EFFECT OF VARIABLE RATES OF CATTLE AND POULTRY MANURE-BASED PHOSPHO-COMPOSTS ON GROWTH, YIELD AND QUALITY OF POTATO (*Solanum tuberosum* L.)

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DECLARATION

I, Mmadi M.J, declare that the research report submitted to the University of Limpopo for the degree of Master of Science in Soil Science is my own work except where indicated and that I have clearly referenced/cited all sources appropriately. I understand that any false claim for this work will be penalised in accordance with the university regulations.

Signed………………………………… Date…………………………………

DEDICATION

I would like to dedicate this work to my loving parents (Julia Mathuding Mmadi and Tlatjane Manas Mmadi) who have supported me all my life, my daughter (Kganya Mathuding Mmadi), my sisters (Lebogang Victioria Mmadi and Modilati Hendrieth Makgatho) and to the almighty God for giving me the strength I needed to complete the work.

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ABSTRACT

Phosphorus (P) deficiency has been reported in 30- 40% of global arable land, which poses a huge threat in potato production because of its critical role in the early vegetative development and tuber formation. The use of low cost ground phosphate rock (GPR) as an alternative P fertilizer source has gained recognition. Although GPR contains high P percentage, its direct application is less beneficial immediately due to its low reactivity which makes P unavailable for plant uptake. In this experiment, GPR was co-composted with cattle and poultry manure in order to enhance P acquisition by the potato crop. The aim of this study was to evaluate the potential of phospho-compost application as a cheaper alternative P-source for potato production. The experiment was conducted on Mondial and Valor… potato cultivars at the University of Limpopo Syferkuil Experimental farm in 2015 and 2016. Poultry (PM) and cattle manure (CM)-based phospho-compost mix ratios of 8:2 and 7:3 were applied at 0, 20, 40, 80 and 120 kg P/ha. The trial was laid out in a split plot arrangement fitted into a randomised complete block design with treatments replicated three times.

Results indicated statistically significant effects of phospho-compost types on soil pH and available P content at both flowering and harvesting growth stages in 2015 and 2016 with the higher available P content found in the PM-based phospho-composts. In both seasons, highly significant differences in fresh and dry leaf samples among phospho-compost types were obtained. Highly significant season x compost type interaction effects were also recorded on leaf biomass as well as the 2015 tuber weight, with highest tuber weight obtained in plots that received PM7:3-based phospho-compost at 80 t/ha rate.

Notwithstanding the non-significant effect of compost type on tuber yield in 2016, higher yield was obtained from PM8:2. Although the grading of tubers showed no significant response to phospho-compost application; the difference between small and medium tubers obtained from 2016 trial was significantly affected by phospho-compost application rates. The CM8:2 mix ratio gave the highest baby tubers (16.87%) while PM7:3 mix ratio gave the highest (36.32%) medium tubers. The grading of the potato tubers revealed a mostly class 1 dominated by baby, small and medium size tubers in the 2015 harvest while the 2016 harvest was also mostly class 1 but dominated by small, medium and large-small size tubers. Tuber size and class were most favored by the PM-based phospho-compost applications in both planting seasons.

None of phospho-compost types and application rates had significant effect on the measured nutrient concentrations of both plant parts. However, the differences in nutrient concentrations across seasons and plant parts were significant except for Ca. The measure tissue P concentration from the 2016 trial was within the required range suggesting that phospho-compost utilization, particularly the poultry manure-based, in potato production can be beneficial in addressing P deficiency. The PM8:2 mixed ratio resulted in increased soil available P content, potato tuber yield in 2016 and the P concentration across the two plant parts evaluated. The concentration of soil available P and tissue P showed increases with higher application rates albeit non-significance. Future research on the optimum application rate is suggested on a wide range of soils for the various phospho-compost types.

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CHAPTER 1

INTRODUCTION

1.1 Background information

Potato (*Solanum tuberosum*) is the fourth major vegetable crop cultivated globally. It is a major food crop widely produced by farmers from Limpopo Province in South Africa (FAO, 2009). The growing issue of food insecurity in the world has increased the demand in agricultural production including that of the potato (Taheri *et al.,* 2012). Therefore, improvement of growth, yield and tuber quality of potato contributes strongly in addressing the agricultural production issues. The potato can be grown on wide variety of soils and climates in South Africa; and thus can results in a constant supply of tubers throughout the year (Van Niekerk, 1984). However, its production is limited by its high nutrient demand, specifically high phosphorus (P) requirement for optimum growth and yield (Balemi, 2009). Therefore, optimization of available P in the soil has become an important aspect in field crop management. Phosphorus participates in a number of processes determining the growth, development and the productivity of the potato plant (Krasmir *et al.*, 2010). It has been proven to be highly essential during the early growth stages of potato plants and in tuber development (Rosen and Bierman, 2008). Thus, readily available P must be applied during planting. Reports have further shown that P can affect the number of tubers and tuber size distribution.

Phosphorus is a fixed element found in insoluble forms that are unavailable to plants (Sibi, 2011). Soils contain P-rich minerals that are slowly released during weathering. Phosphate ions which contain a negative charge are easily adsorbed, forming insoluble forms of aluminium, calcium and iron phosphates. It is further immobilized by microbes which consume the available P and turns it into organic P which is unavailable to plants. The availability of P is highly dependent on its solubilisation and precipitation into inorganic forms by mineralization of the organic compound. Organic P has to be converted to plant available forms $H_2PO_4^{-2}$ or HPO^{-}, called orthophosphates through slow releasing mineralization process. Several mechanisms have been studied in order to increase the solubility of the compound. For example, the use of bacteria and fungi has been reported to being an efficient solubilizing method through the production of organic acids (Sibi, 2011). The problem of P deficiency is more severe on acid soils because P applied is converted to unavailable forms due to reactions with Al- and Fe-hydroxides (Sahrawat *et al.*, 2001).

The recycling of organic residues or animal wastes which are known to return essential P into the soil is mostly used in developing countries to provide low-cost inputs, but these materials are less efficient than chemical fertilizers which are costly (Wani *et al.,* 2009). Nutrient sources such as the rock phosphate, pyrites**,** microbial cultures and vermicompositing are being used in order to make the organic manures more effective (Wani *et al.*, 2009). The possibility of utilizing available low cost ground phosphate rock (GPR) as a source of P has gained increasing interest and has been recognised as a valuable alternative to inorganic P fertilizers. However, the direct application of ground rock phosphate has no immediate beneficial effects due to its low reactivity (Odongo *et al*., 2007). Therefore, it requires further solubilizing agents in order to be beneficial for plants. Conventionally, GPR is chemically processed by reacting it with sulphuric and phosphoric acids leading to the formation of soluble phosphates. This process increases the cost of fertilizers and may also become harmful to the environment (Sibi, 2011). Hence, the use of poultry or cattle manure enriched with rock phosphate is becoming a common practice as a low-input technology to improve P availability (Odongo *et al.,* 2007). Its amendment with compost has a great impact by making P available for plant uptake which improves acquisition and available P-use efficiency due to the chelating of cations by organic acids and other decay products (Hellal *et al*., 2012; Ransom *et al.*, 2011).

1.2. Problem Statement

The problem of inherent poor and/or declining soil fertility is a major constraint to increasing crop productivity in many developing countries. Phosphorus is recognised as the second most important nutrient after nitrogen (N) that limits crop growth and production (Al Sharif *et al*., 2004; Balemi & Negisho, 2012). It is used by many crops including potatoes; and is mostly needed during the early vegetative development and tuber growth. About 19 to 20% of tuber yield reductions in potato due to P deficiency in soil have been reported (Trehan *et al*., 2001). Approximately 30 - 40% of the arable land in the world is P deficient (Vance *et al*., 2003). Soils may however have 400 - 1000 kg P /ha but up to 90% of the total soil P is available in insoluble forms (Lal, 2006). Hence, the amount of available P for plant uptake in the soil solution becomes small compared to the total amount of P in the soil solution because of the restriction in mobility and solubility of P.

Ground phosphate rock (GPR) has high percentage total P which makes it a highly recommended P source. However, its direct application is not beneficial for plant uptake due to the insoluble P forms it contains, especially in dryland conditions. Furthermore, its benefits are also highly limited to many climatic and soil conditions including acidic soils and fast growing annual crops (Akande *et al*., 2005).

1.3. Motivation of the study

It has been reported that with increasing population in developing countries there is increase in food insecurity, which further demands increase in food production (Wani *et al*., 2009). The supply however is limited due to a number of factors which mostly include high input costs in food production. Poorly resourced farmers avoid the use of chemical fertilizers which are largely responsible for high agricultural input costs and harmful effects on the environment (Taheri *et al.,* 2012). Most small-scale farmers depend on the use of organic wastes like crop residues, leaf litter or animal manures in addressing soil fertility problems to increase crop yields. The use of these materials is however limited by their low nutrient contents, particularly P, and thus requires further expensive inorganic nutrient supplementation in order to increase nutrient availability (Wani *et al.*, 2009). The phospho-compost technology constitutes a less expensive P fertilization strategy that can help promote the use of organic-based material for increased crop production and soil physical and biological health (Odongo *et al*., 2007).

1.4. Purpose of the study

1.4.1. Aim

The aim of this study was to evaluate the potential of phospho-compost application as a cheaper alternative P-source for potato production.

1.4.2. Objectives

(i) Evaluate the yield and tuber quality response of potato production under variable application rates of cattle and poultry manure based phospho-composts.

(ii) Evaluate the use of GPR amended with poultry and cattle manure application on P availability and uptake in potato.

(iii) Determine the optimum rate of cattle and poultry-manure based phospho-compost application for potato.

1.4.3 Hypotheses

(i) Variable application rates of cattle and poultry manure based phospho-compost can improve the yield and tuber quality response of potato production.

(ii) The amendment of GPR with poultry manure influences the P availability and uptake in potato.

(iii) The optimum rate of cattle and poultry manure amended with the GPR application potato production can be determined.

