control	0	59l	0.37jkl	6.1ij	3.45h
C10FM	5	66ijkl	0.36kl	6.6ghij	3.95h
	10	67ijkl	0.45ijk	6.7ghij	5.20fgh
	20	70hijkl	0.48ijk	7.0ghij	7.37efgh
	40	75ghijk	0.51ghij	7.6efg	8.80ef
	80	78fghij	0.62efgh	8.5cde	10.42de
C25FM	5	63kl	0.40jkl	6.8ghij	4.52gh
	10	71ghijkl	0.43ijkl	6.8ghij	5.57fgh
	20	68hijkl	0.46ijk	6.7ghij	5.12fgh
	40	89cdef	0.63efg	8.1def	13.15cd
	80	83defg	0.87bc	8.8cd	15.90bc
C50FM	5	60l	0.31l	6.0j	4.15h
	10	70ghijkl	0.50hijk	6.5ghij	5.87fgh
	20	78fghij	0.55fghi	7.2fghi	8.90ef
	40	89cdef	0.81cd	9.3bc	14.75c
	80	101abc	0.93abc	10.3ab	24.52a
C75FM	5	68hijkl	0.31l	6.50ghij	3.95h
	10	69hijkl	0.47ijk	6.3hij	5.10fgh
	20	81efgh	0.73de	8.3cde	10.67de
	40	92bcde	0.83bcd	9.5bc	18.85b
	80	103ab	1.02a	10.3ab	27.45a
C100FM	5	65jkl	0.38jkl	6.6ghij	3.65h
	10	79fghi	0.53ghi	7.5efgh	8.25efg
	20	80fghi	0.67ef	8.3cde	10.95de
	40	94bcd	0.86bcd	9.1cd	18.67b
	80	108a	0.96ab	11.3a	24.65a
NPK fertiliser	100-60-40	92bcde	0.73de	9.1cd	16.22bc

*Means with the same letter(s) in the same column are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range Test; *Rates of composts and NPK are in t ha^{-1} and kg ha^{-1}, respectively; C10FM, C25FM, C50FM, C75FM and C100FM connote compost with 10%, 25%, 50%, 75% and 100% filter materials, respectively*

4.3.3 Main treatment effects on tissue N, P, K and Na contents and uptake

Application of the different compost types and NPK fertiliser had positive and significant ($P<0.001$) effects on tissue N, P and K contents of maize shoot relative to the un-fertilised control but exerted non-significant effects on tissue Na content (Table 12). The range of tissue N content in maize shoot varied between 0.57% (C25FM) and 0.87% (NPK fertiliser) but ranged from 0.16% (C10FM and C25FM) to 0.20% (C75FM) for tissue P content. The tissue N content in maize shoot obtained from C10FM, C25FM, C50FM and C75FM amended pots did not differ significantly from one another and were generally lower than in the NPK fertiliser applied pots. Maize shoot tissue P content from C50FM, C75FM, C100FM and NPK fertiliser amended pots did not differ significantly, while tissue K content from C50FM, C75FM and C100FM pots were statistically at par. The tissue Na content from C25FM and C75FM was significantly higher than the value obtained from the NPK fertiliser applied and un-amended control pots. The difference in mean N, P, K and Na uptake in maize shoot among the different compost types was not significant (Table 12). Nonetheless, quantitatively higher level of each nutrient elements were obtained in the compost treatments in comparison with the un-fertilised control.

4.3.4 Treatment interaction effects on tissue N, P, K and Na contents and uptake

There was a significant ($P<0.001$) compost type x application rate interaction effect on tissue N, P and K contents in maize shoot (Table 13). Significant increases in tissue N content were observed in plant shoot from pots treated with C50FM, C75FM and C100FM at a rate of 80 t ha^{-1} relative to the un-fertilised control. The 80 t ha^{-1} application rate of C100FM gave the highest shoot N content of 1.02%, which differed significantly from the value obtained from all other composts and NPK amended pots. Both C50FM and C75FM applied at 80 t ha^{-1} gave the highest tissue P content of 0.27%, which did not differ significantly from the value obtained from C50FM and C100FM applied at 40 and 80 t ha^{-1}, respectively. All composts applied at 80 t ha^{-1}, except for C25FM, resulted in a significantly higher tissue P increases than the NPK fertiliser treatment. Application of C50FM at 40 t ha^{-1} gave a significantly higher tissue P content than the NPK fertiliser treatment. The C75FM was the only compost applied at a rate of 10 t ha^{-1} that significantly increased tissue P content compared to the un-fertilised control.

Table 12. Effect of different winery solid waste composts on selected maize shoot macronutrients contents and uptake

Treatments	Nutrient content				Nutrient uptake (mg pot^{-1})			
	N (%)	P (%)	K (%)	Na (mg kg^{-1})	N	P	K	Na
C10FM	0.58cd	0.16b	4.02c	317ab	4.27a	1.28a	30a	2.34a
C25FM	0.57cd	0.16b	4.07bc	354a	5.20a	1.63a	38a	3.16a
C50FM	0.63bcd	0.19a	4.44a	341ab	7.90a	2.65a	56a	3.86a
C75FM	0.64bc	0.20a	4.40ab	362a	9.45a	3.06a	63a	5.32a
C100FM	0.68b	0.19a	4.51a	332ab	9.99a	2.86a	64a	4.28a
NPK fertiliser	0.87a	0.19a	1.47e	222b	14.09a	3.16a	23a	3.69a
Control	0.55d	0.13c	3.26d	310ab	1.99a	0.51a	12a	1.10a

Means of nutrient contents with the same letter(s) in the same column are not significantly different at P ≤ 0.05 according to Duncan's Multiple Range Test; Means of nutrient uptake with the same letter in the same column are not significantly different according to Tukey test at P ≤ 0.05; Number of observations for composts treatments is 20 while for both control and NPK fertiliser treatments is 4; C10FM, C25FM, C50FM, C75FM and C100FM connote compost with 10%, 25%, 50%, 75% and 100% filter materials, respectively

Table 13. Compost type x application rate interaction effects on selected maize shoot macronutrients contents and uptake

