# EFFECT OF INORGANIC AND ORGANIC FERTILIZERS ON THE YIELD, FRUIT QUALITY AND SOIL FERTILITY OF LATE VALENCIA (*Citrus sinensis (L.) Osbeck*).

**BY**

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# DECLARATION

I hereby declare that, with the exception of other works properly cited and acknowledged, this work was submitted as a thesis to the Department of Crop Science, School of Agriculture, College of Basic and Applied Sciences, University of Ghana, Legon, for the award of Master of Philosophy in Crop Science degree, is the result of my own research and this Thesis has not been presented for a degree anywhere, either in part, or in whole.

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# ABSTRACT

An experiment to determine the effect of inorganic and organic fertilizers on the yield, fruit quality and soil fertility of Late Valencia (*Citrus sinensi* (L.) Osbeck) was carried out at the Forest and Horticultural Crops Research Centre, Kade in the semi-deciduous forest agro-ecological zone on a 13year old citrus orchard. The experiment was conducted in a randomized complete block design with four replications. The experiment consisted of six treatments: (I) 9 t/ha Oil palm empty fruit bunches (EFB); (II) 4t/ha poultry manure (PM); (III) inorganic fertilizer (N, P, K and Zn) applied at the rate of 90kg/ha N, 60kg/ha P, 80kg/ha K and 4.80kg/ha Zn (IV) 4.5 t/ha EFB plus 45kg/ha N, 30kg/ha P, 40kg/ha K and 2.40kg/ha Zn; (V) 2t/ha PM plus 45kg/ha N, 30kg/ha P, 40kg/ha K and 2.40kg/ha Zn; (VI) Control. The results indicated that there were significant differences in fruit yield between the treatments. The treatment PM+NPKZn recorded the highest yield of 14.71t/ha with the Control recording the least (6.37t/ha). Fertilizer application did not significantly affect any of the fruit quality parameters studied, nor the level of nutrients (N, P, K, Ca and Mg) in the leaves 253 days after fertilizer application. However, leaf N and K levels were generally higher 253 days after fertilizer application over the initial levels although P levels did not change. Leaf N and P content significantly correlated with fruit quality parameters such as fruit size, juice content, juice volume and TSS indicating the importance of these nutrients in promoting improved fruit quality in citrus. Leaf K level however negatively influenced all the fruit quality parameters (fruit size, juice content, juice volume and TSS) except TA. Leaf Ca content positively correlated with fruit size (r= 0.54), juice volume (r= 0.26), total soluble solutes (r= 0.29) and TSS:TA (r= 0.46) but negatively correlated with TA (r= -0.28). Both juice content and volume were significantly influenced by soil total N and soil available P suggesting the importance of these nutrients in improving citrus juice quality. Soil analysis 253 days after nutrient application showed an increase in some soil chemical properties such as Total N, OC and available P while pH level decreased. The study suggests the need for farmers to adopt integrated soil fertility management practices to improve the yield and fruit quality of citrus while maintaining soil fertility of citrus orchards.

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# DEDICATION

This work is dedicated to the late Larissa Seyra Xhasa Ziddah my course mate who passed on during the MPhil program. Thank you very much and you will always be remembered by me.

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| | |
|---|---|
| AILAP | Agricultural Improvement and Land Access Program |
| ANOVA | Analysis of variance |
| B | Boron |
| Ca | Calcium |
| $Ca(NO_3)_2$ | Calcium Nitrate |
| CEC | Cation Exchange Capacity |
| CIGMAG | Citrus Growers and Marketing Association of Ghana |
| CPH | Cocoa Pod Husk |
| DARSA | Department of Agriculture of Republic of South Africa |
| EFB | Oil palm Empty Fruit Bunch |
| Fe | Iron |
| FOHCREC | Forest and Horticultural Crops Research Centre |
| FYM | Farm Yard Manure |
| GEPC | Ghana Export Promotion Council |
| ha | Hectre |
| K | Potassium |
| kg $ha_{-1}$ | Kilogram per hectre |
| $KNO_3$ | Potassium Nitrate |
| LSD | Least Significant Difference |
| Mg | Magnesium |
| Mn | Manganese |
| MoFA | Ministry of food and agriculture |
| MT | Metric tons |
| N | Nitrogen |

| | |
|---|---|
| NPK | Nitrogen Phosphorus Potassium |
| NRC | National Research Council |
| OC | Organic carbon |
| OM | Organic matter |
| P | Phosphorous |
| PM | Poultry Manure |
| TA | Titratable acid |
| t $ha_{-1}$ | Tons per hectre |
| mg $dm_{-3}$ | Milligram per cubic decimeter |
| TSS | Total Soluble Solids |
| Um | Micrometer |
| Zn | Zinc |
| $ZnSO_4$ | Zinc Sulphate |

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# CHAPTER ONE

## INTRODUCTION

Citrus is a genus of flowering plants in the Rutaceae family; it is the most economically important genus of this family. This genus includes species such as limes, lemons, citrons, pomelos and mandarins (New World Encyclopedia, 2008). Citrus are evergreen trees that grow to a height of 183-914cm depending on the variety and rootstock selected. Most varieties are self-pollinated (Lazaneo, 2008).

Citrus grows on a wide range of soils but perform well on soils with good drainage, good fertility and good aeration; soils with pH between 6 - 6.5 are ideal (DARSA, 2009). Orange production accounts for over 50% of the world citrus production with consumption growing at a rate of 3.5% over the past thirty years. Within the same period production and exportation of processed orange products have increased by 4.4% (Sawe, 2017).

In Ghana, citrus is grown mostly by smallholders in the forest regions mainly in the Eastern, Ashanti and Central regions where rainfall amounts exceed 1000mm and is distributed in a bimodal fashion (Ofosu-Budu *et al.*, 2007). The crop serves as income for farmers in these regions thereby contributing to reduction of rural poverty. Close to 90% of the total yearly production is consumed fresh while about 10% is processed into juice and sometimes concentrate for the local market. The nation also exports orange juice to the European markets (GEPC, 2006). In the year 2010, 10,729 metric tons of fresh orange fruits were exported, generating foreign exchange of US$ 654,000 for the country (MoFA, 2011). In 2016, total production reached 690,130 tons which proportionally generated higher foreign exchange for the country (FAOSTAT, 2016).

In West Africa, Ghana and Nigeria together produce 91.13% of about 891,535MT of citrus produced in the region contributing significantly to vitamin C, minerals and dietary fibre requirement for over 250 million peoples in the sub region (FAOSTAT, 2010).

The most widely grown citrus crop in Ghana is the sweet orange especially the Late Valencia cultivar. The late Valencia fruit is succulent and juicy, with a is yellow rind when ripe. The fruits are medium to large in size and have thin rinds (Maurer and Bradley, 1998). There has been significant increase in the cultivation of citrus in terms of acreage in the past decade in the country most of which is concentrated in the Ashanti, Eastern, Brong Ahafo, Western and Volta Regions of Ghana (Asare-Bediako *et al*., 2013). Based on maturity times, we have the following orange varieties in Ghana: Early maturing (August – October) Ovaletto, Sikkan; Mid-season (October – January) Obuasi, Mediterranean sweet and Red Blood; Late maturing (March – April) Late Valencia, Olando and Frost Valencia (AILAP, 2006). The rootstock determines various factors in the plant's life ranging from maturity to disease resistance. Rangpour lime as a root stock was promoted for the cultivation of sweet oranges in the forest region of Ghana because of its quick adaption to the soil (Ofosu-Budu *et al.*, 2007).

Currently the citrus industry has been plagued with some production constrains which have caused it to plummet along with its economic importance to communities which produce the crop and the country at large. Notable among the production constraints is low yields (Asare-Bediako *et al.*, 2013), caused by pests, disease and declining soil fertility. The decline in soil fertility due to continuous cultivation without soil replenishment in sub-Saharan Africa is a major cause of food insecurity and poverty; yields continue to decline on smallholder farmers' fields leading to loss of profit and income (Yeboah *et al.*, 2009). At the core of good yield of any crop is the state of the soil, and currently the Citrus Growers and Marketing Association of Ghana (CIGMAG), have observed low soil fertility in many fields (Brentu, 2016). It is important to ensure that the soil is properly maintained, to ensure fertility. Adoption of organic and inorganic soil fertility management approaches is considered as the most viable way of addressing the challenge of soil degradation (Agyekum, 2016).

Citrus serves as a major source of income for farmers. Even though it is not a food security crop, it is an important cash crop for some farmers in the forest zones of Ghana. Regardless of the importance of this crop to the economy of the country (Ghana), its decline in yield and fruit quality has received little attention. Continuous harvesting without replenishing soil nutrients, has led to soil nutrient mining, which has consequently resulted in low yields of citrus in Ghana (Ofosu-Budu, 1998). Poor soil fertility leads to many nutrient deficiencies which render the crop susceptible to diseases coupled with poor postharvest handling to reduce the quality of fruits. The poor returns of orange farmers make the venture unlucrative resulting in massive cutting of large areas of citrus plantations (Adofo, 2009). Thus, without addressing this problem of soil fertility, the country may end up importing oranges to meet market demand depriving those in the production chain of their livelihoods.

Application of mineral fertilizers to sweet orange significantly increases fruit yield (Ofosu-Budu, 1998). Use of local organic waste (manure), including cocoa pod husk (CPH), poultry manure (PM), empty fruit bunches (EFB) have also been found to increase yield of sweet oranges significantly (Ofosu, 2005). Thus, effective integration of these organic wastes into soil fertility management to improve the fertility of the soil at a very low cost is of significant benefit to citrus production (MOFA, 2005). The combination of mineral and organic fertilizer can help improve yield and fruit quality of oranges (Amankwa, 2005). However, these are avenues that have not been explored extensively to improve the productivity of citrus in Ghana. This study aimed to develop an integrated soil fertility management options to increase the productivity of citrus in Ghana. This experiment will lead to the creation of a local fertilizer module which CIGMAG can adopt to improve citrus production in Ghana.

## OBJECTIVES

The main objective of the study was to determine the effect of inorganic and organic fertilizer and their combination on yield and fruit quality of sweet orange.

### Specific objectives

- Determine the effect of organic and inorganic fertilizers on nutrient content of the leaves
- Determine the effect of organic and inorganic fertilizers on soil chemical properties
- Determine the effect of organic and inorganic fertilizers on the yield
- Determine the effects of organic and inorganic fertilizers on the fruit quality

# CHAPTER 2

## 2.0 LITERATURE REVIEW

### 2.1 Origin and spread of Citrus

Citrus fruits found today are believed to have come from four promiscuous ancestors; the citron, the pomelo, the pepeda and mandarin (Graber *et al.*, 2016). The origin of citrus spans through north-eastern India through the Malay Archipelago and south to Australia (Atta *et al.*, 2012). Currently the fruit is grown worldwide in tropical and sub-tropical regions commercially (Ehler, 2011). Sweet orange was grown for many years in China and reached an advanced stage of cultivation before it was introduced to Europe. The first member of the citrus family was introduced to Europe around 310 B.C (WHW, 2005).

Citrus was introduced into North Africa in the late 4th century as depicted in ancient art from wall paintings in the Egyptian temple at Karnak. Other suggestions perpetuate that the Jews were probably familiar with citrus when they were enslaved in Babylon during the 6th century BC (Malcom, 2006).

In America, Christopher Columbus is credited with introducing citrus seeds there on his second voyage in 1493, whiles another Spanish explorer Ponce de Leon was also known to have planted the first orange tree in Florida between 1513 and 1565 (NRC, 2010). In Brazil, citrus was introduced into the country by the first colonizers in the 16th century from which it spread to other South American countries (BACE, 2010).

Sir Thomas Herbert recorded in his book “Travels” the finding of oranges, lemons and limes on the island of Mozambique in the mid 1600’s (Malcom, 2006). In Ghana citrus production began with the introduction of the West Indian lime in 1913 when an orchard was established at Asuansi Agricultural Research Station (Ofosu-Budu *et al*, 2007). Citrus orchards are now widespread in the country and grow in the Eastern, Ashanti, central and some parts of the Volta region. Major categories of citrus cultivars are Mediterranean and Spanish oranges which are distinguished by fruit morphology and chemical constituents (Ehsani, 2007).