CHAPTER 2

LITERATURE REVIEW

2.1. Potato production in South Africa

Potato production has become one of the most important vegetable crops produced in South Africa (Joubert *et al.,* 2010). Although South Africa is not a major producing country, potatoes and tomatoes have remained as the two major fresh produce industries (Louw, 2004). South Africa represents the 4th potato producing country on the African continent producing 2071930 tons annually (PSA, 2016). In 2008, potato production contributed a gross value of about 43% of major vegetables, 15% horticultural production and 4% agricultural production within the South African context (Joubert *et al.,* 2010). It further accounted for more than 20% of the value of all fresh produce sold on all the major national fresh produce markets (Joubert *et al.,* 2010) and currently South Africa contributes 0.5% globally and 14% of Africa's production (Du Preez, 2011).

The main producing regions are the Western Free State (17%), Eastern Free State (14%), Limpopo (22%) and Sandveld (14 %) (PSA, 2016). Production includes 85% production of table potatoes for consumption and 12% seed production for regeneration. However in 2015, Limpopo planted the most hectares of production area and produced the largest crops of the national harvest which amounted to nearly 51 million of 10kg bags. The most common cultivars are Mondial contributing 42%, Sifra with 14 % while the third place was Valor and Fianna each contributing 6 % (PSA, 2016) during 2010 season. The potato industry has a potential to increase its production if emerging farmers are slowly being given the opportunity to re-enter the market. The contribution has been minimized by obstacles such as rapid changing environment that emerging farmers must adjust to, poor agronomic practices, high cost of seeds and disease/pest control problems (Getachew *et al*., 2012). Furthermore, potato is not considered as a stable or traditional crop hence aggravating the exclusion of emerging farmers from the mainstream (Louw, 2004).

2.2. Nutritional profile of potato tubers

Potatoes are rich in several micronutrients and are more nutritious when eaten with the skin. A single medium sized potato of 150 g provides nearly half the daily adult requirement (100 mg); and constitutes the source of iron, vitamins such as B1, B3 and B6 which are responsible for the formation of red blood cells and minerals such as potassium, P and magnesium (Zaheer and Aktahr, 2016). Potatoes also contain dietary antioxidants, which may play a part in preventing diseases relating to ageing, and dietary fibre, which may lower the incidence of wide range of chronic and acute disease processes like hypertension, heart diseases, cancer, neurodegenerative and other diseases (Masarirambi *et al.,* 2012). Furthermore, potatoes ranked high in glycemic index which is a good dietary for diabetics. Potatoes are very high in carbohydrates in the form of starch and ranged from 66-90 % of dry weight (Zaheer and Aktahr, 2016). Potatoes are not fibre foods, although most of the fibre present is found the skin peel; and comprised of insoluble cellulose, pectins and hemicellulose. They are low in protein ranging from 1-1.5% when fresh and 8-9% when dry. Potassium, which is predominantly concentrated in the skin, benefits heart health. There is currently a growing interest in cultivars with pigmented flesh because they contribute to antioxidant activity (Masarirambi *et al*., 2012).

2.3. Role of phosphorus in potato production

2.3.1. Effect of P on critical growth stages of potato

Application of phosphate during production is essential for optimum growth and yield. Phosphorus is mostly needed at various stages during potato production from the initial growing stages through the entire tuber growth period and formation (Rosen and Bierman, 2008). Flowering, tuber formation and root development largely depend on the availability of P in the soil. Reports by Rosen and Bierman (2008) suggest that adequate P is essential in canopy development, tuber set and starch synthesis. Moreover, it is important in increasing the tuber yield, nutritive quality and resistance of the crop to diseases. Potatoes require adequate P during planting which results in more tubers, growth and dry matter. The tuber initiation stage is the most critical stage which requires enough P for more and bigger tubers to arise (Ekelof, 2007). Furthermore, this stage is also important in the synthesis of starch, its transport and storage. In order for the plant to maintain stronger tuber growth, P is also needed during the flowering and bulking stages (Balemi, 2009). It is highly required up to the tuber development stage while during senescence, negative P uptake can be observed due to nutrients relocation from the leaves to the tubers (Ekelof, 2007).

2.3.2. Effect of low P on potato production

Although P deficiencies cannot be readily seen as compared to N and K in plants, Gaume *et al*. (2001) have shown that P deficiency affects photosynthetic processes by limiting plant growth. Potato plants absorb available P in form of phosphates while P deficient plants tend to transport P from the older tissues to younger actively growing tissues resulting in stunted plants with short internodes and a poor root system (Ndou, 2017). The younger leaves further turn upward or curl and also reduce tuber net development and reduce the specific gravity of the potato. Lower side of the leaf stem may turn purple which largely depends on the type of cultivar planted. According to Balemi (2009), low P supply reduced shoot dry matter yield, relative growth rate, leaf number, whole plant relative leaf expansion rate, total leaf area per plant, plant height and net assimilation rate of P-inefficient genotype, more than that of the P-efficient genotypes. Hence, the resultant stunted plant with short internodes and poor root systems. According to Vance *et al.* (2003), plant roots typically respond to P deficiency through the allocation of more carbon to roots resulting in increased root growth, enhanced lateral root formation, greater exploration of the surface soil, increased length and number of root hairs, enhanced expression of P transporters and exudation of constituents such as organic acids and acid phosphotases that increase P availability (Hellal *et al*., 2013).

Poor to low P soil condition often results in stunted growth and an abnormal dark green colour in crops which may cause interruption of sugar translocation i.e. results in accumulation of the sugars (Sahrawat *et al.*, 2001) while inadequate P limits the plant's response to other major nutrients like N. Furthermore, Ekelof (2007) suggested that P deficiency will highly affect plant metabolic processes such as cell division, respiration and photosynthesis.

2.4. Effect of organic manures on crop production

Organic manure does not only supply nutrients into the soil but also enriches the physical properties of soil (Antil *et al*., 2013). Organic manures provide all the nutrients that are required by plants but in limited quantities. When used, organic manure helps in maintaining C: N ratio in the soil and also increases the fertility and productivity of the soil. It increases the water holding capacity of the soil (Chaundhry *et al*., 2013).

Due to increase in the biological activity; the nutrients that are in the lower depths are made available to the plants. Manures may also act as mulch thereby minimizing the evaporation losses of moisture from the soil (Saleem *et al.,* 2012).

2.4.1. Poultry manure

Poultry manure is considered as one of the most valuable organic resources for fertilizing purposes due to its high macro and micro content of plant nutrients (Singh and Agrawal, 2008). Poultry manure contains 1.0-1.8% N, 1.4-1.8% P_2O_5 and 0.8-0.9% K_2O (Chandra, 2005). Its fertilizing value is also reported to be higher than that of the traditional farmyard manure while it is also widely reported to possess additional benefits of improving soil organic matter and structural stability (Antil *et al*., 2013). Hence, the recycling of organic wastes in agriculture adds the much needed organic and mineral matter to the soil. Similarly, poultry manure supplies P more readily to plants than other organic manure sources (Chandra, 2005).

2.4.2. Cattle manure

According to Lory *et al.* (2004), the application of cattle manure to farmland is an economical and environmentally sustainable mechanism for increasing crop production. The nutrients in the manure can be influenced by the type of diet and how long the manure has rotted. However, Irshad *et al.* (2013) reported NPK contents of 0.6% N, 0.4% P and 0.5% K. Nutrients in cattle manure can replace commercial fertilizers. However, the value of manure is more than the accumulated value of the individual nutrients. Cattle manure has been described as an excellent soil amendment that is capable of enhancing soil quality and also increases crop yields by providing large inputs of nutrients (Whalen *et al*., 2000).

Many of the nutrients in the manure, however, are tied up in the organic fraction and must go through a decomposition process to be converted into the inorganic available forms for plant uptake (Najm *et al*., 2012). Getting the maximum value out of cattle manure requires applying the manure at appropriate rates and frequency; but, the nutrient composition of manure varies considerably. Compared to commercial fertilizers, the relative nutrient content of cattle manure is quite low hence large application rates are often required to obtain an equivalent amount of nutrients. Although untreated manure may constitute storehouse for weed seeds and pathogens, proper composting can eliminate viable weed seeds and pathogens in the product, and odours during application are minimized (Lory *et al.*, 2004).

2.4.3. Sewage sludge

The amendment of agricultural soils with municipal sewage sludge provides a valuable source of plant nutrients, organic matter and acts as a soil conditioner which improves the soil structure (Kidd *et al*., 2006). Research results indicate that application of appropriate sewage sludge rate does not have harmful environmental effect which is why it is used as a source of macro- and micro-nutrients, including P and N, in most farmlands (Bourioug *et al.,* 2014). Its usage however is limited by the addition of heavy metals, eutrophication risks and excess of labile organic matter stressing the need for further investigations on the authorization and spreading use of sewage sludge. A ten-year study which compared sewage sludge amended soils and non-amended soils by Kidd *et al.* (2006) showed increase in soil pH, N, Olsen-extractable-P, dissolved Organic Carbon and exchangeable Ca, Mg and K contents, together with soil metals (Cu, Zn and Mn). The organically bound sludge metals are less available for plant uptake as compared to the metals found in commercial fertilizers (Kidd *et al.,* 2006; Singh and Agrawal, 2008). Dry sewage sludge contains 2.0-3.5% N, 1.0-5.0% P_2O_5 and 0.2-0.5% K_2O (Chandra, 2005).

2.4.4. Crop residues and other forms of organic wastes

The parts of plants left on the soil when crops are harvested are called crop residues (Kabirinejad *et al*., 2014). The use of crop residues as cheaper alternatives has been a common practice known for its great impact on soil health (physical, chemical and biological), crop productivity and greenhouse gas emissions (Baruah and Baruah, 2015). Furthermore, organic amendment affects soil organic carbon pool, nutrients and microbial activities which are important for crop production as a way of recycling micronutrients into the soil (Nagar *et al.*, 2016). Crop residues may also affect the soil physical properties such as porosity, bulk density, water sorptivity and aggregate stability (Shaver, 2010). Shaver, (2010) reported a linear increase in water sorptivity and porosity with decrease in bulk density with crop residue addition over a twelve-year period.