Treatments	Rates*	Nutrient content				Nutrient uptake (mg pot^{-1})			
		N (%)	P (%)	K (%)	Na (mg kg^{-1})	N	P	K	Na
Control	0	0.55cdefg	0.13jk	3.26h	310bcd	1.98l	0.50kl	11.52k	1.10hi
C10FM	5	0.59cdefg	0.10l	3.46gh	250bcd	2.44kl	0.40l	13.52k	0.94i
	10	0.50fg	0.13jk	3.58fgh	277bcd	2.59kl	0.69kl	18.57jk	1.34ghi
	20	0.58cdefg	0.15ghijk	4.18bcdef	435abc	4.19ijkl	1.13ijkl	30.48hij	3.22cdefgh
	40	0.59cdefg	0.19ef	4.15cdef	260bcd	5.20ghij	1.68ghi	36.27gh	2.27defghi
	80	0.67cd	0.24bcd	4.72bc	365abcd	6.91gh	2.53ef	48.89f	3.91cde
C25FM	5	0.50g	0.12kl	3.22h	290bcd	2.14l	0.56kl	13.23k	1.30ghi
	10	0.59cdefg	0.15ghijk	3.88efg	372abcd	3.36jkl	0.88ijkl	21.88ijk	2.04defghi
	20	0.57cdefg	0.16ghij	4.07defg	335abcd	2.90jkl	0.79jkl	20.91ijk	1.80efghi
	40	0.58cdefg	0.18fg	4.42bcde	517a	7.43fg	2.38fg	57.29ef	6.61b
	80	0.64cdef	0.22cde	4.74bc	255bcd	10.17de	3.54cd	75.47cd	4.03cd
C50FM	5	0.57cdefg	0.147hijk	3.88efg	405abcd	2.37kl	0.63kl	16.31k	1.62fghi
	10	0.55cdefg	0.13jk	3.88efg	342abcd	3.25jkl	0.80jkl	22.65ijk	1.77fghi
	20	0.55cdefg	0.17fghi	4.07defg	297bcd	4.87hijk	1.54hij	35.66gh	2.76cdefghi
	40	0.68c	0.25abc	4.79b	310bcd	9.52ef	3.53cd	68.20de	4.67c
	80	0.80b	0.27a	5.58a	350abcd	19.48b	6.72b	135.28b	8.48b
C75FM	5	0.53efg	0.15ghijk	3.67fgh	327abcd	2.02l	0.59kl	14.29k	1.31ghi
	10	0.54defg	0.177fgh	3.92efg	240cd	2.63kl	0.87ijkl	18.72jk	1.13hi
	20	0.62cdefg	0.21de	4.35bcde	367abcd	6.56ghi	2.27fgh	46.32fg	3.71cdef
	40	0.65cde	0.21de	4.30bcde	425abc	12.18cd	4.03c	80.30cd	8.00b
	80	0.88b	0.27a	5.75a	450ab	23.89a	7.51a	155.66a	12.42a
C100FM	5	0.54defg	0.14ijk	3.66fgh	380abcd	1.89l	0.53kl	13.10k	1.31ghi
	10	0.54defg	0.15ghijk	3.93efg	292bcd	4.37ijkl	1.26ijk	32.40hi	2.53defghi
	20	0.63cdefg	0.20ef	4.65bcd	290bcd	6.80gh	2.15fgh	49.53f	3.38cdefg
	40	0.67cd	0.22cde	4.71bc	405abcd	12.24cd	4.03c	86.37c	7.11b
	80	1.02a	0.26ab	5.62a	292bcd	24.64a	6.31b	137.51b	7.04b
NPK fertiliser	100-60-40	0.87b	0.19ef	1.47i	222.50d	14.09c	3.16de	23.43hijk	3.68cdef

*Means with the same letter(s) in the same column are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range Test; *Rates of composts and NPK are in t ha^{-1} and kg ha^{-1}, respectively; C10FM, C25FM, C50FM, C75FM and C100FM connote compost with 10%, 25%, 50%, 75% and 100% filter materials, respectively*

Application of C10FM at rates greater than 10 t ha^{-1} resulted in significant shoot K content increases relative to the un-fertilised control, while C25FM, C75FM and C100FM applied at rates higher than 5 t ha^{-1} significantly increased K content in maize shoots. All the five application rates for C50FM treatment resulted in significant increase in shoot K content over the un-fertilised control. The 80 t ha^{-1} application rate for C50FM, C75FM and C100FM gave the highest increase of up to 76% in shoot K content compared with the un-fertilised control treatment. Application of C25FM at a rate of 5 t ha^{-1} resulted in marginal (1%) but inconsequential decrease in shoot K content relative to the un-fertilised control. The C25FM treatment at a rate of 40 t ha^{-1} increased shoot Na content by 67% over the un-fertilised control.

Application of composts with 50% or more FM at rates beyond 10 t ha^{-1} and those with less than 50% FM at rates higher than 20 t ha^{-1} significantly ($P<0.001$) improved shoot N uptake when compared with the un-fertilised control. Shoot N uptake ranged between 1.89 mg pot^{-1} for C100FM at a rate of 5 t ha^{-1} and 24.64 mg pot^{-1} for C100FM at a rate of 80 t ha^{-1}. Shoot N uptake by plants in pots treated with C50FM, C75FM and C100FM at 80 t ha^{-1} application rate was significantly higher than those in pots treated with the NPK fertiliser. In general, shoot N uptake increased with the increase of compost application rates, except for the application of C25FM. Similarly, application of composts with 50% FM or more at rates higher than 10 t ha^{-1} resulted in a significant ($P<0.001$) increase in shoot P uptake relative to the un-fertilised control. The C10FM compost applied at 5 t ha^{-1} exerted a negative effect on P uptake relative to the un-fertilised control. Compared to the NPK fertiliser treatment, the application of both C75FM and C100FM at rates of 40 and 80 t ha^{-1} as well as C50FM at a rate of 80 t ha^{-1} significantly increased P uptake. Shoot P uptake ranged between 0.40 mg pot^{-1} with C10FM applied at a rate of 5 t ha^{-1} and 7.51 mg pot^{-1} with C75FM at a rate of 80 t ha^{-1}. Treatment with C75FM applied at 80 t ha^{-1} gave the highest shoot P uptake than all other treatments.

Generally, shoot K uptake increased with an increase in compost application rates, except with C25FM application. Shoot K uptake ranged between 13.10 mg pot^{-1} with C100FM at a rate of 5 t ha^{-1} and 155.66 mg pot^{-1} with C75FM at a rate of 80 t ha^{-1}. The 80 t ha^{-1} application rate for all the composts resulted in significantly higher plant K uptake than NPK fertiliser treatment. The same was found true for 40 t ha^{-1} application rate except for C10FM compost. Furthermore, C75FM and C100FM applied at 20 t ha^{-1} similarly gave significantly higher shoot K uptake than the NPK fertiliser treatment. Shoot Na uptake values ranged between 0.94 mg pot^{-1} with C10FM applied at a rate of 5 t ha^{-1} and 12.42 mg pot^{-1} with C75FM applied at a rate of 80 t ha^{-1}. All composts applied at 80 t ha^{-1} improved shoot Na uptake significantly over the un-fertilised control treatment. The C75FM compost applied at 80 t ha^{-1} gave higher increases in shoot Na uptake than all other compost types including the NPK fertiliser treatment.