## 2.2 Sweet Oranges and Late Valencia variety

Important species of citrus include Late Valencia (*Citrus sinensis)* and Tangerine (*Citrus reticulata*). Others include Lemons (*Citrus limon*), Lime (*Citrus aurantifolia*), Tangors, Tangelos and Ortanique (AILAP, 2006). Sweet orange is the most grown citrus cultivar around the world. It originated from southern China and thrives in the tropical and semi-tropical regions (Ehler, 2011). Though, the origin of sweet orange is unknown, it is believed to have come from the hybridization of some primitive citrus species (Xu *et al.,* 2013). Sweet orange varieties include common oranges (Late Valencia being the most popular), Navel oranges (The Washington navel is the best known of them), Blood oranges (distinguished by their red coloration and a tart taste). The Valencia orange was named by an agronomist William Wolfkill, after the Spanish city of Valencia known for massive orange productions (Ehsani *et al*., 2007). Among the numerous varieties of sweet orange, the late Valencia is the most sought after by farmers and consumers probably due to its sweet taste and its wide range of climatic tolerance (Alhassan, 2013).

## 2.3 The botany of the Citrus plant

Citrus is a long-lived perennial evergreen tree with a lifespan of about 50 years (Nicolosi *et al.,* 2000). Most leaves of cultivated citrus have petioles that are winged or not and a single terminal leaflet. Leaves of many citrus plants are compound (ranging from trifoliate to palmately and pinnately compound) and are described as unifoliate (Citrus ID, 2011).

The flowers are in small corymbs with each flower is 2 - 4 cm in diameter, with five (sometimes four) white petals which possess many stamens and are often very strongly scented (New World Encyclopedia, 2008). The tree bears white flowers singly or in whorls of 6 which are 5 cm wide, it has 5 petals and about 20-25 yellow stamens. The flower is a hermaphrodite (possesses both male and female parts) which produces nectar for insect pollination (Etebu *et al.*, 2014).

The fruit of sweet orange is a specialized berry and is oval or round; diameter ranges from 5.7 - 9.5 cm, greenish yellow to orange in color. The internal part of the fruit is fleshy, and it is divided into 10 – 16 segments surrounded by a separable rind (Katz and Weaver, 2003). The features of an orange include: pericap composed of the epidermis; epicarp, a layer of tissue containing plastids which are dark green when immature, and oil glands dispersed throughout; mesocarp, a white pulpy material surrounding the segments which hold the juice vesicles; and seeds arranged around the pulpy core. Citrus possesses tap roots which averagely grow 213.36cm - 365.76cm deep into the soil with majority of the roots clumped in the top 60.96cm of the soil. The width of an orange tree's roots extends well past the drip line with most of the roots concentrated under the tree's branches, lateral roots may extend 1219.2cm or more from an older tree (Jauaregui, 2018).

Fig.1 Late Valencia tree

Fig. 2 Citrus Leaf (Source: Citrus ID, 2011)

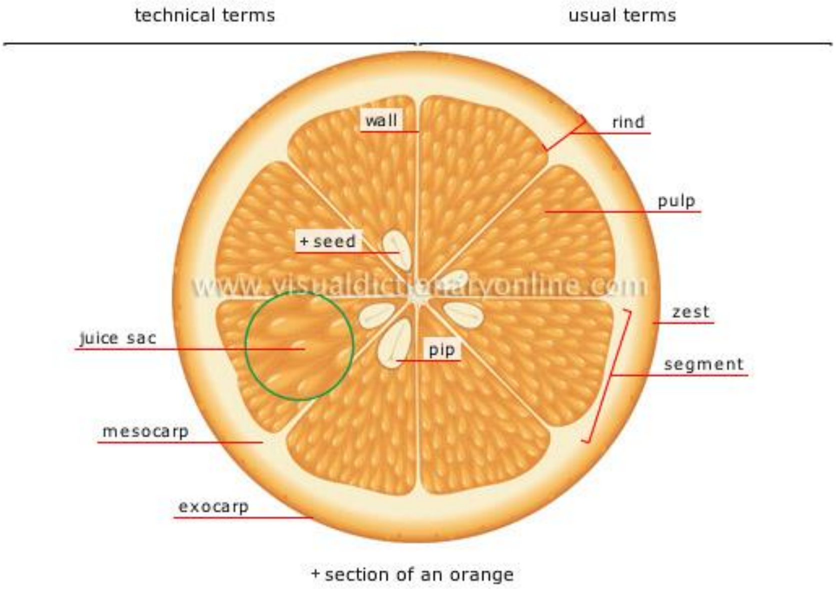

Fig. 3 Section of an orange (Source: www.visualdictionaryonline.com)

Fig.4 Citrus flower (Source: Zielinski, 2013)

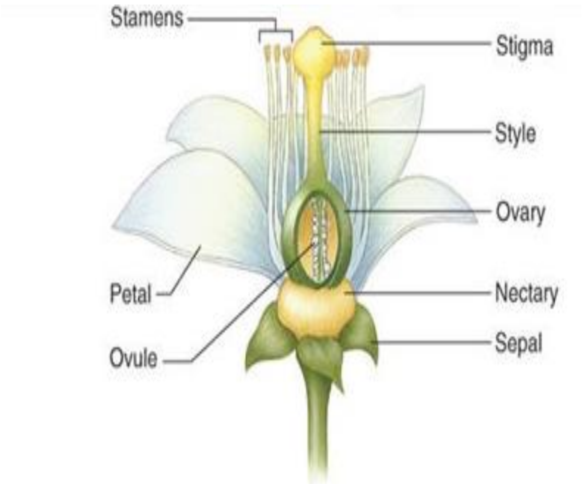

Fig.5 Labelled Flower
(Source: www.broadwaycomputers.us)

### 2.4 Climatic and soil requirements of citrus production

Citrus is cultivated in tropical, subtropical, semitropical and Mediterranean regions from latitude 40°N to latitude 40°S (Moore, 2001). Fruits grown in these regions are distinguished by time of maturity, juice content and fruit colour (most tropical oranges upon ripening still maintain some greenish colour and those in the sub-tropics and Mediterranean assume bright yellowish colour).

Temperature conditions are important to citrus production. A temperature range of $24_0$C and $38_0$C and relative humidity of around 85-90% in the morning and 60-80% in the afternoon is conducive for its cultivation (Ofosu-Budu, 2007). In the subtropics, it can grow between 12º-38º degrees Celsius during summer and 1º-10º C in winter (Perea, 2016).

Citrus requires above 1000 mm rainfall per year, anything below that may hamper the proper growth of the plant (MoFA, 2013). In Ghana it is cultivated under rain-fed conditions and is grown in parts of the country which can meet its water requirements naturally.

Citrus species can thrive in a wide range of soils from sandy soils to those with high level of clay. However, well-drained, medium-textured, deep and fertile soils with pH range of 5.5 to 6.6 are optimum for growing citrus. Waterlogged or saline soils are not suitable. Citrus root does not grow well in acidic soil and might lead to copper toxicity (Boakye, 2016). Growth and development of a plant is dependent on soil characteristics such as drainage, density, soil texture, water-holding capacity, structure, soil depth, erodibility, and the degree to which water can penetrate the soil (DARSA, 2009).

## 2.5 Nutritional requirements of oranges

Generally, plants require nutrients in their right proportion to function well and to produce good yield. Nutrients needed by plants in large quantities are macro nutrients (N, P, K, Ca, Mg, etc) whiles micronutrients (Zn, Mn, Fe, B, etc) are those required in small quantities. Macro nutrients needed by citrus include N, P and K. Yield and quality of fruits depend largely on N and K availability in the soil (Alva *et al*., 2006). Zn and Mn are important micro nutrients for citrus since there are notable deficiencies of it when the tree is deprived (Zekri *et al.*, 2018).

## 2.6 Macro nutrients

### 2.6. 1 Nitrogen (N)

In orange production, N is a major nutrient needed for tree growth and optimum yields as it affects fruit quality (Boakye, 2016). Essential supply of N is required in each plant cell for normal cell division, growth, and respiration (Zekri *et al.*, 2018). It is the main driver of growth at any stage in the tree's life which makes it indispensable. Deficiency symptoms include limited growth; yellowish pale green leaves in fruit bearing trees and shedding of fruits as well as leaves. Citrus Plants which lack nitrogen are also prone to pest and disease attack (Kahl, 2004). N functions well with the proper application of other nutrients like P and K. The imbalance of some nutrients may reduce the effects N may have on the function of the plant. Proteins are not synthesized though there can be abundance of available N when plants are deficient in K (Spectrum Analytic Inc., 2016). N is easily leached or lost in the soil, so most of the time it is applied in splits in citrus (Glozer *et al.*, 2007).

### 2.6.2 Phosphorous (P)

P is essential for proper functioning of cell energy systems and it is a structural component of the cells. P is immobile in soils because it forms insoluble compounds with metals such as Aluminum (Al) and Iron (Fe) and accumulate in mature orchards (Ofosu-Budu *et al.*, 2007). P is necessary for photosynthesis, breakdown of carbohydrates and the transfer of energy within the plant. It enables plants store and use energy from photosynthesis to form seeds, develop roots, grow and resist stresses. P enhances flowering, fruit formation and development of small rootlets (MoFA, 2013). P deficiency on growth include delay of maturity, reduction of forage quality and decreased disease resistance of plants (Osman, 2012). Other symptoms include excessive growth of weak immature wood of the citrus tree.

### 2.6.3 Potassium (K)

K is needed for physiological functions such as formation of sugars, synthesis of proteins, cell division and growth, and neutralization of organic acids. K plays an important role in the formation of fruits and improves flavour, colour and fruit size (Zekri *et al.*, 2018). Optimum levels of K increase crop yields and reduce production losses, increase drought resistance, activates enzyme systems, maintains turgor; decrease water loss, help in photosynthesis and food formation (Boakye, 2016). Deficiency symptoms include fruits remaining small, yellowing of leaf tips and margins, slow growth, small leaves, susceptibility to drought and cold, decrease in fruit size, premature shedding of fruit and reduction of acid concentration in the fruit (Glozer *et al.*, 2007). In the advance stage of K deprivation, leaves fall prematurely and the shoot dies; in addition, leaves thicken and pucker.

### 2.6.4 Magnesium (Mg)

Mg is important for plant growth and health, its deficiency is common in soils that are not rich in organic matter (Patterson *et al.*, 2018). Mg is most important for chlorophyll production. It is involved in photosynthesis, carbohydrate metabolism and synthesis of nucleic acids. It also affects movement of carbohydrate from the leaves to other organs of the plant and in addition stimulate P uptake and transport (Zekri *et al.*, 2018). In citrus production, applying Mg has been proven to significantly increase yield which is due to increase fruit weight (Yara, 2019). One of the main symptoms of Mg is chlorosis of the leaves; this is seen mainly on the margins and tips of old leaves. In severe cases, leaves fall early and the whole leaf blade may perish (FFTC, 2003).

### 2.6.5 Calcium (Ca)

Ca is a key component of plants cell walls and has influence on regulation of enzyme system, phytohormone activities and nutrient uptake (White *et al.*, 2003). Aside, it has been proven to increase yield in citrus; the nutrient has significant effect on reducing many fruit disorders (Yara, 2018). The deficiency of Ca is evident in new root tips, young leaves and shoot tips through distorted growth from improper cell wall formation (Buechel, 2018). Citrus fruits from Ca deprived trees tend to have higher rates of rot when in storage (FFTC, 2003).

## 2.7 Micro nutrient

### 2.7.1 Zinc (Zn)

Zn is a component of various enzymes responsible for driving many metabolic reactions in plants. It is essential for chlorophyll formation, water uptake and it regulates various plant metabolic activities (Zekri *et al.*, 2018). Zn is needed for synthesis of tryptophan, which is a requisite for auxin formation and other growth regulators (Pedler *et al.*, 2000). Provision of Zn in the soil increases fruit yield of citrus grown in highly weathered soils of the tropics (Hippler *et al.,* 2015). Zn deficiency is prevalent in intensively managed citrus orchards (Mattos, 2005). Deficiency symptoms include severe interveinal chlorosis, leaves become progressively smaller and internodes become shorter. Epstein (2005) indicated that the flowering and fruiting process were greatly reduced under severe zinc deficiency. Zn availability is dependent on pH; it is higher in acidic soils and very low in alkaline soils. Deficiency occurs rampantly on soils with alkaline or neutral pH that are sandy or have low organic matter content and usually high in available phosphorus (Nutrient Technologies, 2001).

### 2.7.2 Manganese (Mn)

Mn is an essential nutrient which plays key roles in several physiological processes, particularly photosynthesis. Its role in plants are very crucial. Processes dependent on Mn, include chloroplast formation, photosynthesis, nitrogen metabolism and synthesis of some enzymes (Patterson *et al.,* 2018). In citrus Mn can improve ascorbic acid content of the fruit which improves the fruit quality but its deficiencies are often associated with that of Zn and Fe (Yara, 2019). Deficiency effects result in stunted growth of the plant due to a reduction in its ability to photosynthesise; this tends to reduce crop yield.