The decomposition of organic matter from crop residues increases the content of micronutrients in soil but differs significantly with crop types (Kabirinejad *et al*., 2014). Kabirinejad *et al*. (2014) reported that rice and wheat crops take up 50- 80% of Zn, Cu and Mn which are later recycled through residue incorporation into the soil resulting in a significant decrease in soil pH, and an increase in electrical conductivity (EC), Organic Carbon (OC) and extractable Cu. Legumes are good sources of N as compared to all cultivated crops. Crops such as maize, wheat and rice may require 3-5 months to take up 20 to 40 kg N/ha required to satisfy N requirements, therefore are rarely used for field nutrient recycling (Ladha and Peoples, 1995). Crop residues like cereal straws contain between 0.4 and 1.3 % N, 1.0 to 1.25% potassium with 0.1% P (Smil, 1999).

2.5. Effect of organic manure amendment with phosphate rock on P availability

2.5.1. Solubility of rock phosphate

Phosphorus fertilizer application remains a major practice in the improvement of crop yield but its major constraint is that even though P fertilizer is applied, 20% or less is taken up by crops from rock phosphate due to its non-reactive character (Saleem *et al.,* 2012). Phosphate rock occurs all over the world and is considerably utilized for industrial fertilizer processing but may also be amended with organic materials to improve its efficiency. However, its efficiency depends on its solubilization and the precipitation of its inorganic form (Ekelof, 2007). It is a naturally occurring body found in the calcium matrix as P_2O_5 and may be more effective than the soluble super phosphate. Its efficiency is highly affected by the Ca content, low organic matter and low cation exchange capacity of soil (Lorion, 2004). High soil organic matter promotes the solubility of rock phosphate by forming complexes with the Ca ions (Bradl, 2004; Lorion, 2004). The advantage of the use of ground phosphate rock (GPR) is that macronutrients such as Ca, Mg and K become more available through dissolution (Lorion, 2004).

According to Wani *et al*. (2009), results of field experiments conducted in different states showed that phospho-compost can enrich the P requirement for various crops. Many approaches have been used to increase the solubility of P from GPR, which include incorporation of additives into the rock, partial acidulation, compaction of the rock phosphate with water soluble P fertilizer and microbial methods (Odongo *et al.,* 2007).

Compost as fertilizer or soil conditioner improves the soil quality by enhancing aeration, water status, macro and micro nutrients and aggregate stability which perk up plant growth (Chaundhry *et al.,* 2013). Nonetheless, composting process decreases the content of total C, NH_4-N, C:N ratio, and increase the cation exchange capacity, humification index, degree of polymerization, humification rate, P, potassium and total N (Hellal *et al.,* 2013). However, composting manure with GPR, herein described as co-composting, has been reported to enhance the dissolution of GPR (Akande *et al.*, 2005); and thus contributes positively towards increasing P solubility and availability for plant uptake. It has also been reported to enhance the replenishment of N through the improvement of the overall fertility of soils (Sahrawat *et al.,* 2001). Akande *et al.* (2005) studied the effectiveness of rock phosphate amended with poultry manure on soil available P and yield of maize and cowpea. Findings from their study showed that the GPR solubility and P availability were enhanced by the effect of the poultry manure. Following application of phospho-compost as compared to compost alone, half of the insoluble P in GPR is transformed into citric acid soluble P (Hellal *et al*., 2012). Phosphate fixation is reduced and efficiency of both organic and inorganic P is increased (Kolay, 2007).

2.5.2. Phosphorus use efficiency

According to Vance *et al.* (2003), the improvement of P acquisition and use by plants is critical for economic, humanitarian and environmental reasons. Regrettably, the potential of trees to improve soil P content through nutrient recycling is low as biomass usually contains low amounts of P (Lehmann *et al.*, 2001). However, due to rising energy costs and the unavailability of chemical fertilizers the need for organic manures like poultry manure and cattle manure is increasingly being recognized (Abbas *et al.*, 2012). Hellal *et al*. (2013) emphasized the improvement of the agronomic efficiency of crops, which Fageria and Filho (2008) defined as the economic production obtained per unit of nutrient applied. Nonetheless, the use of hazardous environmental phosphate fertilizers has raised concerns in the strategies required to improve agricultural practices in low P soils (Narang *et al.,* 2000). Such strategies must encourage phosphorus-use efficiency in the soil by the plants; and include among others, those aimed at conservation of use and those directed towards enhanced acquisition or uptake.

Application of phospho-composts from poultry and cattle manures is becoming a common practice as a low-input technology to improve P availability (Odongo *et al.,* 2007). Direct application of non-reactive rock phosphate has been reported not to be beneficial to crop due to its low reactivity (Hellal *et al*., 2013). However, amendment with compost has been reported to promote P availability and plant uptake; and thus improves acquisition and P-use efficiency through the chelating of cations by organic acids and other decay products (Hellal *et al*., 2013; Ransom *et al.*, 2011). The processes that lead to enhanced P uptake include increased production and secretion of phosphatases, exudation of organic acids, greater root growth along with modified root architecture, expansion of root surface area by prolific development of root hairs, and enhanced expression of P transporters (Vance *et al.*, 2003). Hence, sustainable management of P in agricultural land will require the discovery of mechanisms that enhance P acquisition, the exploitation of these adaptations to make plants more efficient at acquiring P and the development of P-efficient germplasm and advance crop management schemes that increase soil P availability (Hellal *et al*., 2012). The most important parameter in measuring the performance of a crop is the ability of the crop to supply nutrients to the seeds (Nielsen *et al*., 2001).

CHAPTER 3

RESEARCH METHODOLODY

3.1. Description of the study site

The study was conducted at University of Limpopo, Experimental Farm, Syferkuil (23° 50’S, 29° 40’E). The site falls within the semi-arid zone of Limpopo Province, with a long term mean annual rainfall of ±495 mm per annum. The farm has a mean annual temperature of 25±1˚C (maximum) and 10±1°C (minimum) with the soils mostly sandy loam in texture and classified as Hutton according to the South Africa classification system (Phefadu and Kutu, 2016) or Rhodic Ferralsol (WRB, 2006). The experiment was initiated in 2015 and also repeated in 2016. Results of pre-planting soil analyses prior to planting of the trial in both years are presented in Table 1.

Table 1: Soil pH and nutrient content at the experimental site prior to planting

Trial Year	pH	P (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Exch-acidity (cmol/kg)	Total cation (cmol/kg)	Zn (mg/kg)
2015	7.41	100	176	1515	712	0.14	14.01	0.8
2016	7.67	94	100	1555	670	0.12	12.12	0.2

3.2. Description of the experiment, research design and trial layout

The field experiment consisted of two phospho-compost types (poultry and cattle manure-based) each applied at five different rates (0, 20, 40, 80 & 120 kg /ha). The 0 kg /ha represented the un-amended control while the 120kg /ha rate represented the recommended compost application rate according to Niederwieser (2003). Broiler poultry manure (PM) and cattle manure-based (CM) phospho-composts used for the study were obtained from the Syferkuil University of Limpopo, Experimental Farm from previously produced by thermophilic process in heap using the windrow composting. The 7:3 and 8:2 phospho-composts mix ratios (manure: GPR ratio, dry mass basis) that were reported to contain significantly higher plant available P than the 9:1 and 5:5 mix ratios in earlier studies were used (Chauke, 2014) and were applied two weeks prior to planting (Table 2).

Table 2: Total N, P and K content in the different phospho-compost treatments

Treatments	Total N (%)	Total P (%)	Total K (%)
PM7:3	0.41	2.63	4.03
PM8:2	0.59	1.70	5.02
CM7:3	0.32	2.28	2.28
CM8:2	0.50	1.90	2.42

PM = poultry manure-based phospho-composts, CM = poultry manure-based phospho-composts, GPR= 36.5% P (Source: Chauke, 2014)

The trial was laid out in a split-split plot arrangement fitted into a randomised complete block design with treatments replicated three times. Each 3 m × 5 m (15 m^2) experimental unit/ plot consisted of an inter- and intra-row spacing of 1 m and 30 cm, respectively, resulting in three rows and 51 plants per plot.

Planting of sprouted seeds of the cultivar Mondial was done on a minimum tilled soil on 300 mm ridges cultivated by a tractor during 2015 planting. The cultivar Valor was however used during 2016 planting because it was the one readily available. Regular irrigation scheduling of 35 to 45 mm water per week was adjusted as required at different plant growth stages and climatic conditions. Weeding was done mechanically once a week to ensure minimum competition. A pest and disease rotation schedule was created. Dithane M 45 and Copper oxychloride 85 WP were used for disease control. Dimethoate (40 EC), Lamdax (5 EC), Malathion (50% EC) were used for pest control. Efekto Red spidercide was used for red spider mite control as recommended by the manufacturer.

3.3. Data collection

3.3.1 Growth, yield and quality parameters collected

The growth parameters measured included the determination of plant height using a tape measure, chlorophyll content using a chlorophyll meter (Opti-Sciences CCM 200 plus) and the counting of the number of leaves and stems on 5 randomly selected plants per plot at flowering stage. Plant tissue sampling of leaves at tuber initiation stage were collected on 5 randomly selected plants per plot, oven-dried to a constant weight at 65^{o}C; and used for colorimetric P uptake determination following the procedure described by Wetzel and Likens (2000).

During harvesting, the middle row was harvested using a fork, the number of tubers per plant were counted and tuber yield was determined using a weighing scale. The tubers from each row were graded into the following size groups by weight: Baby (5-50 g), Small (50-100 g), medium (100-170 g), large-medium (170-200 g) and large (≥ 250 g) as described by Niederwieser (2003). The potatoes were further graded into classes namely class 1, class 2, class 3 and lowest class according to quality requirements marked down by degree of malformations such as decay, insect and mechanical damage, heat and cold damage, wateriness and greening (Wale *et al*., 2008). Nutritional quality parameters collected from the tuber tissues included the analyses of crude protein and dry matter content as described by Sulaiman (2005).

3.3.3 Soil analysis

Surface soil samples (0-15 cm depth) were obtained during flowering (sampling stage 1) and after harvesting (sampling stage 2) for laboratory analysis. Soil pH determination using pH meter was according to Thomas (1982), available P was achieved using the Bray P1 extracting solution containing a mixture of 0.03 M NH4F + 0.025 M HCl (Hellal *et al*., 2013), organic carbon was by the Walkely-Black method (Schumacher, 2002) while mineral N (i.e. ammonium and nitrates) content was as described by Bodelier and Hendrikus (2004).