4.3.5 Main treatment effects on shoot Fe, Cu, Zn, Mn and B contents and uptake

Application of the various compost types exerted inconsequential effects on the Fe and Cu contents of maize shoot but had a significant ($P<0.001$) effect on the content of Zn and Mn relative to the un-fertilised control treatment (Table 14). Composts application also exerted a significant effect on Zn content relative to the NPK fertiliser treatment. The differences in shoot Fe, Cu, Zn and Mn contents among the various compost types were not significant. Quantitatively reduced Fe content in maize shoot was obtained in compost amended soil relative to the un-amended soil with a decrease of between 5.6% in C10FM and 19.1% in C25FM treatment. Similarly, the decrease in shoot Mn content ranged between 27% in C100FM and 32% in C25FM when compared to the un-fertilised control. Maize shoot B content also deeped by between 0.76% (C25FM) and 9.00% (C10FM) compared with the un-fertilised control. There was however, an increase in shoot Zn content following compost application by between 67% (C75FM and C100FM) and 100% (C10FM) over the un-fertilised control. Although none of the shoot Cu, Mn, Zn and B uptake from compost amended soil differed significantly relative to the NPK fertilised and un-amended soil, values obtained were quantitatively higher in the former (Table 14). Only C10FM and C25FM were significantly lower in shoot Fe uptake than the NPK fertiliser treatment.

4.3.6 Treatment interaction effects on shoot Fe, Cu, Zn, Mn and B contents and uptake

Compost type x application rate interaction exerted inconsequential effects on shoot Fe, Cu, Mn and B contents and uptake but had significant ($P<0.001$) effects on Zn content and uptake (Table 15). The application of both C10FM and C25FM at rates higher than 10 t ha^{-1} significantly improved the shoot Zn content. The shoot Zn content ranged between 8 mg kg^{-1} with the NPK fertiliser treatment and 29 mg kg^{-1} with C25FM treatment applied at 80 t ha^{-1}. Generally, the uptake of Zn increased with the increase of compost application rates; and ranged between 0.03 mg pot^{-1} in C10FM applied at 5 t ha^{-1} and 0.57 mg pot^{-1} with both C50FM and C75FM applied at 80 t ha^{-1}.

Table 14. Effect of different winery solid waste composts on maize shoot micronutrients contents and uptake

Treatments	Nutrient content (mg kg^{-1})					Nutrient uptake (mg pot^{-1})				
	Fe	Cu	Zn	Mn	B	Fe	Cu	Zn	Mn	B
C10FM	84a	2.32a	18a	29b	8.30b	0.58b	0.02a	0.14a	0.21a	0.06a
C25FM	72a	2.17a	17a	28b	9.05ab	0.55b	0.02a	0.18a	0.25a	0.09a
C50FM	77a	2.25a	17a	29b	9.00ab	0.88ab	0.03a	0.23a	0.35a	0.11a
C75FM	77a	2.42a	15a	29b	9.15ab	1.03ab	0.03a	0.23a	0.42a	0.14a
C100FM	73a	2.60a	15a	30b	10.77a	0.97ab	0.04a	0.24a	0.35a	0.15a
NPK fertiliser	99a	3.00a	8b	29b	8.75b	1.69a	0.05a	0.14a	0.48a	0.14a
Control	89a	2.37a	9b	41a	9.12ab	0.31b	0.01a	0.03a	0.14a	0.03a

Means of nutrient contents with the same letter(s) in the same column are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range Test; Means of nutrient uptake with the same letter(s) in the same column are not significantly different at $P \leq 0.05$ according to Tukey test; Number of observations for composts treatments is 20 while for both control and NPK fertiliser treatments is 4; C10FM, C25FM, C50FM, C75FM and C100FM connote compost with 10%, 25%, 50%, 75% and 100% filter materials, respectively

Table 15. Compost type x application rate interaction effects on maize shoot Zn content and uptake

Treatments	Rates*	Zn content ($mg\ kg^{-1}$)	Zn uptake ($mg\ pot^{-1}$)
Control	0	9j	0.03f
C10FM	5	9j	0.03f
	10	12hij	0.06f
	20	18defgh	0.13def
	40	25abc	0.20cde
	80	27ab	0.29bc
C25FM	5	10ij	0.04f
	10	12hij	0.07f
	20	18defgh	0.09ef
	40	17efghi	0.23cd
	80	29a	0.47a
C50FM	5	13ghij	0.05f
	10	13ghij	0.08ef
	20	15fghij	0.13def
	40	20cdef	0.29bc
	80	23bcd	0.57a
C75FM	5	11ij	0.04f
	10	15fghij	0.07f
	20	13ghij	0.14def
	40	16efghi	0.30bc
	80	20cdef	0.57a
C100FM	5	10ij	0.04f
	10	11ij	0.09ef
	20	14fghij	0.15def
	40	19cdefg	0.35b
	80	22bcde	0.55a
NPK fertiliser	100-60-40	8j	0.13def

*Means with the same letter(s) in the same column are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range Test; *Rates of composts and NPK are in t ha^{-1} and kg ha^{-1}, respectively; C10FM, C25FM, C50FM, C75FM and C100FM connote compost with 10%, 25%, 50%, 75% and 100% filter materials, respectively*

4.3.7 Main treatment effects on post-harvest soil organic carbon, pH and EC

The application of the different compost types had no significant effects on soil organic carbon (OC) and pH, while the NPK fertiliser treatment exerted a significant effect ($P<0.032$) on soil EC relative to the un-fertilised control (Table 16). The soil EC ranged between 0.09 dS/m in un-fertilised control and 0.51 dS/m in NPK fertilised pot. Soil organic C ranged between 0.11% (control) and 0.43% (C10FM).

4.3.8 Treatment interaction effects on post-harvest soil organic carbon, pH and EC

The compost type x application rate interaction exerted significant effects only on the soil EC relative to the un-fertilised control (Table 17). Compared to the un-fertilised control, soil pH was reduced non-significantly in pots treated with C25FM at rates of 5 and 40 t ha^{-1}, C50FM at a rate of 40 t ha^{-1} and C100FM at a rate of 80 t ha^{-1}.