## 2.8 Effect of inorganic fertilizers on yield and fruit quality

Inorganic fertilizers (also known as chemical or synthetic fertilizers) are plant nutrients artificially and chemically synthesized to provide the essential needs of plants, they include Ammonium nitrate, Ammonium sulphate, Potassium sulphate and Triple super phosphate (Maguire *et al*, 2009). Sweet orange productivity hinges on the management of nutrients available to the plant in the soil.

Ofosu-Budu (1998) observed significant increases in the yield as well as fruit quality when inorganic fertilizer was applied to a Late Valencia field. Application of 100 kg ha$^{-1}$ of N in the form of $Ca(NO_3)_2$ in early spring and foliar sprays of 8 kg ha$^{-1}$ N as $KNO_3$, increased yield of Lue Gim Gong Valencia orange than those of Campbell (Papadakis *et al.*, 2008)

In two long-term experiments on a citrus orchard at two different locations in Sao Paulo, Brazil, Quaggio *et al.* (2006) reported of positive response of sweet orange to N fertilization with the average fruit yield of Pera sweet orange being increased by 33% with an increase in N fertilization from 30 - 240 kg ha$^{-1}$. Yield of Valencia trees increased by 10% above 40 t ha$^{-1}$ across the same tested nutrient rates for Pêra sweet orange.

P is inherently low in tropical and subtropical soils with many plants showing glaring deficiencies of the nutrient (Mattos *et al.*, 2004). In an experiment carried out in two locations, Quaggio *et al.* (2006), observed no significant response to P in the location where the soil was high in P (45 mg dm$^{-3}$) at the 0–20 cm soil depth. In another location however, where soil P was low (9 mg dm$^{-3}$) at the same soil depth, fruit yield increased linearly with P fertilization.

K removal by fruits is equal to N exported by fruits and it is much greater than other nutrients (Alva *et al.*, 1999). In addition, excess K impairs the uptake of Ca and Mg which concurrently stifles the vegetative growth of trees and reduces fruit yield (Cantarella *et al.*, 1992). Quaggio *et al.* (2006), reported that Potassium affected fruit size of Late Valencia which increased with increasing K fertilization rates. Increase in fruit size and yield was reported in Florida with the application of 200 kg ha$^{-1}$ on grape fruit (*Citrus paradisi*) trees, the yield increased from 9 to 54kg per tree (Obreza, 2003). Under tropical conditions Hammami *et al.* (2010) applied 200 kg ha$^{-1}$ per year of K and obtained yields 43 t ha$^{-1}$ year$^{-1}$.

Hippler *et al.* (2015), found out that zinc supply increased yield of Citrus trees grown highly on weathered soils of the tropics due to its intrinsic low availability in the soil solution. Applying Zn fertilizer to the soil increased the nutrient's availability in the soil as well improved its uptake in the orange trees. Sandy loam showed the greatest response to $ZnSO_4$ when applied because of the lower specific metal adsorption compared to that of the clay soil. Citrus is a non-climateric fruit (it does not continue to ripe after harvest) so from inception of planting to harvest, effort has to be made by the farmer to ensure its fruit quality by providing the plant with the right nutrients and ensuring proper postharvest handling (Barry and Giovannoni, 2007). Nutrients that affect citrus fruit quality includes nitrogen, potassium, phosphorus, magnesium, copper and boron (Zekri *et al*., 2012). Reliable maturity and fruit quality parameters include juice content, total soluble solids (TSS), titratable acidity (TA) and the ratio of TSS to TA (Baldwin, 1993).

Koo (1979) observed that as N fertilizer application rate increased, the TSS of Pineapple sweet oranges and Late Valencia also increased. K and N uptake in the leaves also affect or influence fruit quality of citrus (Hammami *et al*., 2010). Similar. results were reported by Khan *et al.* (2011) with regards to 'Kinnow' tangerine. N with the combination of other nutrients led to the establishment of positive correlations between Valencia orange mineral composition and fresh fruit mass and TSS/TA ratio (Pestana *et al*, 2005). Aboutalebi (2013) noticed that larger N amounts produced smaller fruits with low TA. Almedia *et al.* (2002) also detected an increased TSS and TA in "Valencia" orange fruits, when they applied N fertilizers to the soil. P supply had consistent effects on fruit quality on orange varieties used in an experiment by Quaggio *et al.* (2006). Juice content and TA varied significantly with increased P rates. The increase in TSS per area was in relation to the nutrient availability in the soil. Obreza *et al.* (2008) also indicated that, excessive P application can cause the misuse of P and water pollution (eutrophication). High application of P could also lower rind thickness and TA while conversely increasing TSS/TA ratio (Ashkevari *et al*., 2013). Torres *et al*. (2009) noted that there was an increase and decrease in both TA and TSS:TA ratio respectively when foliar P rates were increased. This the authors found when investigating the relationship between macronutrients and the fruit quality of Late Valencia.

According to Zekri *et al.* (2012), TSS:TA ratio and juice colour decrease were observed for K in an experiment on irrigation, nutrition, and citrus fruit quality. K is very important in obtaining good fruit quality since the quality of the fruits are influenced by its availability in the soil (Quaggio *et al.*, 2011). Aular *et al*. (2010), however found out that high leaf K content related to reduction in fruit weight and juice percentage but found that it increased TSS/TA ratio. Almeida and Baumgartner (2002) evaluated K fertilization effects on the fruit quality of Late Valencia in Brazil and found effects of K on TA and TSS without defined trends. Hamza *et al.* (2012) found that the application of foliar K also increased fruit mass, size, colour, firmness and rind thickness.

Rodriguez *et al*. (2005), found that Zn application (13.3 g plant$_{-1}$) on orange trees increased fruit size. Godoy *et al.* (2013) however indicated that Zn and Mn stagnated fruit production. They further stated that the efficiency of Zn and Mn depends on the type of fertilizer used.

### 2.9 Effect of inorganic fertilizers on soil fertility and nutrient content

The basics of applying fertilizers to the soil is to improve the soil in order for it to support plant growth for quite a lengthy period of time. An indication of a good soil is its organic matter content which contributes to soil productivity in many different ways (Fenton *et al*., 2008).

In a study by Celik *et al.* (2010), the application NPK (inorganic fertilizers) on winter wheat and maize had no effect on the state of organic matter in the soils. Organic matter increased slightly with inorganic fertilizer application compared to the control. The increase of root biomass which in turn improved soil organic matter content was noticed by Rasool *et al.* (2007) when they applied inorganic fertilizers.

With an application of 60-40-40 kg ha$_{-1}$ NPK on a plot alongside the application of other forms of fertilizers on different plots, Quansah (2010), recorded higher residual nutrients from the inorganic fertilizer application field which sustained plant growth with good yield. Soil analysis carried out in the district of Sidhi, India, in determining the impact of Continuous use of Chemical Fertilizer after harvest revealed that increasing the levels of fertilizer application helped to increase organic carbon content (Dubey *et al.*, 2012). The research found out that continuous use of N fertilizer increases the available nitrogen status of soil, this was also in line with the findings of Singh *et al.* (2008) who observed that available N content in soil increased significantly with the use of recommended dose of fertilizer. They also observed that, without the use of fertilizer, there is a reduction in available N status due to removal of nutrients with continuous cropping. The findings of Parmar and Sharma (2002) as well as Dubey *et al.* 2012 show that additional application of NPK with the help of available organic carbon in the soil, help to increase P status of Soil.  P and Zn status also increased with the application of inorganic fertilizers (Dubey *et al.*, 2012). Ho Han *et al.* (2016) cautioned however that the long-term use of NPK results in deficiencies in some essential nutrients, which may destroy the physical and chemical properties of the soil.

Larcheveque *et al.* (2011) found that inorganic fertilizers promote growth and root development of plants compared to livestock organic manure. Neshev and Manolov (2016), observed that the application of K led to the increase of P levels in potatoes. The increase in P content was attributed to the synergistic effects of K and other micronutrients from the inorganic fertilizer. The balance between nutrients is very important (Papadakis *et al*., 2004). Foliar content fluctuations of N, P, K, Ca, Mg, Fe, Mn and Zn were evaluated on "Encore" tangerine fruit quality, and it was noted that the application of K had negative impacts on Mg, Ca and Mn. Thus, it can be deduced that excess K may delay Mg . Aular *et al*. (2010), reported that high leaf K content in Late Valencia trees negatively affected rind and juice percentage.

In an experiment where Diammonium phosphate (DAP) was used, N levels was increased by the inorganic fertilizer both in the long and short rain season, but the P levels was not affected (Ndayisaba, 2009). The amounts of N levels reported from this study were in the range reported to that of Gong *et al*. (2011) whose research included manure, inorganic N fertilizers and their combination. The authors found that even with the inclusion of NPK fertilizer N concentration was not affected in the stems and leaves but P tend to decrease in the roots as well as Mg in the leaves. These latter findings were in line with the research of Park *et al*. (2013).

## 2.10 Poultry manure (PM)

Poultry manure has long been recognized as perhaps the most desirable natural fertilizer because of its high nitrogen content. In addition, it supplies other essential plant nutrients and amends the soil through the addition of organic matter (Ahiahonu *et al*., 2011). It is a relatively cheaper source of both macro (N, P, K, Ca, Mg,) and micro (Cu, Fe, Mn, B) nutrients. Owing to its high organic matter content, PM improves soil tilt, increases water-holding capacity, reduces erosion, improves aeration, and promotes the habitation of beneficial organisms in the soil (Gagliardi *et al*., 2002). Poultry manure on average contains 2.20 % N, 1.80 % $P_2O_5$, 1.10 %. $K_2O$, 2.40 % CaO and 0.70 % MgO (FAO, 2005).

## 2.11 Oil palm empty fruit bunch (EFB)

One of the main waste products generated in the processing of palm fruits into oil is the empty fruit bunches (EFB). In the palm oil milling process, one tonne of fresh fruit bunches generates about 0.22 tonne of EFB (Rabumi, 1998). EFB contains high amount of nutrients, particularly P and K as a result of which it is used as a nutrient source in the field (Rabumi, 1998). The average nutrient content of EFB are 0.55, 0.02 and 1.28 percent respectively of N, P and K (Kavitha *et al.,* 2013). Besides, macro nutrients, EFB also contains high amounts of micronutrients such as Fe, Zn, Cu and Mn. EFB has been found to improve soil structure and water holding capacity and reduce soil temperature and soil erosion (Rosenani *et al.*, 1996). EFB is also used as mulch in agricultural lands to control weeds, maintain moisture and prevent soil erosion (Alam *et al.*, 2005).

## 2.12 Effect of PM and EFB fertilizers on yield and fruit quality

The use of PM has produced positive results on a wide range of crops from vegetables to tree crops. In Nigeria increased fruit juice was recorded in Passion fruit when 15t of PM was applied to it (Ani *et al*, 2008). A combination of PM and other synthetic fertilizers has also been reported to give the highest fruit yield in grape fruit (De La Cerda *et al.*, 2012).

In a long-term study to determine the effect of PM on crop production, Nguyen (2010) reported that higher N application rates (336 kg ha$_{-1}$) from PM increased corn yields significantly compared to lower rates (168 kg ha$_{-1}$). Application of manure is known to improve yield of citrus in America and has been proven to be a sustainable citrus production practice (Martinez *et al.*, 2010).

Using different rates of application [(0, 5, 10 and 15) t ha$_{-1}$] of PM in determining the quality of juice produced by Passion fruit in Nigeria, it was noted that, the application of 15 t ha$_{-1}$ poultry manure gave the best juice quality (Ani *et al*, 2008). In the same experiment it was noted that titratable acidity increased (1.9 – 4.35) as the manure rate increased in both seasons. Ofosu-Budu *et al.* (2005) in evaluating the effect of organic manure on yield and fruit quality of sweet orange reported that application of PM resulted in a higher TSS and TSS/fruit compared with the control.

### 2.13 Effect of PM and EFB fertilizer on soil fertility and Nutrient content

The use of organic fertilizers can improve soil fertility appreciably for a long period particularly the application of composts made from organic wastes (Tittarelli *et al.*, 2002). In addition, it supplies other essential plant nutrients and amends the soil by the inclusion of organic matter (Ahiahonu *et al.*, 2011). Soil fertility improved significantly when different organic fertilizers were applied to the soil for a period of time (Mader *et al.*, 2002). EFB has the potential to improve soil structure and water holding capacity, reduce soil temperature and reduce soil erosion (Rosenani *et al.*, 1996).

A six-year study by Canali *et al.* (2004), which included the use of organic fertilizers (compost and PM) to determine long-term effects on soil fertility of citrus orchards indicated that the application of organic fertilizers increased total soil C and N. A plethora of studies have shown that using PM over a long period of time changes the biological and chemical properties of the soil with the increase of organic matter which improves the fertility of the soil (Tejada *et al.*, 2006; Varvel, 2006). Residual effects of manures can boost yield for a period of time after application due to the fact that only a fraction of the N and other nutrients in them become available to the plant in the first year after application (Eghball, 2002).