3.4 Mineral composition in plant tissues

Mineral (Ca, Mg, K, Na, Cu, Fe, Mn & Zn) analysis from 5 g plant tissues (including composts) done following nitric and perchloric acid digestion (AOAC, 2012); and the mineral content in the digest measured on atomic absorption spectrophotometer (AAS). Analysis of N and P in 0.5 g in tissue sample is digested using H_2SO_4 + selenium tablets as catalyst mixture (AOAC, 2012) and concentrations in digest measured colorimetrically using vanadomolybdate reagent on a SKALAR continuous flow (an automated wet chemistry) analyser. The content of crude protein (CP) was estimated from total N using the equation: CP = TN x 6.25 (AOAC, 2012)

3.5 Statistical analysis

Growth and yield parameters collected were subjected to the analysis of variance if the data collected follows the analysis of variance (ANOVA) assumptions, using Statistix 10.0 computer software and the mean separation done using LSD at 5% level of significance. Multiple correlation and regression analyses were run between tuber yield and plant growth parameters.

CHAPTER 4

RESULTS

4.1. Effects of phospho- compost on soil chemical compositions

4.1.1 Soil pH as affected by phospho-compost types and application rates

The results from the ANOVA showed that there was a significant difference ($p<0.05$) in the measured pH value of soil samples collected at flowering and non- significant at harvest stage among the different compost types in 2015 (Appendix 1 & 2, Table 3). In 2015, the highest pH value of 7.77 was recorded at flowering in plots that received CM8:2 and the lowest pH of 7.53 in PM8:2 plots. However, significant differences ($p<0.05$) were observed in both flowering and harvest stages in 2016 (Appendix 3 & 4). In 2016 flowering stage, the highest pH value of 7.71 was observed from the PM8:2 plots and the lowest pH value from PM7:3 (7.63). The pH value of 8.02 recorded from PM8:2 plot at harvest was highest among the phospho-compost treatments while the CM8:2 had the least value of 7.63. There were no observed significant differences in the measured pH values among the phospho-compost application rates as well as compost types x application rates interaction during harvest. Nonetheless, the coefficient of variation among the phospho-compost treatment means was marginal (<3%) from the 2015 trial but generally very high (>24%) in the 2016 trial.

Comparison of pH data from the various treatments across the 2-years revealed highly significant ($p=0.000$) year as well as year of planting x compost types application differences at both soil sampling stages (Appendix 5, Table 4). The highest pH value observed across the 2 years was in CM8:2 plots (7.77) at flowering in 2015 but from PM8:2 plots (8.02) at harvest. These measured highest pH values from CM8:2 and PM8:2 plots, respectively during flowering in 2015 and harvesting stages in 2016 make the soils alkaline.

Table 3: Effects of phospho- compost types and application rates on soil pH

	2015		2016	
Treatments	Flowering stage	Harvest stage	Flowering stage	Harvest stage
Compost types				
PM 8:2	7.53b	7.51a	7.74a	8.02a
PM 7:3	7.55b	7.43a	7.63c	7.90ab
CM 8:2	7.77a	7.81a	7.67bc	7.63c
CM 7:3	7.76a	7.70a	7.71ab	7.67bc
F-value (0.05)	*	NS	*	*
CV	1.82	5.62	7.68	3.50
LSD (≤0.05)	0.12	-	0.066	0.24
Phospho-compost rates (t ha^{-1})				
0	7.66	7.29	7.71	7.81
20	7.50	7.29	7.67	7.79
40	7.73	7.41	7.67	7.79
80	7.64	7.57	7.72	7.84
120	7.65	7.59	7.67	7.81
F-value (0.05)	NS	NS	NS	NS
CV	1.01	3.57	1.03	1.16
LSD (≤0.05)	-	-	-	-

Means within same column sharing the same letters are not significantly different at P≤0.05; *= significantly different, ns= non-significant.

Table 4: Effects of phospho-compost application on soil pH between trial year x compost types interaction at flowering and harvest stages

Year	Compost	Flowering	Harvest
2015	PM8:2	7.52d	7.51ef
2015	PM7:3	7.55d	7.43f
2015	CM8:2	7.77a	7.81bc
2015	CM7:3	7.76a	7.70cd
2016	PM8:2	7.67ab	8.02a
2016	PM7:3	7.63c	7.90ab
2016	CM8:2	7.74ab	7.63de
2016	CM7:3	7.71abc	7.67cde
F-value (0.05)		**	***
CV		1.41	3.21
LSD (<0.05)		0.08	0.18

Means within same column sharing the same letters are not significantly different at P≤0.05; *= significantly different, ns= non-significant.

4.1.2. Available P content as affected by phospho- compost types and application rates

Significant (p<0.05) differences in soil available P content measured were recorded at both sampling stages in 2015 and 2016 following application of the different phospho-compost types (Appendix 1-4, Table 5). In 2015, available P content obtained in soil samples collected at flowering was highest in PM8:2 phospho-compost applied plots (123.33 mg/kg) while CM7:3 applied plots had the least value of 75.87 mg/kg. Available P content at crop harvest measured in PM8:2 compost applied plots (117.13 mg/kg) were also highest while CM7:3 applied plots similarly had the least available P content (74.20 mg/kg).

In the 2016, the highest available P content of 68.47 mg/kg was obtained from PM8:2 plots at flowering stage while the 49.67 mg P/kg from CM8:2 plots was the least. However at crop harvest, the highest available P content of 66.40 mg/kg recorded in the PM7:3 phospho-compost applied plots were 7.4% higher than the obtained value in PM8:2 plot, albeit their statistical similarity. The lowest available P content of 43.53 mg P/kg at harvest was found in the CM8:2 plot. None of the phospho-compost application rates or compost types x application rates interaction exerted any significant effect on the content of soil available P measured during the two sampling stages in 2015 and 2016 (Appendix 1-4).

Table 5: Effects of phospho- compost types and application rates on soil available P (mg/kg) content

Treatments	2015		2016	
	Flowering	Harvesting	Flowering	Harvesting
Compost types				
PM8:2	123.33a	117.13a	68.47a	61.80a
PM7:3	99.93ab	89.60ab	62.87a	66.40a
CM8:2	82.33b	75.07b	49.67b	43.53b
CM7:3	75.87b	74.20b	59.20ab	54.60ab
F-value (0.05)	*	*	*	*
CV	36.49	34.65	20.58	23.70
LSD (≤0.05)	31.10	27.55	11.04	11.93
Phospho-compost rates (t ha^{-1})				
0	99.67	82.00	51.58	48.17
20	84.67	84.58	58.25	64.91
40	102.50	87.75	56.33	48.33
80	93.58	87.58	63.75	55.58
120	96.42	103.33	70.33	65.91
F-value (0.05)	NS	NS	NS	NS
CV	38.43	26.77	27.39	47.89
LSD (≤0.05)	-	-	-	-

Treatment means in columns sharing the same letters are not significantly different at P≤0.05 according to LSD test. *= significantly different, ns= non-significant

4.1.3. Effect of phospho-compost types and application rates on exchangeable K content

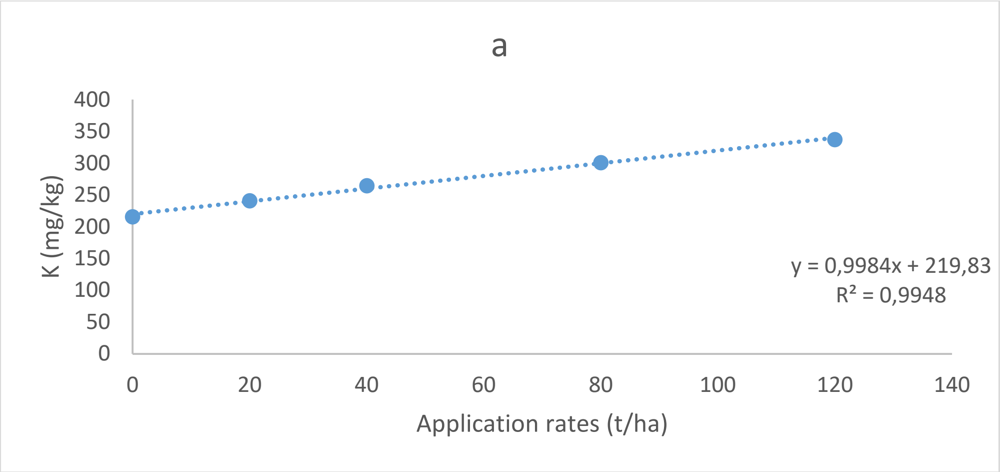
It was observed from the results (Table 6 and appendices 1 & 3) that there was no significant ($p>0.05$) difference in the measured K content among the different phospho-compost types at flowering and crop harvest in 2015. However, significant ($p<0.05$) differences existed in 2016 between the compost types during flowering and harvest (Appendices 3 & 4). The measured exchangeable K contents in 2015 from the various phospho-compost applied plots were quantitatively higher than those measured in 2016. The highest K content measured in the soil was recorded in PM7:3 plots with 234.40 mg/kg and the lowest in CM7:3 with 179 mg/kg in 2016 at flowering stage. The highest exchangeable K content of 202.73 mg/kg in 2016 was obtained from PM7:3 plots while the lowest content of 94.60 mg/kg was recorded in CM8:2 plots at harvest stage.

The effects of phospho-compost application rates on exchangeable K content at harvest stages during 2015 and 2016 trial seasons were not significant ($p>0.05$). Nonetheless, significant differences were observed at flowering in 2015 ($p<0.05$) and 2016 ($p<0.01$). There were positive correlations with linear relationships between phospho-compost application rates and K contents at flowering during 2015 and 2016 (Figure 1). High and positive correlation coefficients (r^2-values) of 0.995 and 0.881 were obtained in 2015 and 2016, respectively suggesting an increase in K contents with increasing phospho-compost application rates.