Table 16. Effect of compost type on post-harvest soil organic carbon (OC) content, pH and EC

Treatments	OC (%)	pH (H_2O)	EC (dS/m)
C10FM	0.43a	8.86a	0.11b
C25FM	0.38a	8.63a	0.11b
C50FM	0.36ab	8.83a	0.11b
C75FM	0.35ab	8.96a	0.12b
C100FM	0.29ab	8.78a	0.11b
NPK fertiliser	0.29ab	7.83b	0.51a
Control	0.11b	8.15a	0.09b

Means with the same letter(s) in the same column are not significantly different at P ≤ 0.05 according to Duncan's Multiple Range Test; Number of observations for composts treatments is 20 while for both control and NPK fertiliser treatments is 4; C10FM, C25FM, C50FM, C75FM and C100FM connote compost with 10%, 25%, 50%, 75% and 100% filter materials, respectively

Table 17. Compost type x application rate interaction effects on post-harvest soil organic carbon (OC) content, pH and EC

Treatments	Rates*	OC (%)	pH (H_2O)	EC (dS/m)
C10FM	5	0.44ab	8.55ab	0.09ghi
	10	0.34ab	8.79ab	0.10fghi
	20	0.48ab	8.96a	0.09ghi
	40	0.44ab	8.97a	0.12cdefg
	80	0.43ab	9.05a	0.16cd
C25FM	5	0.42ab	8.46ab	0.09ghi
	10	0.21ab	8.64ab	0.10fghi
	20	0.42ab	9.13a	0.10fghi
	40	0.37ab	7.84b	0.13cdefg
	80	0.50ab	9.08a	0.16c
C50FM	5	0.11b	8.82ab	0.09i
	10	0.14b	9.11a	0.10fghi
	20	0.53ab	8.60ab	0.11efghi
	40	0.41ab	8.39ab	0.12defgh
	80	0.60a	9.24a	0.21b
C75FM	5	0.22ab	8.76ab	0.08hi
	10	0.35ab	8.60ab	0.09ghi
	20	0.40ab	9.20a	0.13cdef
	40	0.40ab	9.28a	0.15cd
	80	0.38ab	8.96a	0.24b
C100FM	5	0.26ab	8.71ab	0.08i
	10	0.19ab	8.81ab	0.09ghi
	20	0.19ab	9.03a	0.11efghi
	40	0.41ab	8.91a	0.14cde
	80	0.41ab	8.45ab	0.23b
NPK fertiliser	100-60-40	0.29ab	7.83b	0.51a
Control	0	0.11b	8.51ab	0.09ghi

*Means with the same letter(s) in the same column are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range Test; *Rates of composts and NPK are in t ha^{-1} and kg ha^{-1}, respectively; C10FM, C25FM, C50FM, C75FM and C100FM connote compost with 10%, 25%, 50%, 75% and 100% filter materials, respectively*

4.3.9 Main treatment effects on post-harvest soil mineral N, P, K, Na and micronutrients contents

Application of the various compost types had inconsequential effects on the residual soil extractable NH_4-N and NO_3-N contents relative to the un-fertilised control, but gave significantly lower contents than the NPK fertiliser treatment (Table 18). The residual soil NH_4-N content decreased by a range of between 54% (C75FM) and 65% (C50FM), while residual soil NO_3-N content increased by between 0.19 mg kg^{-1} (C50FM) and 0.61 mg kg^{-1} (C75FM) when compared to the un-fertilised control. Available P and extractable K contents in soil amended with composts were significantly ($P<0.001$) affected (Table 18). Although there was an increase in the residual available P content in compost amended soils by between 1.79 mg kg^{-1} (C50FM) and 5.11 mg kg^{-1} (C100FM) over the un-fertilised control, the increase was only significant with C25FM, C75FM and C100FM. Residual soil K content increased by the compost types ranged between 107 mg kg^{-1} (C10FM) and 195 mg kg^{-1} (C75FM) relative to the un-fertilised control. The residual K contents in composts with more than 50% FM were statistically similar. Nonetheless, compost amended soils had significantly higher residual soil K content than the NPK fertiliser treatment.

Application of the different compost types resulted in a significant ($P<0.001$) increase in residual soil Na content relative to the NPK fertiliser and un-fertilised control treatments (Table 18). The range of increase in soil Na content was between 70% with C100FM and 120% with C75FM in comparison with the un-fertilised control. Composts and NPK fertiliser application exerted significant ($P<0.001$) effects on the contents of Zn and Mn relative to the un-fertilised control treatment but inconsequential effects on Fe and Cu contents (Table 18). Residual soil Zn content following compost application increased by between 27.11% (C100FM) and 54.23% (C25FM). The residual soil Mn content significantly increased in C50FM, C75FM and C100FM treatments relative to the un-fertilised control. The residual Cu content measured from soil amended with the different compost types as well as in NPK fertiliser treatment were comparable. The decrease in residual soil Cu content by application of the different compost types ranged from 11% with C75FM to 25% with C50FM when compared with the un-fertilised control.

Table 18. Effect of compost type on post-harvest soil mineral N, Bray-1 P, exchangeable K, Na and extractable micronutrients contents (mg kg^{-1})

Treatments	Mineral N		Bray-1 P	Exch. K	Exch. Na	Extractable micronutrients			
	NH_4^+	NO_3^-				Fe	Cu	Zn	Mn
C10FM	1.17b	0.70b	3.59cd	131c	20a	11.01a	0.44ab	0.90ab	10.14bc
C25FM	1.06b	0.78b	4.01c	154bc	21a	10.46ab	0.42ab	0.91ab	10.22bc
C50FM	0.94b	0.57b	3.44cd	182ab	20a	9.18b	0.38b	0.83bc	10.71b
C75FM	1.22b	0.99b	6.28b	219a	22a	11.49ab	0.45ab	0.79bc	12.76a
C100FM	1.08b	0.83b	6.76b	189ab	17a	10.66ab	0.44ab	0.75c	11.89ab
NPK fertiliser	31.98a	45.18a	17.14a	16d	5c	11.75a	0.40b	1.17a	5.98d
Control	2.68b	0.38b	1.65d	24d	10b	12.21a	0.51a	0.59d	8.32c

Means with the same letter(s) in the same column are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range Test; Number of observations for composts treatments is 20 while for both control and NPK fertiliser treatments is 4; C10FM, C25FM, C50FM, C75FM and C100FM connote compost with 10%, 25%, 50%, 75% and 100% filter materials, respectively

4.3.10 Treatment interaction effects on post-harvest soil mineral N, P, K, Na and micronutrients contents

The compost types x application rate interaction effects on the residual soil NH_4-N and NO_3-N contents were not significant relative to the un-fertilised control but significant for Bray-1 P and K at 80 t ha^{-1} application rate for all compost types (Table 19). Residual Bray-1 P and K contents measured from C75FM and C100FM treatments applied at 80 t ha^{-1} were comparable to the NPK fertiliser treatment and significantly higher than those obtained from un-fertilised control. The highest residual Bray-1 P content of 17.54 mg kg^{-1} was obtained from C100FM, while residual soil K content of 500 mg kg^{-1} was recorded in C75FM treatment both at 80 t ha^{-1} application rate.