When it comes to nutrient uptake of organic fertilizers, it is not as quick as inorganic fertilizers because nutrients are slowly released from the substances into the soil. An experiment conducted by Nguyen *et al.* (2010) which included PM and chemical fertilizer treatments revealed that one of the sole PM treatments gave the highest N uptake in the corn with no significant differences observed in the N uptake of the other treatments including that of the chemical fertilizer. These observations agreed with results from Cheatham (2003) who had used the same experimental site and design. Steven *et al.* (2005) concluded from his study on the effects of long-term N application rates on the ability of crop N uptake, that N uptake increased with increase in fertilizer application rates. Bakayoko *et al*. (2009) also stated that, cattle manure increased the sum of the exchangeable bases, cations and the cation exchange capacity, which increased nutrient content of the plants.

### 2.14 Effect of organic and inorganic fertilizers (combination) on yield and fruit quality.

The application of inorganic nitrogen (170 kg ha$_{-1}$) improved the soil along with the amendment of 3.1 t ha$_{-1}$ of sheep manure as organic matter and this increased yield and fruit quality of grapefruit (Abdalla *et al*., 2008). De la Cerda *et al.* (2012) noted in their experiment that, the combination of PM and inorganic fertilizer also improved the yield of grape fruit. These results showed that inorganic fertilizer amended with chicken manure improved yield. The result also proved that applying high quantities of chicken manure may not be necessary. Combined fertilizer application of PM+NPK fertilizer produced significant higher yields higher than those produced by sole organic and inorganic fertilizers (Quansah, 2010). Boateng and Oppong (1995) also agreed that combining organic and inorganic fertilizers improved maize yield in their experiment. They stipulated that the plots treated with PM and NPK (20-20-0) gave the best yield.

Results from the experiment of De la Cerda *et al.* (2012) revealed that brix/acidity relation in grapefruit results indicated no statistically significant difference and nothing notable was recorded for fruit quality in all the treatments including the combination of organic and inorganic fertilizer. However, the combination of organic and inorganic fertilizers by Islam *et al.* (2017) improved sweet orange fruit quality especially fruit size and TSS.

### 2.15 Effect of organic and inorganic fertilizers (combination) on soil fertility and nutrient content

The use of organic and inorganic fertilizers increased crop yields over the use of either organic or inorganic fertilizer alone (Quansah, 2000). Combining fertilizers is a good option because, organic matter levels are corrected and nutrients also added to the soil. This improves the physical, chemical and biological properties of the soil. Positive results were found when 3.1 ton ha$_{-1}$ of sheep manure combined with inorganic fertilizer (170 kg ha$_{-1}$ of nitrogen) was applied to the soil (Abdalla *et al*., 2008). Chand *et al.* (2006) found that the integrated use of farm yard manure and NPK was significant in maintaining soil fertility for seven years in a research to determine the impact of organic and in organic fertilizers on the soil. The use of organic manure and inorganic fertilizers over times appears to be the best approach in providing greater stability and improving soil fertility (Islam *et al*., 2011).

The use of organic fertilizer and chemical fertilizer was reported to increase the contents of N, P and K in sugarcane leaves compared to chemical fertilizer alone (Bokhtiar *et al.*, 2005). The use of PM+NPK promoted significantly higher nutrient content in the grain and stover of maize over the sole organic or inorganic treatments. The combined treatments also improved the soil environment (Quansah, 2010). Girma *et al.* (2017), reported that, the use of inorganic fertilizers alone along with its combination and FYM recorded highest shoot and tuber growth and P levels.

# CHAPTER 3

# MATERIALS AND METHODS

## 3.1 Experimental site

The experiment was carried out at the Forest and Horticultural Crops Research Centre (FOHCREC) at Okumaning near Kade in the Demkyembour District of the Eastern Region of Ghana. The area experiences a bi-modal rainfall pattern with a 30-year annual average of 1433mm (Adjei-Nsiah, 2012). The major rainy season occurs between March and July with a short dry spell in August and the minor rainy season starts in September and ends in November. The total rainfall amount during the experimental period (May 2018 to April 2019) was 1918mm. FOHCREC is located in the semi-deciduous forest agro-ecological zone of Ghana with an altitude of 135.9m above sea level (Asamoah-Asante, 2016). The experiment was conducted on a 13-year-old Late Valencia (budded onto Rough lemon rootstock) orchard measuring 1.3ha.

## 3.2 Soil

The soils of this area developed from rocks of the Birimian system, which consist of argillaceous sediments metamorphosed into phyllite (Adu, 1992). The soils are generally known as Acrisols in the FAO-UNESCO Revised Legend and as Ultisols in Soil Taxonomy (Soil Survery Staff, 1998) but they belong to the forest Ochrosol great soil group of the Ghanaian soil classification system (Brammer, 1962).

## 3.3 Experimental Design

The experiment which was on-station was conducted in a Randomized Complete Block Design (RCBD) with four replications. In each block there were 6 treatments, which were (1) Oil palm empty fruit bunches (OPEFB); (2) poultry manure (PM); (3) mineral fertilizer (N, P, K and Zn), (4) OPEFB plus N, P, K and Zn; (5) PM plus N, P, K and Zn; (6) Control. Each treatment consisted of 6 experimental plants. Guard rows separated each treatment and replication.

## 3.4 Soil and leaf sampling

Soil and leaf samples were taken before the various fertilizer treatments were applied to the fields. The initial soil samples were taken at the depths of 0-30cm and 0-60 using soil auger at different points of the field. Soil was then mixed thoroughly, and a sub sample was taken to the laboratory, air–dried and sieved through a 2 mm screen for the determination of both physical and chemical properties. Leaf samples were collected from twenty trees, about 8-10 leaves per tree taken from non-fruiting twigs at the same height of the trees. The leaves taken were 5-7 months old. Leaf samples were oven dried at 70$_o$C for 48hrs and taken to the laboratory for foliar analysis.

Final soil sample was taken 253 days after fertilizer application to determine the residual effects of the fertilizer application on the soil chemical properties. For the final soil sampling, soil was taken from only the 0 - 30 cm depth of the soil from all the 24 treatment plots using soil auger. Leaf samples were also taken and analysed in order to ascertain their nutrient contents 253 days after fertilizer application.

### 3.5 Soil Analysis

Soil pH was measured in a 1:2.5 soil-water ratio using a glass electrode (H19017 Microprocessor) pH meter. The soil N was determined by the micro–Kjedahl method (AOAC, 1970) while available soil P was extracted by the Bray P1 extractant, measured by the Murphy blue colouration and determined on a spectronic 20 at 882 Um (Murphy and Riley, 1962). Soil K, Ca and Mg were extracted with a 1M NH4OAC, pH 7 solution, then K analysed with a flame photometer while Mg and Ca were determined with an atomic absorption spectrophotometer (Jackson, 1958).

## 3.6 Plant analysis

### 3.6.1 Determination of plant nitrogen

Total nitrogen in the plant samples were determined by the acid digestion Kjeldahl method. One–tenth gram (0.1 g) of milled plant sample was weighed into a 250 mL Kjedahl flask and a tablet of digestion accelerator (selenium catalyst), was added followed by 5 mL concentrated sulphuric acid. The mixture was digested until the digest became clear. The flask was then cooled and its content transferred into a 100 mL volumetric flask with distilled water and quantitatively made up to volume. A 5 mL aliquot of the digest was taken into a Markhan distillation apparatus. Five millilitres (5 mL) of 40% NaOH solution was added to the aliquot and the mixture distilled. The distillate was collected in 5 mL of 2% boric acid solution. Three drops of a mixed indicator containing methyl red and methylene blue were added to the distillate in a 50 mL Erlenmeyer flask and then titrated against 0.01M HCl acid solution (Bremner, 1965). The percent nitrogen was calculated from the titre value.

$$\% \text{ N} = \frac{\text{Titre value} \times 0.1 \text{ HCL} \times 14.007}{\text{Weight of plant sample (mg)}} \times 100$$

### 3.6.2 Determination of Plant Total Phosphorus

Five millilitres (5 mL) aliquot of the digest was taken into a 50 mL volumetric flask in duplicates. The pH was adjusted using P–nitrophenol indicator and neutralized with a few drops of 4M $NH_4OH$ until the solution turned yellow. Eight millilitres (8 mL) of reagent B; prepared by dissolving 1.056 g of ascorbic acid in 200 mL of reagent A (12 g of ammonium molybdate) + 0.2998 g of antimony potassium tartrate dissolved in 250 mL of distilled water. The dissolved reagents were added to 1000 mL 0f 2.5M $H_2SO_4$ (148 mL of conc. $H_2SO_4$), mixed thoroughly and made to the 2000 mL mark (Watanabe & Olsen, 1965). The solutions were mixed thoroughly by shaking and allowing to stand for 15 minutes for the colour to stabilize. The colour changed to blue of different shades depending on the concentration of phosphorus available in the soil. A blank was prepared with distilled water and 8 mL of reagent B. The spectrophotometer was calibrated using 25 mg $L^{-1}$ standard P solution prepared in the same manner as above. The total P was determined on a spectronic 20 at 882 Um (Murphy and Riley, 1962).

### 3.6.3 Determination of Potassium, Magnesium and Calcium

Exchangeable K in the digest was determined by aspirating directly into Jenway flame photometer (PFP7). Calcium and Mg in the extract were determined using the Atomic Absorption Spectrometer (AAS). All parameters determined were expressed in percentages.

### 3.7 Organic fertilizers analysis

The organic fertilizers used were poultry manure (PM) and oil palm empty fruit bunch (EFB). The PM was sampled from 10 sacks containing the manure used for the experiment, mixed together and sub-sample taken for the analysis. This was oven dried at $70_oC$ for 48hrs and taken to the laboratory for analysis. EFB was subsampled from the bulk sample and oven dried at $70_oC$ for 48hrs and taken to the laboratory for analysis. Both samples were analysed for N, P, K, Ca and Mg. N was determined by macro-Kjeldahl method with total P determined by Bray 1 method and soil K by ammonium acetate extraction. Ca and Mg were extracted with a 1M $NH_4OAC$, pH 7 solution and were determined with an atomic absorption spectrophotometer.

### 3.8 Fertilizer doses for treatments

The amounts of various inorganic fertilizers used were 90 kg $ha^{-1}$ N, 60 kg $ha^{-1}$ P and 80 kg $ha^{-1}$ K. Nitrogen was applied as sulphate of ammonia (21% N); P as triple super phosphate (46% $P_2O_5$), K as potassium chloride (60% $K_2O$) and zinc as zinc sulphate (35% Zn). Nitrogen was applied as split in June and September. The poultry manure and empty fruit bunches were applied once at 4 and 9 tons per hectare respectively.

Table 3.1 Treatment description

| Treatment | Description |
|---|---|
| I | 9 t $ha^{-1}$ oil palm empty fruit bunches (OPEFB) |
| II | 4 t $ha^{-1}$ Poultry manure (PM) |
| III | 90 kg N $ha^{-1}$, 60 kg P $ha^{-1}$, 80 kg K $ha^{-1}$ and 4.8kg/ha Zn |
| IV | 4.5 t $ha^{-1}$ OPEFB plus 45 kg N $ha^{-1}$, 30 kg $ha^{-1}$ P, 40 kg $ha^{-1}$ K and 2.4 kg/ha Zn |
| V | 2t $ha^{-1}$ PM plus 45 kg N $ha^{-1}$, 30 kg $ha^{-1}$ P, 40 kg $ha^{-1}$ K and 2.4kg/ha Zn |
| VI | Control |

### 3.9 Fertilizer application

The inorganic fertilizers were applied in furrows made in a form of ring around the base of the trees about 100 cm away from the main trunk. The organic fertilizers were applied in a form of ring spread around the base of the plant about 100 cm away from the main trunk.

## 3.10. Cultural Practices carried out

### 3.10.1 Weed control

Weeding was done on the field as and when necessary. Weeding was done manually and also using weedicides. The chemicals used were glyphosate and 2,4-dinitrophenylhydrazine used on woody weeds. 150ml of glyphosate and 75ml of 2,4-dinitrophenylhydrazine were mixed in 15l of water in a knapsack sprayer and was sprayed on the field.

### 3.10.2 Disease control

The most prevalent diseases on the field were citrus black spot (*Guignardia citricarpa*) and angular leaf spot disease (*Pseudocercospora angolensis*). These were controlled with the application of fungicides carbendazim (40mls) plus Mancozeb (30g) per 12 litres of water at 4 weekly intervals until 3 weeks to first harvest commencing from 15th August 2018 using mistblowers.