Table 6: Soil exchangeable K and Ca content (mg/kg) as affected by phospho-compost types and application rates

Treatments	Exchangeable K (mg/kg)				Exchangeable Ca (mg/kg)			
	2015		2016		2015		2016	
	Flowering	Harvest	Flowering	Harvest	Flowering	Harvest	Flowering	Harvest
Compost types								
PM8:2	286.47	230.47	192.00a	162.47ab	1713.5	1674.9	1210.5ab	1338.3a
PM7:3	271.60	234.40	163.87b	202.73a	1578.9	1466.4	1407.7a	1321.9a
CM8:2	220.40	201.60	160.93b	94.60c	1545.0	1404.8	995.9b	967.4b
CM7:3	257.40	179.53	149.93b	116.53bc	1274.5	1375.4	976.9b	1033.2b
F-value (0.05)	NS	NS	*	*	NS	NS	*	*
CV	42.34	33.83	13.64	48.59	29.67	26.89	23.24	22.40
LSD (≤0.05)			20.31	62.56	-	-	238.28	233.21
Phospho-compost rates (t ha^{-1})								
0	215.58b	194.42	140.33	152.52	1591.6	1354.3	959.4b	1089.5
20	240.67b	169.25	151.58b	136.92	1476.9	1280.1	1147.7ab	1023.5
40	264.50ab	206.25	162.58b	119.75	1452.6	1472.4	1143.4ab	1150.4
80	300.84b	226.33	165.67b	144.00	1422.9	1560.4	1211.8a	1275.4
120	337.17a	261.25	213.25a	167.50	1695.9	1734.8	1276.3a	1287.3
F-value (0.05)	*	NS	*	NS	NS	NS	**	NS
CV	37.80	42.78	26.88	70.82	23.32	29.4	18.71	31.84
LSD (≤0.05)	81.40	-	37.26	-	-	-	178.59	-

Treatment means in columns sharing the same letters are not significantly different at p<0.05 according to LSD test; *= significantly different, ns= non-significant



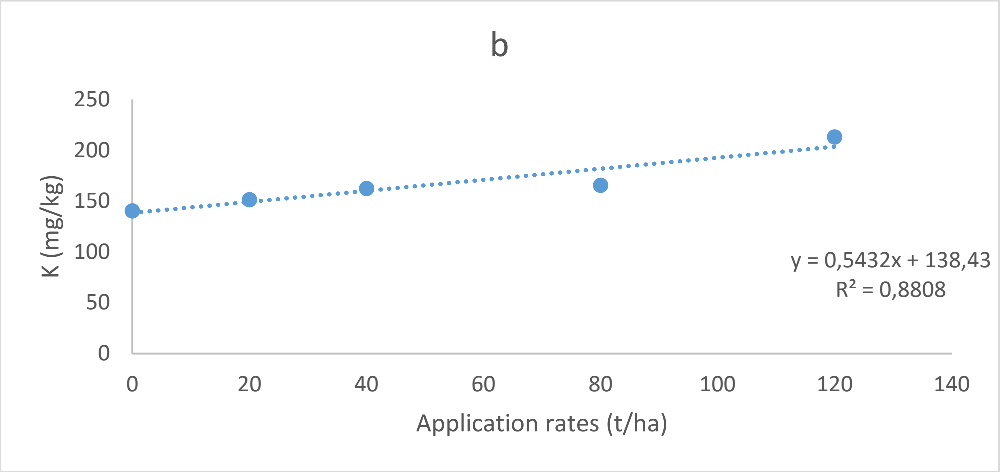


Figure 1: Exchangeable K (mg/kg) content as affected by phospho- compost application rates.

4.1.4. Exchangeable Ca content as affected by phospho-compost types and application rates

No significant ($p>0.05$) differences were observed in the Ca content across compost types in the soil samples taken during 2015 at flowering (Appendix 1) and harvest (Appendix 3). However, the differences in 2016 at flowering (Appendix 2) and harvest stages (Appendix 4) were significant ($p<0.05$). The maximum concentrations of Ca were observed from the PM7:3 with 1407.7 mg/kg at flowering while minimum Ca concentrations were found in CM7:3 and CM8:2 with 976.9 mg/kg. On the other hand, the PM8:2 phospho-compost mix ratio gave the highest Ca content (1338.3 mg/kg) while the CM8:2 compost types gave the least Ca content (967.4 mg/kg) at harvest (Table 6). There was an increase in Ca contents with increasing application rates.

Similar to the measured exchangeable K content, highly positive and significant correlation coefficients (r^2-value) of 0.798 and 0.815 were observed during flowering and harvest respectively (Figure 2). Compost types and x application rates had no significant relationship on the Ca content.

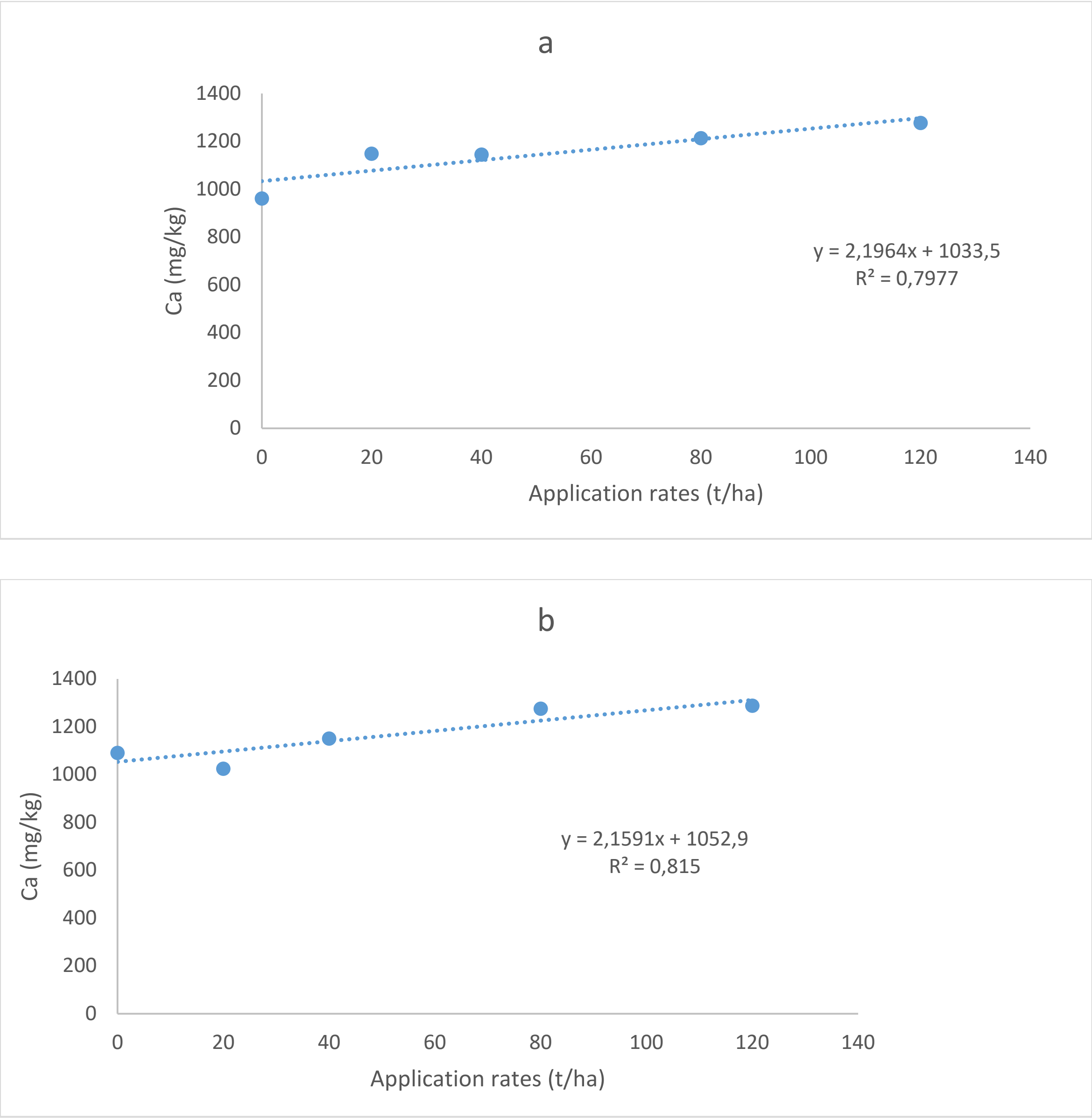


Figure 2: Exchangeable Ca (mg/kg) soil content as affected by phospho-compost rates. (a) flowering and (b) harvest

4.1.5. Variation in soil chemical composition as affected by phospho-compost types and application rates

Phospho-compost type had inconsequential (p>0.05) effect on the Mg and total cation contents of soil samples taken at flowering and harvest stages during 2015 and 2016

(Appendix 1-4). However, significant differences ($p<0.001$) were observed during flowering in the content of exchangeable acidity across compost types in 2015. The highest exchangeable acidity value of 0.10 cmol/kg was measured in soil samples with PM8:2 and PM7:3 amendment while the lowest value of 0.04 cmol/kg was measured in CM8:2 plots at flowering stage (Table 7). The exchangeable acidity measured at harvest was in PM7:3 phospho-compost amended plots was highest while the lowest value of 0.50 cmol/kg in was measured in CM8:2 and CM7:3 phospho-compost amended plots. The content of Zn measured at harvest in 2016 differed significantly ($p<0.05$) across compost types (Table 8; Appendix 3); being highest (0.29 mg/kg) in PM8:2 phospho-compost amended plot and least (0.10 mg/kg) in CM7:3 and CM8:2 amended plots.

The rates of compost application showed no significant ($p>0.05$) effects on the soil chemical contents at both sampling stages except for the total cation at harvest and exchangeable acidity at flowering in 2015. There was a positive correlation with a linear relationship (Figure 3) on total cation content. There was an increase in Exchangeable acidity and total cation contents with increasing application rates. High correlation coefficients (r^2-values=0.79 and 0.084) were observed on the exchangeable acidity and total cation respectively. Furthermore, significant differences were found between the compost types x application rates interaction on the mg ($p<0.05$) and exchangeable acidity ($p<0.01$) contents (Table 9). This was further illustrated in figure 4 showing a relative increase in Mg content with increasing application rates on the PM8:2 treatment. The same trend was also observed on the PM7:3 compost type. CM8:3 however, showed its optimum content at 40 t/ha. CM7:3 showed lower contents at higher application rates and higher contents at lower application rates. Furthermore, the results showed a decreasing exchangeable acidity with increasing application rates on the PM7:3 compost type. Optimum application rates were observed at 80t/ha from the PM8:2 but 40 t/ha on CM8:2 phospho-compost.