The effects of interactions between compost types and application rates on soil Fe content were not significant in comparison to both the un-fertilised control and NPK fertiliser treatment (Table 20). The same was found true for residual extractable Cu relative to the un-fertilised control except for C25FM, C50FM and C75FM treatments applied at rates of 20, 40 and 5 t ha^{-1}, respectively (Table 20). The different compost types applied at 80 t ha^{-1} significantly ($P<0.001$) increased the residual soil Zn content when compared with the un-fertilised control except C50FM applied at 40 t ha^{-1}. Similarly, except for C25FM applied at 20 t ha^{-1} and C50FM as well as C75FM applied at 5 t ha^{-1}, all other compost rates resulted in a significant increase in soil Mn content when compared with the un-fertilised control (Table 20). The highest residual soil Mn content of 18.50 mg kg^{-1} was obtained in pots treated with C75FM at a rate of 80 t ha^{-1}.

Table 19. Compost type x application rate interaction effects on post-harvest soil mineral N, P, K and Na contents (mg kg^{-1})

Treatments	Application rates*	Mineral N		Bray-1 P	Exchangeable	
		NH_4^+	NO_3^-		K	Na
C10FM	5	1.21b	0.67b	2.62fg	38lmn	12hijk
	10	1.31b	0.71b	2.45fg	62klmn	16ghij
	20	0.88b	0.54b	7.04cde	96ijklm	18fghi
	40	1.38b	0.74b	1.86fg	164efghi	22defg
	80	1.05b	0.87b	3.98efg	297cd	35ab
C25FM	5	0.95b	0.62b	3.20fg	47klmn	12hijk
	10	1.01b	0.63b	4.85def	92ijklmn	15ghij
	20	1.13b	0.85b	2.15fg	117ghijk	16ghij
	40	1.01b	0.74b	4.92def	195ef	27bcd
	80	1.18b	1.07b	4.91def	319c	34ab
C50FM	5	0.86b	0.36b	0.76g	48klmn	10ijk
	10	0.82b	0.62b	2.21fg	112hijkl	15ghij
	20	1.06b	0.54b	2.31fg	146fghij	19efgh
	40	1.02b	0.76b	4.04efg	189efg	22defg
	80	0.95b	0.56b	7.88cd	413b	33abc
C75FM	5	1.42b	0.59b	3.16fg	52klmn	11hijk
	10	1.33b	0.58b	1.89fg	83jklmn	13hij
	20	0.81b	0.90b	3.62efg	183efgh	26cdef
	40	1.06b	0.96b	8.35c	279cd	26cde
	80	1.48b	1.93b	14.39b	500a	36a
C100FM	5	1.08b	0.46b	1.36fg	54klmn	9jk
	10	1.20b	0.74b	3.95efg	101ijklm	15ghij
	20	0.97b	0.60b	3.19fg	150fghij	17ghij
	40	0.97b	0.83b	7.77cd	229de	19defgh
	80	1.17b	1.51b	17.54a	413b	27bcd
NPK fertiliser	100-60-40	31.98a	45.18a	17.14ab	16n	5k
Control	0	2.68b	0.38b	1.65fg	24mn	10ijk

*Means with the same letter(s) in the same column are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range Test; *Rates of composts and NPK are in t ha^{-1} and kg ha^{-1}, respectively; C10FM, C25FM, C50FM, C75FM and C100FM connote compost with 10%, 25%, 50%, 75% and 100% filter materials, respectively*

Table 20. Compost type x application rate interaction effects on extractable micronutrients contents (mg kg^{-1}) of post-harvest soil samples

Treatments	Application rates*	Extractable micronutrients			
		Fe	Cu	Zn	Mn
C10FM	5	10ab	0.43abcde	0.64ghij	8.57efghi
	10	13a	0.52ab	0.73fghij	10.36cdefgh
	20	10ab	0.45abcde	0.90defg	9.75cdefgh
	40	10ab	0.43abcde	0.93def	10.75cdefgh
	80	10ab	0.37cde	1.30ab	11.31cdefg
C25FM	5	12a	0.52ab	0.60hij	8.98cdefghi
	10	10ab	0.43abcde	0.70fghij	9.57cdefgh
	20	8b	0.36de	0.74efghij	7.99ghi
	40	11ab	0.44abcde	1.01cd	12.22bcd
	80	9ab	0.37cde	1.51a	12.36bc
C50FM	5	9ab	0.38bcde	0.60hij	7.67hi
	10	10ab	0.40abcde	0.69fghij	10.44cdefgh
	20	9ab	0.41abcde	0.64ghij	10.06cdefgh
	40	8b	0.35e	0.81defgh	10.38cdefgh
	80	8b	0.37cde	1.44a	15.0b
C75FM	5	8b	0.36de	0.51ij	7.49hi
	10	11ab	0.48abcde	0.55hij	10.65cdefgh
	20	13a	0.50abcd	0.81defgh	12.18bcd
	40	11ab	0.45abcde	0.92def	15.0b
	80	13a	0.47abcde	1.18bc	18.50a
C100FM	5	10ab	0.40abcde	0.48j	8.80defghi
	10	11ab	0.53a	0.75efghi	12.16bcd
	20	10ab	0.43abcde	0.66ghij	11.54cdef
	40	10ab	0.45abcde	0.87defg	11.96bcde
	80	10ab	0.42abcde	0.99cde	15.0b
NPK fertiliser	100-60-40	11ab	0.40abcde	1.17bc	5.98i
Control	0	12ab	0.51abc	0.59hij	8.32fghi

*Means with the same letter(s) in the same column are not significantly different at P ≤ 0.05 according to Duncan's Multiple Range Test; *Rates of composts and NPK are in t ha^{-1} and kg ha^{-1}, respectively; C10FM, C25FM, C50FM, C75FM and C100FM connote compost with 10%, 25%, 50%, 75% and 100% filter materials, respectively*

CHAPTER 5
DISCUSSION

5.1 Characterization of winery solid waste materials and the composts

The pH (KCl) values of C75FM and C100FM composts were relatively high relative to the optimum value defined by Allen and Kariuki (2014) and may be potentially harmful to plants (Woods End Research Laboratory, 2005). Application of these composts should be done with care such as establishing the optimum rates that can maintain the soil pH (H_2O) level within the range of 6.0 to 7.0, so as to promote optimum nutrient uptake by plants (Resh, 2012). For instance, application of these composts on alkaline soils may exert adverse effect while under acidic soils, it may help to increase pH and consequently reduce aluminium toxicities and enhance nutrient availability (Basri *et al.,* 2013).