### 3.10.3 Pest control

From 5th – 6th November 2019, the field was sprayed against termites and other insects using chlorpyriphos at 75ml mixed with 12 litres of water. This was followed by the cutting of mistletoes, a plant parasitic weed normally found on tree crops.

### 3.10.4 Collection of fallen fruits and Harvesting

From October 2018 to January 2019, fallen fruits were collected, counted and weighed. These fruits fell due to disease and insect pest infestation. The fruits after counting and weighing were disposed of to ensure farm sanitation and control of the spread of the diseases to other fruits. Fruits were harvested on 15th February, 2019. The fruits were counted and weighed on the field.

## 3.11 Determination of fruit quality.

Parameters measured in determining fruit quality were fruit size, juice content, juice volume, Total soluble solids (TSS), total acid (TA) and the TSS:TA ratio. For the fruit quality assessment, 10 fruits were sampled from each treatment. A Vernier calliper was used in measuring the fruit size, the juice volume after juice were extracted was measured with volumetric flask. TA was determined by titration with NaOH and phenolphthalein indicator in 100mL of juice. A refractometer was used in determine the percentage TSS. Maturity index (MI) was expressed as the relation TSS/TA.

## 3.12 Statistical analysis

Data collected were subjected to analysis of variance (ANOVA) using Genstat statistic software. The least significance difference (LSD) test at 5% probability level was used to compare the treatment means where significant differences were observed.

# CHAPTER FOUR

## 4.0 Results

### 4.1 Effect of fertilizers on yield

The results of the effect of fertilizer application on fruit yield of Late Valencia are presented in Table 4.1. Fruit yield per tree differed significantly (P<0.05) among the different treatments. Mean fruit yield per tree ranged from 22.92 kg with the control treatment to 53.08kg with trees that received PM+NPKZn. According to Table 4.1, the treatment PM+NPKZn recorded the highest mean yield of 14.74 t/ha followed by EFB, NPKZn, NPKZn+EFB, PM with the Control recording the least yield of 6.37 t/ha. In comparing the means, significant differences were found between PM+ NPKZn and PM, PM+ NPKZn and Control, EFB and PM, EFB and Control. Table 4.1 also shows no significant difference in number of fruits per tree between treatments but EFB and PM+NPKZn recorded higher mean fruit number than the control with 184 and 172 mean number of fruits per tree respectively compared with 151 fruits in the control.

Table 4.1. Effect of fertilizer application on yield of Late Valencia

| Fertilizer | Mean number of fruits per tree | Mean fruit yield per tree (Kg) | Mean fruit yield per hectare (t/ha) |
|---|---|---|---|
| PM+NPK+Zn | 172.00 | 53.08a | 14.74a |
| EFB | 184.00 | 51.53a | 14.31a |
| NPKZn | 139.00 | 41.83ab | 11.62ab |
| NPKZn+EFB | 114.00 | 34.48ab | 9.57ab |
| PM | 95.00 | 25.86b | 7.18b |
| Control | 151.00 | 22.92b | 6.37b |
| LSD (5%) | NS | 17.64 | 4.90 |

NS=Not significant

Table 4.2 shows the number of fruits that dropped as a result of insect pests (fruit flies) and diseases (mention the diseases) in each treatment and their corresponding weight in tons/ha. There were no significant differences ($P<0.05$) in the number and weight of fruits that dropped between the treatments. However, greater quantity of fruits (9.46 tons/ha) dropped in the EFB treatment followed by NPKZn (9.23 tons/ha) treatment. The control recorded the lowest weight of fruit drop with 6.16 tons/ha.

Table 4.2 Number and weight of fruits that dropped due to pests and diseases prior to harvest

| Fertilizer | Mean number of fruits drop per tree | Mean weight of fruit drop per tree (kg) | Mean weight of fruit drop per hectare (tons/ha) | % yield loss due to pests and diseases |
|---|---|---|---|---|
| PM+NPKZn | 85a | 30.24a | 8.40a | 36 |
| EFB | 119a | 34.05a | 9.46a | 40 |
| NPKZn | 100a | 33.19a | 9.23a | 44 |
| NPKZn+EFB | 76a | 24.62a | 6.84a | 41 |
| PM | 103a | 30.83a | 8.56a | 54 |
| Control | 106a | 22.19a | 6.16a | 50 |
| LSD | NS | NS | NS | - |

NS=Not significant

## 4.2 Effect of fertilizers on Fruit quality

### 4.2.1 Fruit size

The effect of organic and mineral fertilizer application on fruit quality of Late Valencia shows that there were no significant differences in the fruit sizes among the different treatments. All the treatments except for the EFB produced bigger fruit sizes than the Control. PM+NPKZn recorded the highest fruit diameter of 75mm while the EFB recorded the smallest fruit diameter of 72.32mm.

### 4.2.2 Juice content

The treatments did not have any significant effect on the juice content of the fruits (Table 4.3.) However, PM recorded the highest juice content of 59.86%. The Control recorded the least content of 54.64%.

### 4.2.3 Juice volume

Significant differences were not observed between treatments in the juice volume of the fruits from the various types of fertilizers applied. However, PM+NPKZn produced fruits with the highest juice volume followed by NPKZn, PM, NPKZn+EFB, EFB and the Control. All fertilizer treatments outperformed the Control.

### 4.2.4 Total soluble solids (TSS)

The TSS ranged from 8.83% to 9.80% with no significant differences observed among the different treatments. TSS or brix is an indication of the fruit maturity or the sugar content of the fruits. Even though there were no significant differences observed among the treatments, the combination of PM and NPKZn showed greater tendency to produce juice with higher TSS.

### 4.2.5 Titratable acid (TA)

Titratable acid ranged from 0.42% for PM+NPKZn to 0.54% for the PM treatment with no significant differences among the treatments.

### 4.2.6 TSS:TA

TSS: TA measured how matured the fruit is. PM+NPKZn recorded the highest ratio while the PM recorded the lowest ratio although there were no significant differences between the treatments.

Table 4.3 Effect of organic and mineral fertilizer application on fruit quality of Late Valencia sweet orange

| Fertilizer | Fruit diameter (mm) | Juice content (%) | Juice volume (ml) | TSS (%) | TA (%) | Mean TSS:TA |
|---|---|---|---|---|---|---|
| PM+NPKZn | 75.02 | 59.80 | 79.75 | 9.80 | 0.43 | 23.82 |
| EFB | 72.32 | 57.99 | 71.15 | 8.88 | 0.46 | 19.33 |
| NPKZn | 74.80 | 59.35 | 78.70 | 9.23 | 0.48 | 19.30 |
| NPKZn+EFB | 73.02 | 58.98 | 76.00 | 9.10 | 0.42 | 23.70 |
| PM | 73.92 | 59.86 | 76.90 | 8.90 | 0.54 | 17.47 |
| Control | 72.32 | 54.64 | 64.54 | 8.83 | 0.47 | 21.16 |
| LSD (5%) | NS | NS | NS | NS | NS | NS |

NS=Not significant

## 4.3 Effect of fertilizer application on leaf nutrient content

Table 4.4 shows the nutrient content of the leaves prior to the treatment application. The leaf analysis revealed that, the N content of the leaves was medium (2.37%); the P and K contents were also medium with values of 0.14% and 1.20% respectively. The leaf analysis also indicated very low Mg content while Ca content was optimum according to Obreza *et al.* (2008).

Table 4.4. Nutrient content of leaf sample of the Late Valencia trees prior to the application of the treatments

| K (%) | Ca (%) | Mg (%) | N (%) | P (%) |
|---|---|---|---|---|
| 1.20 | 2.34 | 0.43 | 2.37 | 0.14 |

Fertilizer application did not significantly affect the level of nutrients (N, P, K, Ca and Mg) in the leaves 253 days after the application, although PM+NPKZn and PM treated plants appeared to have higher N level in the leaves compared with the control while EFB had higher K level in the leaves (Table 4.5.). Generally, the nutrient levels in the leaves increased 253 days after the application of the fertilizer. The N level in the leaves at the start of the experiment was 2.37% (Table 4.4) compared to an average of about 3% 253 days after application of the fertilizers (Table 4.5). K level in the leaves also increased from the initial level of 1.2% to an average of 1.5% 253 days after the fertilizer application. P level in the leaves 253 days after application did not increase from the initial level of 0.14% while Ca and Mg levels decreased from the initial levels of 2.34 and 0.43% respectively to an average of about 2.19% and 0.29%.

Table 4.5 Effect of organic and mineral fertilizer application on nutrient content in the leaf of Late Valencia sweet orange 253 days after fertilizer application.

| Fertilizers | K (%) | Ca (%) | Mg (%) | N (%) | P (%) |
|---|---|---|---|---|---|
| PM+NPKZn | 1.46 | 2.22 | 0.25 | 3.20 | 0.15 |
| EFB | 1.84 | 2.13 | 0.32 | 3.15 | 0.15 |
| NPKZn | 1.28 | 2.33 | 0.32 | 3.11 | 0.14 |
| NPKZn+EFB | 1.34 | 2.19 | 0.29 | 3.08 | 0.13 |
| PM | 1.45 | 2.11 | 0.38 | 3.25 | 0.13 |
| Control | 1.48 | 2.20 | 0.23 | 3.05 | 0.13 |
| LSD (5%) | NS | NS | NS | NS | NS |

NS=Not significant

## 4.4. Fruit quality parameters in relation with leaf nutrient content

Fruit diameter (r= -0.56), juice content (r= -0.25), juice volume (r= -0.44) and TSS:TA (r= -0.24) (Table 4.6) had negative relationship with K nutrient level in the leaves. Leaf Ca content positively correlated with fruit size (r=0.54), juice volume (r=0.26), TSS (r=0.29) and TSS:TA (r= 0.46) but negatively correlated with TA (r= -0.28). Leaf Mg related positively with juice content (r= 0.59), juice volume (r= 0.41) and TA (r= 0.70) but had negative relationship with TSS (r= -0.34) and TSS:TA (r= -0.76). Leaf N related positively with fruit size (r= 0.49), juice content (r= 0.69), juice volume (r= 0.57), TSS (r= 0.28), TA (r= 0.49) but related negatively with TSS:TA (r= -0.37). Leaf P displayed positive relationship with fruit size (r= 0.28), juice content (r= 0.28), juice volume (r= 0.28), TSS (r= 0.54) but displayed negative relationship with TA (r= -0.35). Significant positive correlation existed between Mg uptake and juice content (r= 0.15), juice volume (r= 0.41) as well as TA (r= 0.70). However, a negative correlation was recorded between Mg uptake and TSS (r= -34) and TSS:TA (r= -37)

Table 4.6. The Pearson's correlation matrix between fruit quality parameters and leaf nutrient levels

| Variables | Fruit diameter (mm) | Juice content (%) | Juice volume (ml) | TSS (%) | TA (%) | TSS:TA | K (%) | Ca (%) | Mg (%) | N (%) | P (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fruit diameter (mm) | | | | | | | | | | | |
| Juice content (%) | 0.73** | | | | | | | | | | |
| Juice volume (ml) | 0.86** | 0.96** | | | | | | | | | |
| TSS (%) | 0.79** | 0.53** | 0.69** | | | | | | | | |
| TA (%) | 0.07 | 0.07 | -0.03 | -0.49** | | | | | | | |
| Mean TSS:TA | 0.08 | -0.04 | 0.10 | 0.60** | -0.91** | | | | | | |
| K (%) | -0.56** | -0.25** | -0.44** | -0.32** | 0.00 | -0.24** | | | | | |
| Ca (%) | 0.54** | 0.06 | 0.29** | 0.46** | -0.28** | 0.24** | -0.63** | | | | |
| Mg (%) | 0.15 | 0.59** | 0.41** | -0.34** | 0.70** | -0.76** | 0.06 | -0.33** | | | |
| N (%) | 0.49** | 0.69** | 0.57** | 0.28** | 0.49** | -0.37** | 0.18* | -0.43** | 0.60** | | |
| P (%) | 0.28** | 0.28** | 0.28** | 0.54** | -0.35** | 0.13 | 0.53** | 0.12 | -0.12 | 0.30** | |

** = significant at P < 0.05 (r>0.16), ** = significant at P < 0.01 (r>0.21), TSS = Total Soluble Solids, TA = Titratable Acid, K = Potassium, P = Phosphorus, N = Nitrogen, Mg = Magnesium, Ca = Calcium*

### 4.5. Leaf mineral nutrient content in relation to soil mineral content

Percent leaf K significantly related positively with soil pH (r= 0.47), soil Total N (r= 0.79), Organic carbon (r= 0.70), soil K (r= 0.64), soil Mg (r= 0.90) and Ca (r= 0.32) but related negatively to available P (r= -0.55). Leaf Ca negatively correlated with all the soil parameters except for available P which had no relationship with leaf Ca content. Leaf Mg had positive relationship with soil pH (r= 0.29), O.C (r= 0.43), Total N (r= 0.45), available P (r= 0.31), exchangeable K (r= 0.67), exchangeable Ca (r= 0.51) but negative relationship with exchangeable Mg (r= -0.21). Leaf N content positively correlated with soil pH (r= 0.48), Total N (r= 0.56), Ca (r= 0.88), Mg (r=0.21) and K (r= 0.70) but correlated negatively with Na (r= -0.35). There was no significant relationship between leaf N content and soil OC and available P. Leaf P had positive relationship with soil N (r= 0.69), OC (r= 0.39), K (r= 0.21), Mg (r= 0.71) and Ca (r= 0.51) but had negative relationship with soil pH (r= -0.19) and available P (r= -0.47).