Table 7: Effect of phospho-compost types and application rates on soil mineral contents of trace elements in 2015

Treatments	Flowering				Harvest			
	Mg (mg/kg)	Exch Acidity (cmol/kg)	Tot cation (cmol/kg)	Zn (mg/kg)	Mg (mg/kg)	Exch Acidity (cmol/kg)	Tot cation (cmol/kg)	Zn (mg/kg)
Compost types								
PM7:3	648.67	0.10	14.06	0.48	645.40	0.10	13.91	0.41b
PM8:2	659.33	0.09	14.76	0.54	640.13	0.09	14.32	0.59a
CM7:3	618.47	0.09	12.10	0.37	602.47	0.08	12.42	0.39b
CM8:2	705.67	0.09	14.06	0.32	606.20	0.09	12.55	0.37b
F-value	NS	NS	NS	NS	NS	NS	NS	*
CV	16.68	30.09	21.70	44.70	12.04	26.81	15.92	34.10
LSD (≤ 0.05)	-	0.024	-	-	-	-	-	1.89
Phospho-compost rates (t ha^{-1})								
0	640.83	0.08	13.85	0.37	622.75	0.09	12.47bc	0.45
20	629.83	0.09	13.26	0.34	578.58	0.08	11.66c	0.44
40	636.33	0.09	13.25	0.46	666.50	0.09	13.45abc	0.40
80	678.83	0.09	13.39	0.50	626.17	0.10	14.37ab	0.41
120	704.33	0.11	15.23	0.47	623.75	0.09	14.22b	0.48
F-value	NS	*	NS	NS	NS	NS	*	NS
CV	14.56	25.60	17.20	48.41	14.05	24.38	18.52	30.04
LSD (≤ 0.05)	-	0.024	-	-	-	-	1.89	-

Treatment means in columns sharing the same letters are not significantly different at $P \leq 0.05$ according to LSD test. *= significantly different, ns= non-significant

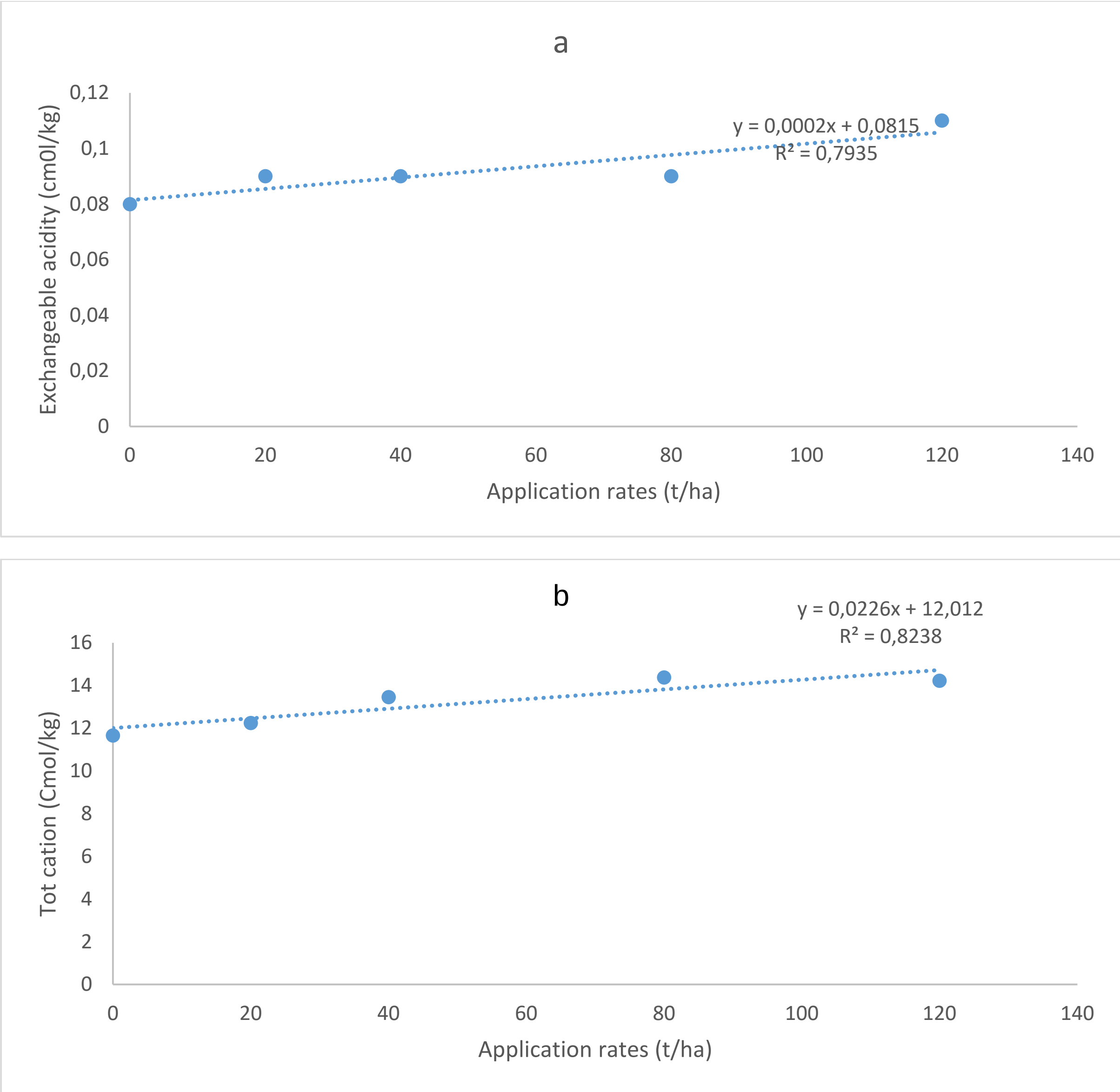


Figure 3: Effect of variable rates of phospho-compost on (a) exchangeable acidity (b) total cation content (Cmol/kg).

Table 8: Phospho-compost types and application rates effects on soil mineral contents of trace elements in 2016

	Flowering				Harvest			
Treatments	Mg (mg/kg)	Exch Acidity (cmol/kg)	Tot cation (cmol/kg)	Zn (mg/kg)	Mg (mg/kg)	Exch Acidity (cmol/ kg)	Tot cation (cmol/ kg)	Zn (kg/L)
Compost types								
PM8:2	571.40	0.10a	113.43	0.29	583.53	0.09a	97.74	0.29a
PM7:3	558.87	0.10a	11.60	0.21	562.33	0.10a	11.92	0.19ab
CM8:2	575.12	0.04b	10.44	0.15	589.20	0.05b	67.42	0.12b
CM7:3	569.60	0.07ab	16.80	0.10	587.60	0.05b	10.58	0.10b
F-value	NS	*	NS	NS	NS	**	NS	*
CV	10.79	53.42	505.41	98.46	8.50	29.67	450.83	85.03
$LSD_{(\leq 0.05)}$	-	0.04	-	-	-	0.02	-	0.03
Phospho-compost rates (t/ha)								
0	563.25	0.09	10.85	0.18	572.08	0.08	11.08	0.22
20	581.58	0.08	11.05	0.18	601.58	0.07	118.23	0.19
40	550.50	0.07	10.72	0.16	602.17	0.08	10.93	0.14
80	547.58	0.06	19.37	0.18	544.67	0.06	11.27	0.15
120	600.83	0.08	138.22	0.23	582.83	0.07	83.06	0.17
F-value	NS	NS	NS	NS	NS	NS	NS	NS
CV	10.85	40.54	515.94	89.24	14.17	54.89	422.34	113.14
$LSD_{(\leq 0.05)}$	-	-	-	-	-	-	-	-

Treatment means in columns sharing the same letters are not significantly different at P≤0.05 according to LSD test. *= significantly different, ns= non-significant

Table 9: Phospho-compost types x application rates interaction effect on Mg and exchangeable acidity contents in the soil

Compost types	Application Rates (t ha^{-1})	Mg (mg/kg)	Ex. acidity (Cmol/kg)
PM8:2	0	522ef	0.10a
PM 8:2	20	555bcde	0.08ab
PM8:2	40	579bcde	0.10a
PM8:2	80	614abc	0.10a
PM8:2	120	618ab	0.09a
PM7:3	0	575bcde	0.11a
PM7:3	20	563bcde	0.10a
PM7:3	40	551bcde	0.09a
PM7:3	80	533def	0.10a
PM7:3	120	581bcde	0.09a
CM8:2	0	563bcde	0.05bc
CM8:2	20	611abcd	0.05bc
CM8:2	40	663a	0.09a
CM8:2	80	468f	0.00d
CM8:2	120	606abcd	0.05bc
CM7:3	0	623ab	0.08ab
CM7:3	20	601abcde	0.08ab
CM7:3	40	537cdef	0.02cd
CM7:3	80	570bcde	0.04bc
CM7:3	120	563bcde	0.07ab
F-value (0.05)		*	**
LSD(≤0.05)		80.97	0.04

Treatment means in columns sharing the same letters are not significantly different at P≤0.05 according to LSD test. *= significantly different, ns= non-significant