The ideal EC value of composts is reported to range between 1 and 10 dS/m (US Composting Council, 2010). Salinity problems may be expected following application of these composts on agricultural soils because of their much higher EC values. The higher EC values reported in these composts may be attributed to the presence of a larger amount of soluble salts, possibly from the degradation of organic materials (Shyamala and Belagali, 2012). Such high EC values had been reported to exert deleterious effects on the plants and seed germination (Woods End Research Laboratory, 2005). The high Na levels in the winery solid waste materials possibly originated from the contribution of Na containing cleaning detergent used in the wineries. Thus, repeated application of Na-rich composts may trigger sodicity problems in soils. However, Leaon (1995) reported that when such composts with high EC values are used as soil amendment, the desired ranges may not apply because of the diluting effect of mixing the compost with soil.

The high carbon content of the winery solid wastes and the resulting composts suggests that they could be used as C and energy sources for soil micro-organisms. This may enhance soil microbial growth and activity, and consequently increasing the availability of nutrients to plants (Malik *et al.,* 2013). The typical reported values of the total N content in compost may vary between 1.0% and 1.5% (Paulin and O’Malley, 2008). The

C10FM, C50FM and C75FM had total N contents higher than 1.5%. The C:N ratios of the composts varied from 6.5 (C50FM) to 13.8 (C25FM). The winery solid waste composts are expected to increase the plant available N due to possible enhanced N mineralisation in view of the low C:N ratios (Bruce, 2011; Fertiliser Society of South Africa, 2007).

Potassium is an essential macronutrient and it is found in higher levels in grape marc composts (Patti *et al.,* 2004). The total K contents of waste perlite and a mixture of grape skins and seeds were higher than those of resulting composts while the total K content of waste DE was higher than that of C10FM and C25FM composts. Therefore, the composting process reduced the total K content. Potassium is highly soluble, and consequently, it may have leached during the composting process (Mangan *et al.,* 2014). When the soil Ca:Mg ratio is less than 2, it is more difficult for plants to take up K and the soil structure may be broken down due to dispersion of the soil particles (Reid and Dirou, 2004). The Ca:Mg ratios of the composts were very high, therefore, the application of these composts may improve the Ca:Mg ratio of the soil and consequently the plant K uptake and soil structure. The Fe level of composts was high and could be attributed to the high levels of Fe in the waste material.

5.2 Laboratory incubation study of winery solid waste composts

Significant increases in mineralisation of NH_4-N following application of all composts, except C75FM, showed that these composts could be sources of N to agricultural soils. Mineralised K significantly increased in the order C100FM > C75FM > C50FM > C25FM > C10FM > control. This shows the effect of varying composts with the percent content of waste filter material. Significant increase in released K following application of these composts shows that these composts may be better K sources. The use of organic amendments such as these composts may be a possible alternative source of N and K to inorganic chemical fertilisers. This may be beneficial to resource-poor farmers who cannot afford the use of inorganic fertilisers due to their high costs and low accessibility (Odhiambo and Magandini, 2008; Farhad *et al.,* 2011; Kutu, 2012). The organic amendments have also been reported to improve soil physical structure and soil health (Sarwar *et al.,* 2008; Farhad *et al.,* 2011). Potassium is the third macronutrient required by plants, after N and P (Abbas *et al.,* 2011) and K is responsible for regulating the cell osmotic potential, translocating sugars and forming starch (Boh *et al.,* 2013). The use of these composts will help in supplying N and K to soils; and these nutrients together with P and water are considered as the major limiting factors in crop growth, development and yield (Delwar *et al.,* 2010).

5.3 Greenhouse evaluation of maize performance and changes in chemical properties of soil following application of winery solid waste composts

5.3.1 Maize dry matter yield, number of functional leaves per plant, stem diameter and plant height

The maize dry matter yield was improved by the application of winery solid waste composts. The increase in dry matter yield may be due to the beneficial effects of composts in supplying plant nutrients, improving cation exchange capacity and water retention (Peng *et al.,* 2013). Increasing the cation exchange capacity helps in improving the retention of plant nutrients within the rooting zone (Singh and Agrawal, 2008). The increase in maize dry matter yield following the application of winery solid waste composts is attributed to the increase in nutrient availability to the plants (Nguyen *et al.,* 2012). Generally, a trend of increasing dry matter yield with increasing rate of composts applied was observed, except for C25FM treatment. This is in line with the findings of Kokkora (2008), who showed that forage maize dry matter yield increased with increase of onion compost application rate. In this study, the trend for increased dry matter yield with increasing compost application rate may be attributed to decreased growth limiting factors, such as low nutrient availability, with increasing compost application rate. The regression analysis showed that the C100FM gave optimum dry matter yield at a rate of 522 g pot^{-1}, and this could make C100FM a better compost than composts with 25%, 50% and 75% FM which gave optimum dry matter yield at very high application rates. Therefore, the production and use of C100FM could be advantageous in promoting maize dry matter production and as a way of eliminating more waste filter materials.

The finding that the application of C50FM, C75FM and C100FM at 80 t ha^{-1} significantly increased dry matter yield and the number of functional leaves per plant than the NPK fertiliser treatment indicated a better growth performance of maize with those composts than with the NPK fertiliser treatment. This may indicate the increased N, P and K availability for crop uptake from those composts treatments. Sarker *et al.* (2012) also observed a better growth performance of radish with the highest rate of compost than with the NPK fertiliser. The increase in stem diameter indicated improved growth of maize plants after the addition of winery solid waste composts to the soil. The study by Lima *et al.* (2004) also showed an increase in stem diameter of maize plants following application of organic waste compost. Generally, composts application improved dry matter yield, stem diameter and plant height in the order C100FM > C75FM > C50FM > C25FM > C10FM > control. This clearly shows that the higher the percent content of FM in composts the higher the agronomic potential of these composts. Studies by Lima *et al.* (2004) and Jackson *et al.* (2013) have also shown increase in maize plant height following compost application.