Table 4.7. The Pearson's correlation matrix between nutrient levels in leaves and soil 253 days after treatment application

| Variables | K (%)/Leaf | Ca (%)/Leaf | Mg (%)/Leaf | N (%)/Leaf | P (%)/Leaf | pH 1:2.5 | OM (%) | Total N (%) | O.C (%) | Ca | Mg | K | Na | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K (%)/Leaf | | | | | | | | | | | | | | |
| Ca (%)/Leaf | -0.63** | | | | | | | | | | | | | |
| Mg (%)/Leaf | 0.06 | -0.33** | | | | | | | | | | | | |
| N (%)/Leaf | 0.18* | -0.43** | 0.60** | | | | | | | | | | | |
| P (%)/Leaf | 0.53** | 0.12 | -0.12 | 0.30** | | | | | | | | | | |
| pH 1:2.5 | 0.47** | -0.97** | 0.29** | 0.48** | -0.19* | | | | | | | | | |
| OM (%) | 0.69** | -0.26** | 0.43** | -0.01 | 0.40** | 0.08 | | | | | | | | |
| Total N (%) | 0.79** | -0.50** | 0.45** | 0.56** | 0.69** | 0.39** | 0.74** | | | | | | | |
| O.C (%) | 0.70** | -0.29** | 0.43** | -0.02 | 0.39** | 0.10 | 1.00** | 0.74** | | | | | | |
| Ca | 0.32** | -0.44** | 0.51** | 0.88** | 0.51** | 0.48** | 0.22** | 0.77** | 0.22** | | | | | |
| Mg | 0.90** | -0.50** | -0.21* | 0.21** | 0.71** | 0.41** | 0.47** | 0.75** | 0.47** | 0.43** | | | | |
| K | 0.64** | -0.84** | 0.67** | 0.70** | 0.21* | 0.78** | 0.53** | 0.82** | 0.54** | 0.77** | 0.51** | | | |
| Na | 0.74** | -0.43** | 0.10 | -0.35** | 0.10 | 0.25** | 0.84** | 0.46** | 0.85** | -0.14 | 0.49** | 0.38** | | |
| P | -0.55** | -0.04 | 0.31** | 0.05 | -0.47** | 0.20* | -0.18* | -0.19* | -0.16 | 0.20* | -0.49** | 0.08 | -0.23** | |

** = significant at P < 0.05 (r>0.16), ** = significant at P < 0.01 (r>0.21), K = Potassium, P = Phosphorus, N = Nitrogen, Mg = Magnesium, Ca = Calcium, OM=Organic matter, O.C=Organic carbon.*

### 4.6 Fruit quality parameters in relationship with soil nutrient levels.

From Table 4.8, fruit diameter significantly related positively with soil Ca (r= 0.39) and soil available P (r= 0.18) but negatively correlated with soil pH (r= -0.42), soil O.C (r= -0.47), Mg (r= -34), N (r= -0.08) and K (r= -0.20). Juice content positively correlated with soil total N (r= 0.39), Ca (r= 0.79), K (r= 0.38) and available P (r= 0.53). There was however, negative correlation between Juice content and Na content (r= -0.44) of the soil. There was a significant positive correlation between Juice volume and soil total N (r= 0.19), Ca (r= 0.65) and available P (r= 0.52) but juice volume correlated negatively with O.C (r= -016) and Mg (r= -0.25) according to table 4.8.

TSS showed no significant correlation with soil total N (r= 0.01), Mg (r= 0.09), P (r= 0.10) but negatively correlated with soil organic carbon (r= -0.45), K (r= -0.27) and positively correlated with Ca (r= 0.39).

Total Acidity had negative relationship with Mg (r= -0.32), Na (r= -0.09) and available P (r= -0.17). TSS:TA negatively correlated with soil total N (r= -0.29), organic carbon (r= -0.41), Ca (r= -0.10) and K (r= -0.44) but positively correlated with available P (r= 0.29).

Table 4.8. The Pearson's correlation matrix between Soil nutrient 253 days after application of fertilizers and fruit quality parameters

| Variables | pH 1:2.5 | OM (%) | Total N (%) | O.C (%) | Ca | Mg | K | Na | P | Fruit diameter (mm) | Juice content (%) | Juice volume (ml) | TSS (%) | TA (%) | TSS:TA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH 1:2.5 | | | | | | | | | | | | | | | |
| OM (%) | 0.08 | | | | | | | | | | | | | | |
| Total N (%) | 0.39** | 0.74** | | | | | | | | | | | | | |
| O.C (%) | 0.10 | 1.00** | 0.74** | | | | | | | | | | | | |
| Ca | 0.48** | 0.22** | 0.77** | 0.22** | | | | | | | | | | | |
| Mg | 0.41** | 0.47** | 0.75** | 0.47** | 0.43** | | | | | | | | | | |
| K | 0.78** | 0.53** | 0.82** | 0.54** | 0.77** | 0.51** | | | | | | | | | |
| Na | 0.25** | 0.84** | 0.46** | 0.85** | -0.14 | 0.49** | 0.38** | | | | | | | | |
| P | 0.20* | -0.18* | -0.19* | -0.16 | 0.20* | -0.49** | 0.08 | -0.23** | | | | | | | |
| Fruit diameter (mm) | -0.42** | -0.44** | -0.08 | -0.47** | 0.39** | -0.34** | -0.20* | -0.85** | 0.18* | | | | | | |
| Juice content (%) | 0.04 | 0.03 | 0.39** | 0.03 | 0.79** | -0.13 | 0.38** | -0.44** | 0.54** | 0.73** | | | | | |
| Juice volume (ml) | -0.17* | -0.14 | 0.19* | -0.16 | 0.65** | -0.25** | 0.12 | -0.61** | 0.52** | 0.86** | 0.96** | | | | |
| TSS (%) | -0.32** | -0.44** | 0.01 | -0.45** | 0.39** | 0.09 | -0.27** | -0.69** | 0.10 | 0.79** | 0.53** | 0.69** | | | |
| TA (%) | 0.23** | 0.02 | 0.05 | 0.01 | 0.10 | -0.32** | 0.37** | -0.09 | -0.17* | 0.07 | 0.07 | -0.03 | -0.49** | | |
| TSS:TA | -0.11 | -0.41** | -0.29** | -0.41** | -0.10 | 0.14 | -0.44** | -0.24** | 0.29** | 0.08 | -0.04 | 0.10 | 0.60** | -0.91** | |

** = significant at P < 0.05 (r>0.16), ** = significant at P < 0.01 (r>0.21), K = Potassium, P = Phosphorus, N = Nitrogen, Mg = Magnesium, Ca = Calcium, OM=Organic matter, O.C=Organic carbon, TSS=Total soluble solids, TA=Titratable Acid*

### 4.7 Effect of inorganic and organic fertilizers on soil fertility

Table 4.9 shows the initial soil chemical and physical properties of the experimental site. The pH of the 0-30cm and 30-60cm depths showed that the soil was acidic (Horneck *et al.*, 2011). The soil had moderate levels of N and low levels of exchangeable Ca and K. P content in the 0-30cm depth was high but was medium in the 0-60cm (Horneck *et al.*, 2011).

Table 4.9. Initial chemical and physical properties of soil of the experimental site

| Soil depths | pH 1:2.5 | O.C (%) | Total N (%) | OM (%) | Ca | Mg | K | Na | P ppm | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Exchangeable cations cmol/kg | | | | | | | |
| 0-30cm | 5.24 | 1.70 | 0.17 | 2.93 | 3.20 | 1.70 | 0.33 | 0.29 | 22.48 | 52.00 | 36.00 | 12.00 |
| 30-60cm | 5.15 | 0.85 | 0.11 | 1.46 | 2.13 | 0.96 | 0.34 | 0.27 | 19.29 | 54.00 | 28.00 | 18.00 |

Table 4.10 shows the nutrient compositions of the PM and the EFB used in the experiment. The PM had N percentage of 2.49% while P and K contents were 1.47% and 0.08% respectively. The N content of the EFB was 0.98% while the P and K contents were 0.12% and 0.10% respectively.

Table 4.10. Chemical properties of the PM and EFB used in the experiment.

| Fertilizer | % C | % Mg | % N | % P | %K | C:N |
|---|---|---|---|---|---|---|
| PM | 6.88 | 1.62 | 2.49 | 1.47 | 0.08 | 2.76 |
| EFB | 0.35 | 0.21 | 0.98 | 0.12 | 0.10 | 0.36 |

Fertilizer application had significant effect on soil pH, organic carbon, organic matter (OM) available P but did not have any effect on soil total N (table 4.11). The control plot had the lowest pH of 4.82 while the plot that received the PM had the highest soil pH of 5.04. Soil organic carbon (O.C) also ranged from 1.68% for the plot that received the NPK+Zn to 2.14

with the plots that received the EFB. Table 4.11 also shows that soil available P was highest (44.63ppm) in the plot that received NPKZn+EFB and least (21.85ppm) on the control plot. Generally, the OM content of the soil increased in all the treatments 253 days after application compared to the initial level of the soil. The N content of all the treatments also appreciated compared to the initial levels (Table 4.11). With the exception of K which increased in all the treatments 253 days after the fertilizer application, the soil level of all the other exchangeable cations (Ca and Mg) declined sharply 253 days after nutrient application

Table 4.11. Soil chemical properties of the experimental soil 253 days after treatment application

| Fertilizers | pH 1:2.5 | OM (%) | Total N (%) | O.C (%) | Ca | Mg | K | Na | P ppm |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Exchangeable cations cmol/kg | | | | |
| PM+NPKZn | 4.83ab | 2.93b | 0.21 | 1.69b | 2.63 | 1.41 | 0.39 | 0.30b | 28.14b |
| EFB | 4.92ab | 3.69a | 0.23 | 2.14a | 2.53 | 1.62 | 0.44 | 0.34a | 23.10b |
| NPKZn | 4.54b | 3.23ab | 0.20 | 1.86ab | 2.18 | 0.93 | 0.36 | 0.31b | 29.42b |
| NPKZn+EFB | 4.89ab | 3.17ab | 0.20 | 1.84ab | 2.29 | 1.09 | 0.39 | 0.32ab | 44.63a |
| PM | 5.04a | 3.11ab | 0.21 | 1.80ab | 2.61 | 1.09 | 0.44 | 0.31b | 34.14ab |
| Control | 4.82ab | 2.99b | 0.19 | 1.73b | 1.86 | 1.19 | 0.36 | 0.32b | 21.85b |
| LSD (5%) | 0.43 | 0.60 | NS | 0.35 | NS | NS | NS | 0.02 | 14.19 |

NS=Not significant

# CHAPTER FIVE

## 5.0 Discussion

### 5.1 Effect of fertilizer applications on yield

The yield obtained in this study was generally low compared with what has been obtained at the same location in earlier studies by Ofosu-Budu (1998) but compares favourably with reports by Islam *et al.* (2017) in Bangladesh. The low yields obtained in this study was partly due to high fruit drops across the treatments (Table 4.2). Percent yield loss as a result of fruit drop due to insect pests and diseases ranged between 36% and 50% with the control treatment recording the highest yield loss.

There were significant differences (P<0.05) in yield amongst the treatments. Yield per hectare ranged from 6.3 to 14.7 t/ha with all treatments outperforming the Control. Trees from the plots that received PM+NPKZn gave the highest yield of 14.74 t/ha. This may be attributed to the high amount of N (2.49%) contained in the PM (organic) in addition to the high N content of the NPK (inorganic) fertilizer. Nitrogen has been observed to play a critical role in the production of citrus (Cantarella *et al*., 2003; Alva *et al*., 2006). In a similar experiment, Abdalla *et al.* (2008) applied 170 kg/ha of N with 3.1 t/ha of sheep manure to grapefruit and observed a significant increase in fruit yield. Other studies (Derla Cerda *et al*., 2012; Islam *et al*., 2017) have also shown significant increases in fruit yields in sweet oranges with the combined application of inorganic and organic fertilizers. The combination of NPKZn+EFB did not perform well as that of PM+NPKZn and this could be due to the high nutrient content in PM compared to that of the EFB (Ahiahonu *et al*, 2011).