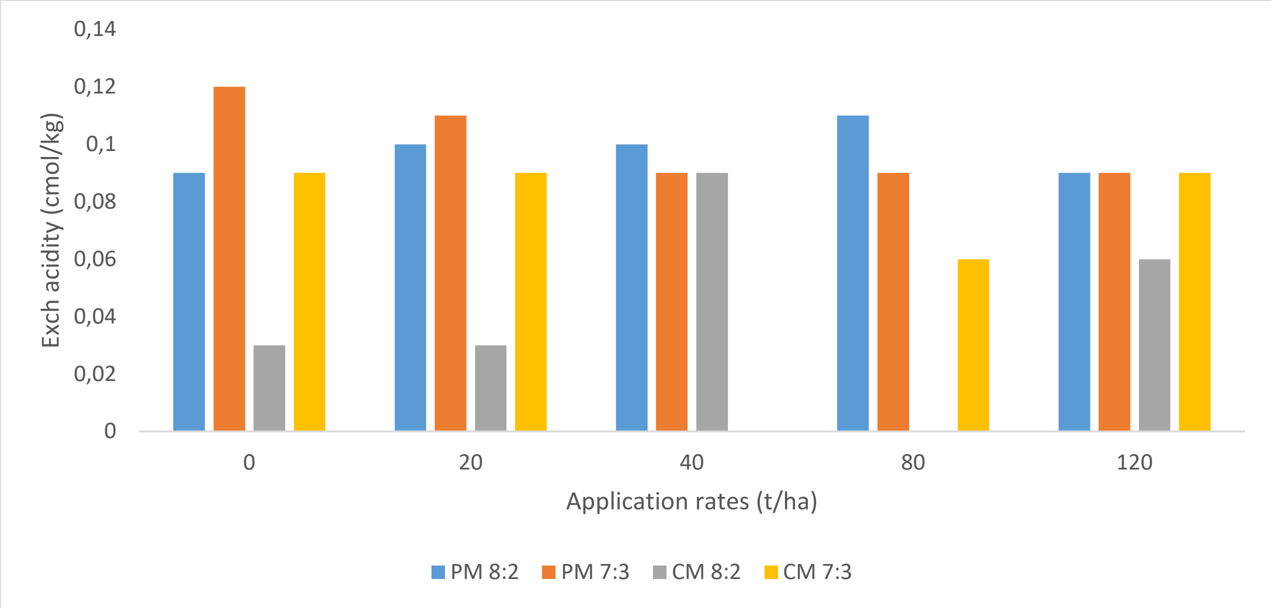


Figure 4: Effects of application rates on soil exchangeable acidity (Cmol/kg) content

4.2. Effect of phospho-compost application on growth and yield parameters

4.2.1 growth parameters

There were no significant ($p>0.05$) differences between the compost types, rates of application and their interaction on the plant population, number of stems/plant, number of leaves/ plant, plant height and chlorophyll content in both trials. However highly significant ($p<0.001$) differences were observed between 2015 and 2016 on plant fresh and dry leaves (Appendix 7 & 8). The results show the highest population of 48 plants/plot was obtained in 2015 (table 10) and lowest population of 43 plants/plot in 2016 (table 11). The number of stem recorded in 2015 was two times higher than in 2016. Similarly higher trend was observed on the plant height in 2015 and 2016. Higher number of leaves per plant was obtained in 2015 than in 2016. However, the chlorophyll content behaved in vice versa as the other earlier reported growth parameters. Higher chlorophyll content was observed in 2015 with 43.13 cci and lower in 2016 with 16.25 cci. The fresh and dry leaves weight had less significant variation between trials years. The maximum fresh leaves weight of 13.13 g and dry weight of 3.36 were found in 2016. Minimum fresh leaves weight and dry leaves weight of 13.06 g and 3.06 g were observed in 2015. Highly significant ($p<0.001$) effects were further evident on the fresh and dry leaves weight collected between the trial year x compost types interaction (Appendix 9). In 2015, fresh leaves weight ranged between

13.75- 22.09 g and dry leaves weight ranged between 2.26- 3.90, with the highest weight found in the PM7:3 and the lowest in CM7:3 (table 12). There was a decrease in the fresh leaves weight during 2016 trial which ranged from to 7.48 to 9.16 g. The maximum weight was recorded from the PM7:3 and the minimum weight from the CM 7:3 compost types (Figure 5). dry leaves weight ranged from 3.07 to 3.65 g with the lowest weight from PM8:2 and highest weight from CM8:2 compost types.

Table 10: effect of phospho- compost types and application rates on growth parameters in 2015

Treatments	Plant pop/ Plot	No. stems/ plant	No. leaves/plant	Fresh leaves (g)	Dry leaves (g)	Plant height (cm)	Chlorophyll content (cci)
Compost types							
PM 7:3	47	5.85	90.43	8.64b	3.07b	28.55	19.06
PM 8:2	48	5.81	79.41	9.19a	3.29 ab	28.04	15.64
CM 7:3	51	6.35	84.37	9.21b	3.65a	27.96	13.84
CM8:2	45	5.80	89.56	7.48c	3.42ab	28.55	16.46
F-value	NS	NS	NS	***	***	NS	NS
CV(LSD $p \leq 0.05$)	13.87	10.99	19.38	(2.89)	(0.63)	16.29	34.28
Phospho-compost rates t/ha							
0	49	5.91	86.58	8.74	3.33	28.27	16.29
20	49	6.23	89.61	8.82	3.24	27.72	15.46
40	47	5.73	85.33	8.80	3.39	28.60	15.81
80	46	6.12	84.86	8.76	3.43	28.03	14.90
120	48	5.77	83.34	7.99	3.40	28.58	18.79
F-value	NS	NS	NS	NS	NS	NS	NS
CV (LSD $p \leq 0.05$)	8.45	13.32	10.70	22.84	29.99	10.42	33.81

Treatment means in columns sharing the same letters are not significantly different at $P \leq 0.05$ according to LSD test. *= significantly different, ns= non-significant

Table 11: Effect of phospho-compost types and application rates on growth parameters 2016

Treatments	Plant pop/ plot	No. Stems/ plant	No leaves / plant	Fresh leaves (g)	Dry leaves (g)	Plant height (cm)	Chlorophyll content (cci)
Compost types							
PM 8:2	43.80	6	72.30	8.64	3.07	38.89	43.80
PM 7:3	43.80	6	73.56	9.16	3.29	38.83	43.80
CM8:2	42.80	6	77.61	9.21	3.65	38.25	42.13
CM 7:3	42.13	6	76.47	7.48	3.42	39.75	42.80
F-value	NS	NS	NS	NS	NS	NS	NS
CV(LSD $p \leq 0.05$)	11.76	11.26	10.04	32.10	15.52	14.26	11.76
Phospho-compost rates (t ha^{-1})							
0	44.92	6	72.19	8.74	3.33	39.13	44.92
20	42.50	6	76.28	8.82	3.24	37.78	42.50
40	43.08	6	75.06	8.79	3.39	40.15	43.00
80	43.00	6	75.83	8.76	3.43	39.42	43.08
120	42.17	6	74.15	7.99	3.40	38.17	42.17
F-value	NS	NS	NS	NS	NS	NS	NS
CV(LSD $p \leq 0.05$)	10.12	13.10	8.75	23.92	13.76	8.71	10.12

Treatment means in columns sharing the same letters are not significantly different at $P \leq 0.05$ according to LSD test. *= significantly different, ns= non-significant

Table 12: Trial year X compost types as affected by phospho-compost application on growth and yield parameters

Trial year	Compost types	Plant population	Fresh leaves (g)	Dry leaves (g)	No tubers/ row	Dry matter %	Tuber yield t/ha)
2015	PM 8:2	48.40	18.02b	3.28bcd	10.28	3.15	16.00
	PM 7:3	46.73	22.09a	3.90a	12.14	4.84	22.14
	CM8:2	45.40	17.03b	2.83d	10.44	4.53	20.82
	CM 7:3	51.13	13.75c	2.26e	9.10	4.62	20.56
2016	PM 8:2	43.80	8.63d	3.07cd	8.74	6.29	33.04
	PM 7:3	43.80	9.16d	3.29bcd	9.22	5.70	27.54
	CM8:2	42.13	9.21d	3.65ab	9.71	6.81	33.44
	CM 7:3	42.80	7.48d	3.42abc	9.78	6.27	30.42
F-value		NS	***	***	NS	NS	NS
LSD (≤0.05)		-	2.29	0.52	-	-	-

Means in same column with the same letters are not significantly different at P≤0.05. *= significantly different, ns= non-significant

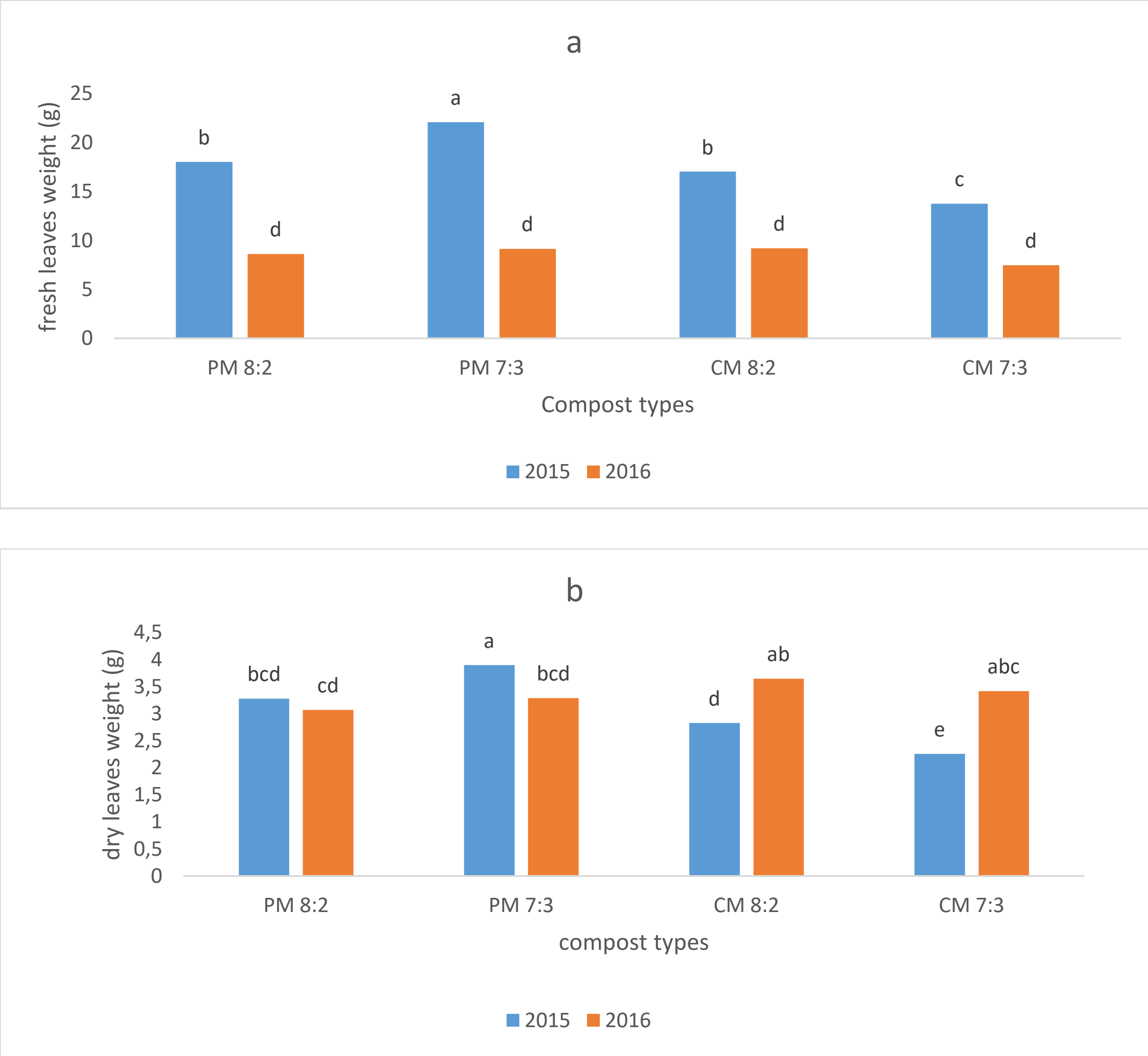


Figure 5: Effect of phospho- compost types on (a) fresh leaves weight and (b) dry leaves weight