5.3.2 Shoot N, P, K and Na contents and uptake

The significant increase in shoot N content following the application of composts with ≥ 75% FM with reference to the un-fertilised control could be attributed to increased availability of N after the addition of these composts. The treatments did not exceed the average critical nutritional tissue standard for N of 4% (Arakaki, 2008). The application of composts with ≥ 50% FM at a rate of 80 t ha^{-1} gave significantly higher shoot N uptake than the NPK fertiliser treatment. This shows a better supply of N in the soil from those composts treatments. In general, shoot N uptake increased with the increase of compost application rates except for the application of C25FM. This indicates higher availability of N to plants with higher composts application rates, which may be due to increased organic matter (Aziz *et al.,* 2010; Palm *et al.,* 2001).

All composts applied at a rate of 80 t ha^{-1}, except C25FM, gave significantly higher shoot P content than the NPK fertiliser treatment. This indicates higher availability of soil P from those composts treatments than the NPK fertiliser treatment. Composts with ≥ 50% FM induced significantly higher shoot P content than those with ≤ 25% FM. This indicates higher availability of P from composts with ≥ 50% FM than those with ≤ 25% FM. There were no treatments that exceeded the average critical nutritional tissue standard for P of 0.4% (Arakaki, 2008). The increase in shoot P content and uptake following the application of winery solid waste composts could be attributed to increased P availability in the soil (Aziz *et al.,* 2010).

The K content of shoot from composts treatments exceeded the average critical nutritional tissue standard for K of 3.3% (Arakaki, 2008), indicating that these composts are excellent sources of K for maize plant growth. The increase in shoot K content by compost types was between 23% (C10FM) and 38% (C100FM) over the un-fertilised control. Shoot K uptake increased with increasing compost application rates, except in the C25FM treatment; and this may be due to increased levels of K in the soil with increasing compost application rate. Wakeel *et al.* (2005) have also reported increases in total K uptake by maize plants with increasing K levels of soils low in clay contents. The compost types had no significant effect on shoot Na content and uptake in comparison with the un-fertilised control. This may be due to the high availability of K in the soil following the application of composts, which caused maize plants to take up more K, thereby reducing the Na uptake. Subbarao *et al.* (2003) reported that K and Na compete for absorption sites in the root.

5.3.3 Shoot Fe, Cu, Zn and Mn contents and uptake

The shoot Fe content was decreased by the application of compost types. The decreases in shoot Fe contents may be due to decreased plant available Fe in the soil which could be as a result of high soil pH (Schulte, 1992). The treatments did not exceed the average critical nutritional tissue standard for Fe of 175 mg kg^{-1} (Arakaki, 2008). Only compost types with ≥ 75% FM caused positive effects on shoot Cu uptake when compared to the un-fertilised control, although the effects were not significant. No treatment exceeded the average critical nutritional tissue standard for Cu of 4 mg kg^{-1} (Arakaki, 2008). The results showed that 40 and 80 t ha^{-1} of both C75FM and C100FM as well as 80 t ha^{-1} of C50FM were sufficient to increase shoot Cu uptake with reference to the un-fertilised control.

Zinc is an essential plant micronutrient and is an important catalytic component of several enzymes (Fageria, 2010). Shoot Zn content and uptake were increased following application of compost types despite the high soil pH. High soil pH reduces Zn availability and hence its uptake by crops (Hafeez *et al.,* 2013). The increase in shoot

Zn content and uptake regardless of the high soil pH may be due to the high content of Zn in the composts. The Zn content of shoot from C10FM, C25FM and C50FM treatments exceeded the critical level of 15 mg kg^{-1} (Arakaki, 2008). This suggested that these composts could be good sources of Zn to maize, which requires relatively high amounts of Zn (Bundy, 1998). The general increase in Zn uptake by maize plants with increasing compost application rates could be attributed to the increase in the organic matter content of the soil (Mousavi, 2011) with higher compost application rate. The treatments did not exceed the average critical nutritional tissue standard for Mn of 166 mg kg^{-1} (Arakaki, 2008).

5.3.4 Soil pH and EC

The non-significant effects of the winery solid waste composts on soil pH indicates that the high pH level of winery solid waste composts does not have an effect on soil pH when these composts are used as a soil amendment. The NPK fertiliser treatment decreased the soil pH by 7.99% in comparison with the un-fertilised control. The decrease in soil pH following application of NPK fertiliser could be attributed to the acidifying effect of inorganic fertiliser (Wang *et al.,* 2010). The application of winery solid waste composts did not increase soil EC to an extent where soil salt content could have an adverse effect on crop growth (Fertiliser Society of South Africa, 2007).

5.3.5 Post-harvest soil mineral N, P, K, Zn, Mn and Fe contents

The fact that the compost types differed non-significantly from each other in their effects on soil NO_3-N content proved that variation of composts with the percent content of filter materials had no effect on the release of NO_3-N into the soil. The increase in soil available P content following application of C25FM, C75FM and C100FM showed that these composts may be of agronomic use in supplying P to crops. The C75FM and C100FM proved to be the best composts in improving soil available P. The fact that the compost types gave higher residual soil K content than the un-fertilised control and NPK fertiliser treatments suggests that these composts are good sources of K. The increases in soil K content following application of winery solid waste composts could be attributed to their high K level. In general, the post-harvest soil K content showed a trend of increasing with increases in application rates of the composts. The significant increases in soil Zn and Mn suggested that the winery solid waste composts could be beneficial in supplying Zn and Mn to sandy soils. Sandy soils inherently have low total Zn levels (Schulte, 2004); therefore, the winery solid waste composts could be cheaper and more environmentally friendly alternative sources of Zn to inorganic fertilisers. The decrease in soil Fe content after the addition of winery solid waste composts proved that the high level of Fe in these composts did not have detrimental effects on crops.

CHAPTER 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The increase in wine production in South Africa has led to massive production of winery solid waste. This study aimed to contribute significantly to address the winery solid waste disposal problems through compost production and also provide a value-added product for increasing crop production in sandy soils. The winery solid waste materials consisting of a mixture of perlite and diatomaceous earth collectively described as wine filter materials (FM), grape marc (berry stalks, skins and seeds) and chopped grapevine pruning materials were composted through a thermophilic process. The mix rates of FM were 10%, 25%, 50%, 75% and 100% per compost heap which lead to the production of five composts herein designated as C10FM, C25FM, C50FM, C75FM and C100FM, respectively. After curing, the composts were subjected to detailed chemical analysis.