The mean yield recorded for EFB was 14.31 t/ha, which was higher than the control. This could be due to the fact that it also serves as a mulching material which improves the soil by controlling weeds, maintaining soil moisture and minimising erosion (Molla *et al.*, 2004). In addition, EFB also adds nutrients to the soil through its decomposition (Rabumi, 1998). The sole treatment of EFB performed better than the NPKZn+EFB probably because the amount of the EFB material applied (16kg/tree) for the NPKZn+EFB treatment was not as high as that of the sole treatment (32kg/tree). The appreciable content of N (0.98%) in the EFB and its mulching ability helped increase yield more than the control and other treatments in this experiment. Kheong *et al.* (2010), reported that the application of EFB on oil palm trees significantly increased root proliferation which in turn increased the yield. However, in our present study we did not study the rooting system. Martinez *et al.* (2012), reported that organic fertilizer application improved yield of citrus in South America and manure application is used as sustainable citrus production practice. The other organic fertilizer treatment of only PM (4 t ha$_{-1}$) outperformed the Control treatment in terms of fruit yield as well, but the yield was very low. This was probably because the quantity applied was not sufficient. Ofosu-Budu *et al.* (2005), in a similar study applied 18 kg/tree (5 tons/ha) compared to 13.5 kg/tree (4 tons/ha) used in this experiment and reported significant increase in fruit yield compared with the control.

The NPKZn treatment recorded higher yield than NPKZn+EFB, PM and the Control. Though the comparison of the NPKZn treatment with the control did not show significant difference using the LSD obtained but Ofosu-Budu, (1998), observed significant increases in the yield when inorganic fertilizer alone was applied on a Late Valencia field. He reported yield increases of 90% compared to the control. In this study, though the difference in yield between the control and the NPKZn treatment was not significant, the inorganic fertilizer treatment out-yielded the control by 43%. In a similar experiment, Nasreen *et al.* (2013) recorded significant differences in yield (512 fruits per plant) when 300g, 125g and 225g per plant of N, P and K respectively was applied on mandarin in Bangladesh. Monga *et al.* (2004) also reported an increase in fruit number with the application of NPK. The application of organic and inorganic fertilizers perhaps helped in improving soil fertility and supply of sufficient nutrients resulting in improved growth and development of the trees which reflected in higher yields due to higher fruit set and fruit weight (Nasreen *et al*., 2013).

### 5.2 Effect of fertilizer application on fruit quality

Major fruit quality parameters in citrus include juice content, total soluble solids (TSS), titratable acidity (TA) and the ratio of TSS to TA (Baldwin, 1993). The TSS showed no significant difference (P>0.05) among the various treatments. Though there were no significance differences among the treatments, PM+NPKZn produced fruits with highest TSS while control treatment recorded the least. In a similar study, Islam *et al.* (2017), noted a rise in TSS upon the application of organic and inorganic fertilizers on sweet orange. Mansour *et al.* (2007) also found out that the combination of organic and inorganic fertilizers increased the TSS of Washington navel oranges. Other studies (Koo, 1979; Khan *et al*., 2011, Quaggio *et al*., 2006) have also, reported that TSS content of sweet oranges increased with application of inorganic fertilizers (N, P and K). The application of only PM was better than that of the EFB in terms of TSS though they showed no significant difference. In a similar experiment by Islam *et al.*, (2017) treatments which included poultry manure and inorganic fertilizers recorded high TSS of 8.0% and 7.0% which was low compared to the 9.80% and 8.9% obtained with the PM+NPKZn and the PM alone in this experiment.

Although there were no significant differences between treatments with regards to the TSS:TA, PM+NPKZn recorded the highest ratio compared to the Control. In a similar experiment De la Cerda *et al.* (2012) also found no significant differences between treatments concerning

TSS:TA when inorganic and organic fertilization were applied on grape fruits. The organic fertilizer treatments had lower TSS:TA (17.47-19.33) compared with the control but the values obtained in this experiment were higher than that reported by Ofosu-Budu *et al.* (2005), (14.86) for sweet orange upon the application of 7.5 t/ha cocoa pod husk.

Juice content showed no significant differences between the various treatments but all the treatments outperformed the control. In a similar experiment in Nigeria, Ani *et al.* (2008) reported that PM had significant effect on fruit juice content of passion fruit. However, mineral fertilizer did not significantly influence fruit juice content in our studies, Quaggio *et al.* (2006) observed significant influence of P fertilizer on fruit juice content of sweet orange in Brazil. Although fertilizer application did not significantly influence fruit size, PM+NPKZn, NPKZn, PM and NPKZn+EFB had bigger mean fruit sizes than the control. In Bangladesh, Nasreen *et al.* (2013) reported that application of NPK improved fruit size of Kinnow mandarin. The increase in fruit size due to fertilizer application could be attributed to the increased K content of the soil Quaggio *et al.* (2006).

### 5.3 Fruit quality parameters in relation with leaf nutrient content

The nitrogen levels in the leaves positively influenced fruits size, juice content, juice volume, TSS and TA. This agreed with Zekri *et al.*, (2012) who reported on Irrigation, nutrition, and citrus fruit quality. Aular *et al.* (2010) reported that high K content reduces juice content which supports our finding in this experiment that leaf K content negatively correlate with juice content. In our present study, the EFB and the control treatments which recorded high K content in the leaves also recorded low juice content. As reported by Quaggio *et al.* (2006) our results suggest that P content in the leaf significantly positively influence fruit quality of citrus such as fruit size, juice content and juice volume. In this experiment, leaf P content correlated negatively with TA but positively with TSS:TA which contradicts the findings of Torres *et al*. (2009) that there was an increase in TA and a decrease in TSS:TA ratio with increasing P application rates.

### 5.4 Fruit quality parameters in relationship with soil nutrient levels.

Some fruit quality parameters such as TSS, juice content, fruit size are directly related to nutritional status of the plant and the soil (Hunche, 1999). Fruit juice correlated positively with soil N and P in this experiment. This agrees with the findings of Reddy *et al.* (2017) who also reported positive correlation between soil N and P and fruit juice content in sweet orange in India. In the same study Reddy *et al.* (2017) however, reported no relationship between any of the fruit quality parameters with Ca and Mg. However, in this study there was a positive correlation between Ca and most of the fruit quality parameters including TSS, juice content and fruit diameter but negative correlation between Mg and fruit quality parameters such as fruit diameter, juice content and TA. The finding that soil N negatively correlated with TSS:TA also contradicts the studies by Pestana *et al.* (2005) who reported positive correlation between soil N and TSS:TA of Late Valencia.

### 5.5 Effect on fertilizer application on leaf nutrient content

Generally, there were no significant differences between the treatments for any of the nutrients analysed in the leaves. Compared with reports by Obreza *et al.* (2008) the N content in the leaves of all treatments 253 days after fertilizer application (3.05-3.20%) were above optimum compared with the initial content in the leaves (2.37%) in this experiment. Treatments that received PM had higher N content in the leaves than the other treatments. The higher leaf N content of these treatments may probably be due to the higher N content of PM. Nguyen *et al.*

(2010), also reported that PM application resulted in higher N uptake in the corn stalks compared with other treatments and the control, though there were no significant differences among the treatments. Similar observations were also made by Cheatham, (2003) in soybeans. The EFB and the PM+NPKZn treatments also recorded the highest P content (0.15%) in the leaves which was optimum for citrus (Obreza *et al.*, 2008). The 3.11% leaf N content obtained with the sole inorganic treatment of NPKZn in this experiment compares favourably with the findings of Li *et al.* (2019) in China, who recorded lower leaf N content of 2.21% in Satsuma. Ca concentrations in the leaves were low (2.11-2.33) while those of Mg were optimum (0.23-0.38%) for citrus as reported by Obreza *et al.* (2008). Similar findings were reported by Quaggio *et al.* (2005) who also obtained low foliar concentration of Ca and Mg.

## 5.6. Leaf mineral nutrient content in relation to soil mineral content

There was positive correlation between soil pH and leaf P and Ca in this study which agrees with the findings of Li *et al.* (2015) who reported significant positive correlation between soil pH and leaf P content although, they reported soil N negatively correlated with leaf N which contradict the findings of this study. They attributed the negative correlation to the increase of N leaching which contributed to the low N in the soil. Yu *et al*. (2007) also reported that Ponkan (*Citrus reticulata*) leaf N was positively related with soil N corroborating the findings of the study. The negative correlation between soil P and leaf P observed in the study agrees with observations made by Li *et al.* (2015) that leaf P had negative relation with soil P. Leaf K which correlated positively with soil K in this experiment was contrary to observation made by Tang *et al.* (2013) who reported negative correlation between leaf K and soil K in sweet orange. As observed by Li *et al.* (2015), a positive relationship between leaf Mg and soil Mg was recorded in this study. In their studies Li *et al*. (2015) attributed the positive relation between leaf Mg and soil Mg to soil acidification which lowered soil exchangeable Mg level, thus reducing $Mg^{2+}$ uptake which eventually resulted in leaf Mg deficiency.

### 5.7. Effect of fertilizers on soil fertility

Generally, the OM as well as N, P and Na content of the soil increased 253 days after application of fertilizer compared with the initial levels in the soil. Fertilizer application also significantly influenced soil chemical properties. Canali *et al.* (2004) in a similar experiment in a citrus orchard also reported that organic manure increased total N content of the soil as found in this experiment. The increase in P in the soil (Table 4.11) could be due to the release of P from both the organic and inorganic fertilizers applied. The general drop in pH of the soil in all the treatments could be attributed to high rainfall resulting in leaching of basic cations thereby slowly acidifying the soil. (Kennedy, 1986). Leaching of N in the nitrate form is also a very important factor leading to soil acidity (Huang *et a*l., 2014).

There were significant differences in the soil organic matter content of the various fertilizer treatments. Soil carbon is a direct indication of the OM content of the soil and it is a direct reflection of the soil's health (Horneck *et al.*, 2011). Generally, the organic matter content of the soil was high (Horneck, 2011) for all the treatments including the control but EFB had the highest content of 3.69% which agreed with Rosenani *et al.* (1996), who found that EFB improves organic matter content of soils. Kaur *et al.* (2005) comparing organic and inorganic fertilizers and their combination on soil chemical and biological properties, found that organic fertilizers increased soil organic matter content, highlighting its importance in tropical soils which was also confirmed by Bilkis *et al.* (2017). The EFB recording higher OM than the NPKZn+EFB could be because inorganic fertilizer doesn't add much to the OM content of the soil as compared to organic fertilizers (Shabani *et al.*, 2011). Rasool *et al.* (2007), also found out that OM content slightly increased with inorganic fertilizer application as compared to the control due to the increase in root biomass. In India, Dubey *et al.* (2012) in determining the impact of inorganic fertilizer on the soil after harvest revealed that increasing the levels of fertilizer application contributed to increasing soil organic matter (Dubey *et al.*, 2012). The OM content of the soil of the PM treated plots were not significantly different from the control which was contrary to the findings of Tejada *et al.* (2006) and Varvel (2006) who reported that PM increased OM content immensely in the soil.

There were significant differences (P>0.05) between treatments in the P status of the soil after 253 days of application of the fertilizers. There was a general increase in P concentrations in the soil after 253 days of application when compared to the initial P concentration. The concentrations were medium for all the treatment with the exception of NPKZn+EFB which was high (Horneck *et al.*, 2015). The combination of NPKZn+EFB had the highest mean of 44.63ppm which confirms earlier reports by Parmar and Sharma (2002) and Dubey *et al.* (2012) who found that application of NPK with the help of available organic carbon in the soil, helped to increase P status of Soils. The PM treatment had an appreciable level of P (34.14ppm) in the soil. Rahman *et al.* (2013), reported that organic manure increased OM in the soil which in turn mineralizes to release P and other nutrients in the soil. The increase in soil P in this experiment could also be due to the fact that the plants were not able to utilize large quantities of P provided through the soil fertilization which is similar to what Singh *et al.* (2007) reported.

The initial pH of the soil at the experimental site was acidic (5.24 at a depth of 0-30cm) (Mostara *et al.*, 2008) though it falls within the optimum range for citrus which is 5 and 6 (Xie *et al.*, 1997). However, soil analysis after 253 days after fertilizer application revealed a decline in pH of the soils of the various treatments making the soil very acidic. The plots which received the PM application had the highest mean pH of 5.04 which remained acidic. These observations were however not in agreement with Whalen *et al.* (2000), who stated that organic manure application increases soil pH. Chang *et al.* (1990), however reported that the application of organic fertilizer decreased soil pH over time in their experiment. The decline in pH of the sole inorganic treatment agreed with Liu *et al.* (2010), who found out that inorganic fertilizers decrease soil pH.