A laboratory incubation study was conducted for a period of 42 days to determine the nutrient release characteristics of the winery solid waste composts. Sandy and sandy loam soils were used. Each of the five composts was mixed in plastic pots with 1.2 kg of each of the two soils. A control of each of the soil types was included. Composts were applied at a calculated rate of 200 kg N ha^{-1}. Soil samples were collected 7, 14, 21, 28, 35 and 42 days after incubation had started and analysed for NO_3-N, NH_4-N, P and K. Results revealed that the compost types differed non-significantly in the amount of released NH_4-N with each other; and were significantly higher in released NH_4-N than the control except for C75FM. Of all the composts, only C100FM significantly released more NO_3-N than the control. The mean amount of P mineralised from the different composts did not differ significantly. Mineralised K significantly increased in the order C100FM > C75FM > C50FM > C25FM > C10FM > control. The effects of the interaction between compost type and days after incubation were significant only on the release of NH_4-N and K. The NH_4-N and K release was significantly influenced by the interaction between compost type and soil type. The interaction between soil type and days after incubation exerted significant effect only on the release of NH_4-N.

A pot experiment was conducted in a greenhouse for a period of 63 days to assess the effects of composts on maize performance and on soil chemical characteristics. The treatments comprised of five application rates (5, 10, 20, 40 and 80 t ha^{-1}) of five winery solid waste composts, NPK fertiliser and a single un-fertilised control. The pots were arranged in a completely randomized design, with each treatment replicated four times. Maize cv. SNK2147 was used as a test crop. The data on maize growth and yield were recorded at harvest of shoots. Total shoot contents and uptake of N, P, K, Na, Fe, Cu, Mn, Zn and B were determined. The post-harvest soil samples were also collected and analysed for selected soil chemical properties. Results showed that composts with ≥ 50% FM applied at 80 t ha^{-1} significantly increased dry matter yield than the NPK fertiliser treatment. The compost types significantly increased dry matter yield, plant height, stem diameter and number of functional leaves per plant relative to un-fertilised control.

The C75FM and C100FM treatments significantly increased shoot N content relative to the un-fertilised control. Shoot P content was significantly increased by application of composts compared to the un-fertilised control. The K content of shoot from composts treatments exceeded the critical nutritional level. Plant tissue Zn content from C10FM, C25FM and C50FM treatments exceeded the critical nutritional level. The differences in shoot Fe, Cu, Zn and Mn contents among the various compost types were not significant. The effects of compost type on the uptake of N, P, K, Na, Fe, Cu, Zn, Mn and B were not significant relative to the un-fertilised control. The application of the different compost types had no significant effects on soil organic carbon and pH while NPK fertiliser treatment exerted a significant effect on soil EC relative to the un-fertilised control. The compost types decreased soil NH_4-N non-significantly relative to the un-fertilised control but significantly compared to the NPK fertiliser treatment.

Compared to the un-fertilised control, the application of C25FM, C75FM and C100FM significantly increased the soil available P content. Generally, soil K and Na contents increased with the increasing compost application rate. The effects of compost type and application rate interaction on soil Fe content were not significant. Soil Zn and Mn contents were significantly increased by the application of composts compared to the un-fertilised control. In conclusion, the incubation study showed that these composts may be of agronomic importance in supplying N and K to soils. Application of these composts exerted beneficial effects on maize performance and soil. The C100FM proved to be a better compost for the production of maize dry matter. Field experiments under variable conditions are recommended for confirmation of these findings.

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APPENDICES

Appendix 1. Mean squares for ANOVA table for amount of NH_4-N, NO_3-N, P and K released from incubated winery solid waste composts

Source of variance	DF	NH_4-N	NO_3-N	P	K
Compost type (CT)	5	18341***	1798.3***	3.2284^{ns}	1134520***
CT x DAI interaction	25	14601***	485.1^{ns}	0.8064^{ns}	6400***
CT x ST interaction	5	17130***	212.2^{ns}	3.7459^{ns}	16160***
DAI x ST interaction	5	20173***	835.1^{ns}	1.4039^{ns}	1050^{ns}

*ns = non-significant; ***significant at $P \leq 0.05$*

Appendix 2. Summary of ANOVA table for data on selected maize growth parameters, dry matter yield and total nutrients contents in plant shoot from the greenhouse study

Source of variance	No. of functional leaves per plant	Plant height	Dry matter yield	Stem diameter	N	P	K	Na	Fe	Cu	Zn	Mn	B
Compost type	13.63*	1640.29*	153*	0.27*	0.06*	0.006*	6.30*	28759^{ns}	394^{ns}	0.63^{ns}	103*	92*	11.30*
Compost type x rate interaction	8.66*	745*	202*	0.18*	0.06*	0.009*	2.92*	20722^{ns}	650^{ns}	0.79^{ns}	131*	63*	8.31*
Replication	1.32^{ns}	1149.14*	63*	0.06*	0.14*	0.003*	2.53*	12761^{ns}	6295*	8.05*	13.19	26^{ns}	41.20*
Error	0.84	95.06	5.55	0.01	0.006	0.0004	0.13	21880	552	0.7	15.42	30	3.49

*ns = non-significant; *significant at* $P \leq 0.05$

Appendix 3. Summary of ANOVA table for data on nutrients uptake

Source of variance	N	K	P	Na	Fe	Cu	Zn	Mn	B
Compost type	135*	4550*	10.86*	21.53*	1.33*	0.0016*	0.04^{ns}	0.16*	0.02*
Compost type x rate interaction	171*	6661*	16.29*	32.70*	1.28*	0.001*	0.12*	0.24*	0.03*
Replication	1.15^{ns}	292*	1.09*	6.95*	0.17^{ns}	0.002*	0.02*	0.07*	0.01*

*ns = non-significant; *significant at P ≤ 0.05*

Appendix 4. Summary of ANOVA table for soil analysis data from the greenhouse study

Source of variance	pH	OC	EC	NH_4-N	NO_3-N	P	K	Na	Fe	Cu	Zn	Mn
Compost type	0.85*	0.07^{ns}	0.0001*	611.96*	1266.87*	139.18*	44960.67*	259.93*	12.48*	0.01^{ns}	0.17^{ns}	38.92*
Compost type x rate interaction	0.54^{ns}	0.06^{ns}	0.0001*	141.31*	292.68*	82.39*	68199.81*	298.40*	8.57^{ns}	0.01^{ns}	0.30^{ns}	30.23*
Replication	0.19^{ns}	0.03^{ns}	0.0005*	21.28*	4.03^{ns}	1.64^{ns}	7295.86*	51.29^{ns}	17.81^{ns}	0.01^{ns}	0.14*	27.15*
Error	0.35	0.06	0.0022	3.24	2.19	4.49	2111.13	25.4	5.51	0.007	0.02	4.15

*ns = non-significant; *significant at $P \le 0.05$*