Soil analysis after 253 days of application showed a general increase in soil total N in all the treatments. The level of soil total N at the beginning of the experiment was medium (0.17%) (Horneck *et al.*, 2011), but increased to an average of 0.21% 253 days after application of fertilizer although there were no significant differences between treatments. Both sole EFB and PM application resulted in moderately high levels of total N, 0.23% and 0.21% respectively. Canali *et al.* (2004), indicated that the use of organic fertilizers increased total N in citrus orchards. Application of PM and NPKZn increased total soil N content by about 24% which supports the findings of Ho Han *et al.* (2016) who observed an increase in N concentrations of the soil after the application of NPK and PM. Ahiahonu *et al.* (2011) making similar observation attributed the increase in N concentrations from the application of PM to the fact that PM is generally high in N and in addition to increasing the soil organic matter content. The sole inorganic fertilizer treatment which had lower soil N of 0.19% had limited effect on the soil N compared with the organic treatments and the combination of PM+NPKZn. However, Zuoping *et al.* (2014), applying higher rates of NPK reported of high N concentrations.

K concentration in the soil initially was moderate (0.33 cmol/kg) but increased by 25% after the application of PM and EFB, after 253 days of application. Ahiahonu *et al.* (2011), also observed an increase in soil K content after the application of PM to the soil. Contrary to the findings of Wright *et al.* (2007), who observed an increase in Mg content after fertilizer application, there was a decline in soil Mg levels after application of both organic and inorganic fertilizers in this experiment.

# CHAPTER 6

## 6.0 Conclusion and Recommendations

Results obtained from this study showed significant differences ($P<0.05$) in yield between citrus among the various soil amended treatments. The combination of the organic and inorganic fertilizer (PM+NPZn) produced the highest yield of 14.71 t/ha indicating the potential of PM+NPKZn in improving soil fertility and enhancing yield of citrus in Ghana. Though the yield was low, if proper steps are taken to reduce the incidence of diseases and pests which caused fruit drop, higher yield could be obtained. Thus, in areas where PM is in abundance, it could be used in combination with inorganic fertilizer by farmers to increase their citrus yields and improve soil fertility.

The results showed that fertilizer applications did not significantly influence any of the fruit quality parameters. However, PM when applied with NPKZn has a higher tendency to produce fruits with large fruit sizes, high juice volumes, high TSS and TSS:TA. It was observed that fertilizer application improved nutrient content in the leaves with the application of PM having higher tendency to improve leaf N content.

The study also suggests that application of organic manure either alone or in combination with inorganic fertilizers, can improve soil chemical properties including OC and P content of the soil and the productivity of citrus. However, the residual effects of the application of the fertilizers should be studied for the next fruit harvest before a definite recommendation can be made.

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# Appendix

Appendix 1. ANOVA table for mean number of fruits per tree

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Block stratum | 3 | 32326. | 10775. | 2.01 | |
| Block.*Units* stratum | | | | | |
| Fertilizers | 5 | 23029. | 4606. | 0.86 | 0.529 |
| Residual | 15 | 80224. | 5348. | | |
| Total | 23 | 135579. | | | |

Appendix 2. ANOVA table for mean yield per tree

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Block stratum | 3 | 2327.8 | 775.9 | 5.66 | |
| Block.*Units* stratum | | | | | |
| Fertilizers | 5 | 3247.1 | 649.4 | 4.74 | 0.009 |
| Residual | 15 | 2055.1 | 137.0 | | |
| Total | 23 | 7630.0 | | | |

Appendix 3. ANOVA table for yield in t/ha

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REPLICATIONS stratum | 3 | 179.61 | 59.87 | 5.66 | |
| REPLICATIONS.*Units* stratum | | | | | |
| Fertilizers | 5 | 250.55 | 50.11 | 4.74 | 0.009 |
| Residual | 15 | 158.57 | 10.57 | | |
| Total | 23 | 588.73 | | | |

Appendix 4. ANOVA for mean number of fruit drop per tree

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Block stratum | 3 | 21572. | 7191. | 4.38 | |
| Block.*Units* stratum | | | | | |
| Treatment | 5 | 4635. | 927. | 0.57 | 0.726 |
| Residual | 15 | 24612. | 1641. | | |
| Total | 23 | 50819. | | | |

Appendix 5. ANOVA for mean weight of fruit drop per tree (kg)

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Block stratum | 3 | 2711.5 | 903.8 | 2.79 | |
| Block.*Units* stratum | | | | | |
| Treatment | 5 | 453.1 | 90.6 | 0.28 | 0.917 |
| Residual | 15 | 4860.7 | 324.0 | | |
| Total | 23 | 8025.3 | | | |

Appendix 6. ANOVA for mean weight of fruit drop t/ha

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| replication stratum | 3 | 209.30 | 69.77 | 2.79 | |
| replication.*Units* stratum | | | | | |
| Treatment | 5 | 34.88 | 6.98 | 0.28 | 0.917 |
| Residual | 15 | 374.70 | 24.98 | | |
| Total | 23 | 618.89 | | | |

Appendix 7. ANOVA for mean fruit diameter

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Block stratum | 3 | 119.310 | 39.770 | 13.61 | |
| Block.*Units* stratum | | | | | |
| Fertilizers | 5 | 26.970 | 5.394 | 1.85 | 0.164 |
| Residual | 15 | 43.840 | 2.923 | | |
| Total | 23 | 190.120 | | | |

Appendix 8. ANOVA for mean Juice content

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Block stratum | 3 | 434.24 | 144.75 | 12.25 | |
| Block.*Units* stratum | | | | | |
| Fertilizers | 5 | 78.52 | 15.70 | 1.33 | 0.305 |
| Residual | 15 | 177.22 | 11.81 | | |
| Total | 23 | 689.98 | | | |

## Appendix 9. ANOVA for mean Juice volume

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Block stratum | 3 | 3200.66 | 1066.89 | 12.76 | |
| Block.*Units* stratum | | | | | |
| Fertilizers | 5 | 653.75 | 130.75 | 1.56 | 0.230 |
| Residual | 15 | 1254.15 | 83.61 | | |
| Total | 23 | 5108.56 | | | |

## Appendix 10. ANOVA for mean TSS

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Block stratum | 3 | 2.6813 | 0.8938 | 0.93 | |
| Block.*Units* stratum | | | | | |
| Fertilizers | 5 | 2.6771 | 0.5354 | 0.56 | 0.729 |
| Residual | 15 | 14.3412 | 0.9561 | | |
| Total | 23 | 19.6996 | | | |

## Appendix 11. ANOVA for mean TA

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Block stratum | 3 | 0.176750 | 0.058917 | 8.95 | |
| Block.*Units* stratum | | | | | |
| Fertilizers | 5 | 0.035483 | 0.007097 | 1.08 | 0.411 |
| Residual | 15 | 0.098750 | 0.006583 | | |
| Total | 23 | 0.310983 | | | |

## Appendix 12. ANOVA for mean TSS:TA

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Block stratum | 3 | 344.88 | 114.96 | 6.43 | |
| Block.*Units* stratum | | | | | |
| Fertilizers | 5 | 132.66 | 26.53 | 1.48 | 0.253 |
| Residual | 15 | 268.08 | 17.87 | | |
| Total | 23 | 745.62 | | | |

Appendix 13. ANOVA for mean K uptake in the leaves

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| rep stratum | 3 | 0.3043 | 0.1014 | 0.74 | |
| rep.*Units* stratum | | | | | |
| Treatment | 5 | 0.7599 | 0.1520 | 1.10 | 0.400 |
| Residual | 15 | 2.0689 | 0.1379 | | |
| Total | 23 | 3.1331 | | | |

Appendix 14. ANOVA for mean Ca uptake in the leaves

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| rep stratum | 3 | 0.12735 | 0.04245 | 0.98 | |
| rep.*Units* stratum | | | | | |
| Treatment | 5 | 0.12163 | 0.02433 | 0.56 | 0.728 |
| Residual | 15 | 0.64932 | 0.04329 | | |
| Total | 23 | 0.89829 | | | |

Appendix 15. ANOVA for mean Mg uptake in the leaves

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| rep stratum | 3 | 0.02337 | 0.00779 | 0.60 | |
| rep.*Units* stratum | | | | | |
| Treatment | 5 | 0.06556 | 0.01311 | 1.01 | 0.443 |
| Residual | 15 | 0.19395 | 0.01293 | | |
| Total | 23 | 0.28288 | | | |

Appendix 16. ANOVA for mean N uptake in the leaves

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| rep stratum | 3 | 0.18438 | 0.06146 | 1.68 | |
| rep.*Units* stratum | | | | | |
| Treatment | 5 | 0.10991 | 0.02198 | 0.60 | 0.700 |
| Residual | 15 | 0.54836 | 0.03656 | | |
| Total | 23 | 0.84265 | | | |

## Appendix 17. ANOVA for mean P uptake in the leaves

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| rep stratum | 3 | 0.0054953 | 0.0018318 | 2.42 | |
| rep.*Units* stratum | | | | | |
| Treatment | 5 | 0.0016819 | 0.0003364 | 0.44 | 0.811 |
| Residual | 15 | 0.0113758 | 0.0007584 | | |
| Total | 23 | 0.0185531 | | | |

## Appendix 18. ANOVA for mean pH of the soil

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| rep stratum | 3 | 0.06637 | 0.02212 | 0.27 | |
| rep.*Units* stratum | | | | | |
| Treatment | 5 | 0.56247 | 0.11249 | 1.39 | 0.284 |
| Residual | 15 | 1.21689 | 0.08113 | | |
| Total | 23 | 1.84573 | | | |

## Appendix 19. ANOVA for mean Organic matter in the soil

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| rep stratum | 3 | 1.3509 | 0.4503 | 2.86 | |
| rep.*Units* stratum | | | | | |
| Treatment | 5 | 1.4712 | 0.2942 | 1.87 | 0.160 |
| Residual | 15 | 2.3652 | 0.1577 | | |
| Total | 23 | 5.1873 | | | |

## Appendix 20. ANOVA for mean Total N of the soil

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| rep stratum | 3 | 0.012142 | 0.004047 | 3.94 | |
| rep.*Units* stratum | | | | | |
| Treatment | 5 | 0.003380 | 0.000676 | 0.66 | 0.660 |
| Residual | 15 | 0.015406 | 0.001027 | | |
| Total | 23 | 0.030928 | | | |

Appendix 21. ANOVA for mean Organic carbon of the soil

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| rep stratum | 3 | 0.45452 | 0.15151 | 2.86 | |
| rep.*Units* stratum | | | | | |
| Treatment | 5 | 0.49499 | 0.09900 | 1.87 | 0.160 |
| Residual | 15 | 0.79578 | 0.05305 | | |
| Total | 23 | 1.74530 | | | |

Appendix 22. ANOVA for mean Ca of the soil

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| rep stratum | 3 | 2.8620 | 0.9540 | 1.39 | |
| rep.*Units* stratum | | | | | |
| Treatment | 5 | 1.4121 | 0.2824 | 0.41 | 0.833 |
| Residual | 15 | 10.2893 | 0.6860 | | |
| Total | 23 | 14.5634 | | | |

Appendix 23. ANOVA for mean Mg of the soil

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| rep stratum | 3 | 0.8079 | 0.2693 | 1.29 | |
| rep.*Units* stratum | | | | | |
| Treatment | 5 | 1.2631 | 0.2526 | 1.21 | 0.353 |
| Residual | 15 | 3.1395 | 0.2093 | | |
| Total | 23 | 5.2104 | | | |

Appendix 24. ANOVA for mean K of the soil

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| rep stratum | 3 | 0.042228 | 0.014076 | 3.17 | |
| rep.*Units* stratum | | | | | |
| Treatment | 5 | 0.024423 | 0.004885 | 1.10 | 0.401 |
| Residual | 15 | 0.066673 | 0.004445 | | |
| Total | 23 | 0.133324 | | | |

Appendix 25. ANOVA for mean Na of the soil

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| rep stratum | 3 | 0.0008203 | 0.0002734 | 1.34 | |
| rep.*Units* stratum | | | | | |
| Treatment | 5 | 0.0031126 | 0.0006225 | 3.05 | 0.043 |
| Residual | 15 | 0.0030573 | 0.0002038 | | |
| Total | 23 | 0.0069902 | | | |

Appendix 26. ANOVA for mean P of the soil

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| rep stratum | 3 | 115.25 | 38.42 | 0.43 | |
| rep.*Units* stratum | | | | | |
| Treatment | 5 | 1394.90 | 278.98 | 3.14 | 0.039 |
| Residual | 15 | 1330.95 | 88.73 | | |
| Total | 23 | 2841.10 | | | |