4.2.2. Tuber yield

Average number of tubers per stem were not significantly ($p>0.05$) influenced by the compost types, rates of application and their interaction in 2015 (Appendix 7) and 2016 (Appendix 8). The number of stems however, ranged between 10–12 in 2015 (Table 13) which were lower than the number of tubers obtained in 2016. Analysis of variance showed highly significant ($p<0.001$) effect between the compost types on the dry matter % in 2015. Highest dry matter of 4.84 % was observed from the PM7:3 plots and the lowest percentage of 3.16% was found in the PM8:2 treatment. Although higher dry matter percentages were observed in 2016, there were no significant ($p<0.05$) differences between the compost types applied. The values ranged from 5.70%-6.71%. Furthermore, the application rates and Compost types x application rates interactions had no significant differences on the dry matter percentage.

Differences between the compost types significantly ($p<0.05$) influenced potato tuber yield (Appendix 8) with a CV% of 32.2 in 2015. The highest tuber yield of 22.14 t/ha was obtained in the PM7:3 plots while the least tuber yields of 16 t/ha was obtained from the PM8:2 compost type application (Table 13). However, phospho-compost types had no significant ($p>0.05$) impact on the tuber yields obtained in 2016. There were no significant ($p>0.05$) differences between the application rates and compost types x application rates interaction on the yield obtained in both trials. It was evident that the highest tuber yields were observed from the PM7:3 in 2015 and CM8:2 in 2016 (Figure 6). Optimum tuber yields were also observed on the 80t/ha application rate and the lowest on 120 t/ha in 2015. However, highest yields were obtained from the 0, 20 and 40 t/ha application rates in 2016. Analysis of variance in appendix 8 shows a non- significant relationship between the trial years on the percent dry matter, number of tubers per row and the tuber yield. Furthermore, no significant differences existed between the trial year x compost types interaction on the percent dry matter, number of tubers per row and the tuber yield.

Table 13: Effect of phospho-compost types and application rates on tuber yield

Treatments	2015			2016		
	No tuber/ stem	Dry matter (%)	Yield (t/ha)	No tuber/ stem	Dry matter (%)	Yield (t/ha)
Compost types						
PM7:3	10	4.84a	22.14a	14.13	5.70	27.54
PM8:2	12	3.16b	16.00b	13.13	6.29	33.04
CM7:3	11	4.63a	20.56a	14.40	6.27	30.42
CM8:2	10	4.64a	21.24a	13.00	6.71	33.02
F-value	NS	***	**	NS	NS	NS
CV(LSD $p \leq 0.05$)	22.52	(0.88)	(32.2)	23.60	38.65	38.65
Phospho-compost rates (t ha^{-1})						
0	12	4.03	19.58	12.42	6.35	31.87
20	10	4.53	20.28	13.75	5.79	31.26
40	10	4.11	19.97	13.67	6.84	32.04
80	11	4.76	21.65	13.58	5.85	28.56
120	11	4.15	18.47	13.92	6.39	31.20
F-value	NS	NS	NS	NS	NS	NS
CV(LSD $p \leq 0.05$)	18.65	30.29	23.32	12.38	33.88	33.88

Treatment means in columns sharing the same letters are not significantly different at P≤0.05 according to LSD test. *= significantly different, ns= non-significant

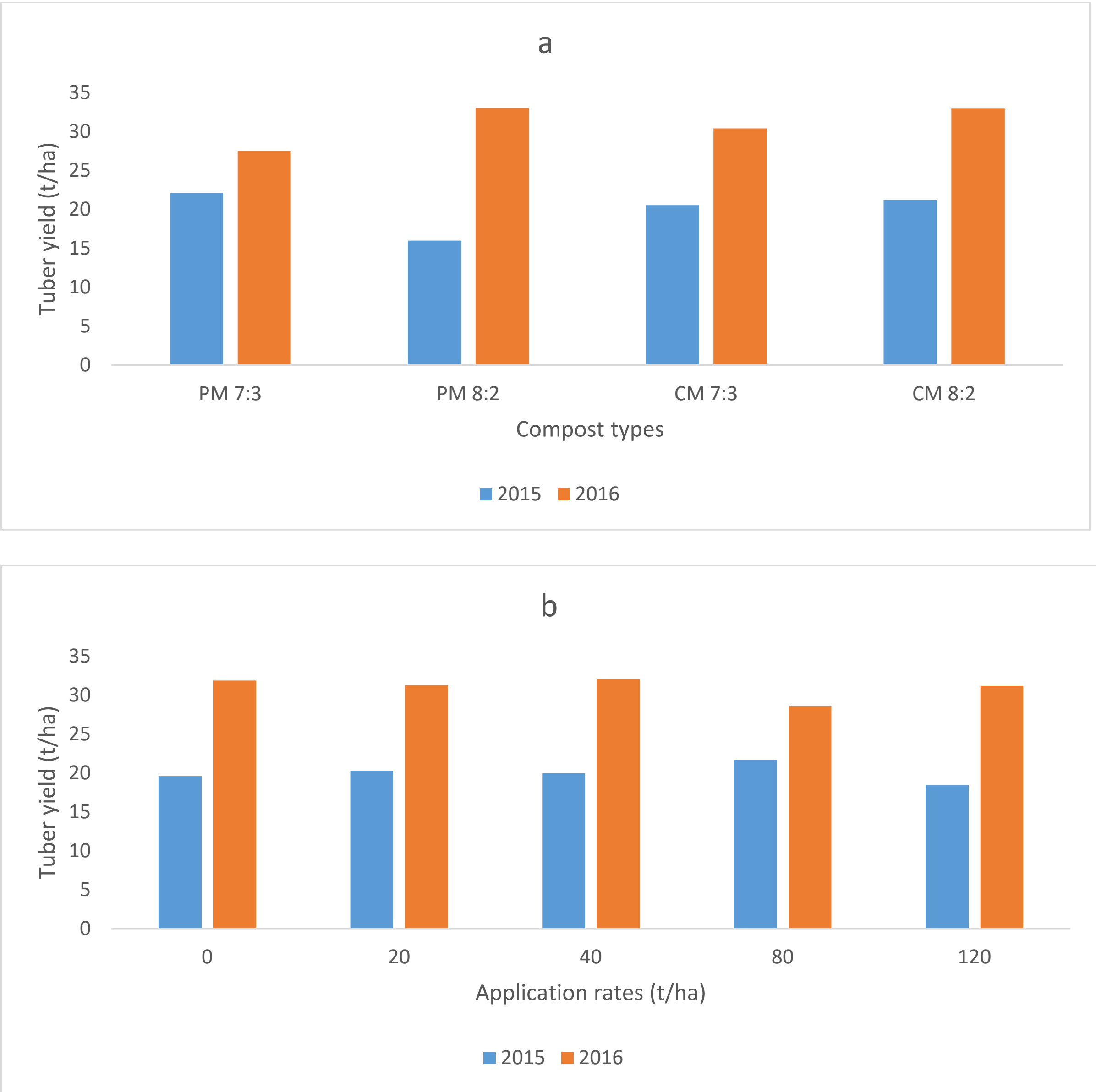


Figure 6: Effect of phospho- compost application on tuber yield (t/ha). (a) compost types and (b) application rates

4.3. Correlation and regression analyses on growth as affected by phospho-compost application

A non-significant relationship was observed on the number of stems/plant and number of leaves/plant (Table 14). However, a highly significant relationship was observed on the plant height and chlorophyll content with p-value of 0.00. The number of stems/plant showed a negative but significant correlation on the tuber yield and dry matter (Table 15). A similar relationship was observed also on the number of leaves/plant with tuber yield and dry matter. However, a positive and significant correlation was observed between the number leaves/plant and the number of stems/plant. Furthermore, there was a positive significant correlation between plant height and tuber yield and dry matter with a negative significant correlation on number of stems/plant and number of leaves/plant. A positively significant correlation was also observed between the chlorophyll content and tuber yield, dry matter percentage and plant height. However, negative but significant correlation was observed between chlorophyll content and number of stems/plant and number of leaves /plant. It is evident that both plant height and plant height^2 were significant predictors of p-values of 0.0036 and 0.0299 respectively with a polynomial fit (table 16). From this output, the estimated regression equation was $Y=21.95+0.59152X+0.06550X^2$ (r^2= 0.415; *p*-value=0.073) [Appendix 11].

Table 14: Poisson Regression tuber yield and plant growth parameters as affected by phospho-compost application

Predictor Variables	Coefficient	Standard error	Coefficient/ standard error	p-value
Constant	1.92	0.27	7.25	0.00
No.stems/plant	0.01	0.03	0.39	0.70
No.leaves/plant	2.57	1.35	1.91	0.06
Plant height (cm)	0.02	4.27	4.70	0.00
Chlorophyll content (Cci)	0.01	2.56	5.24	0.00

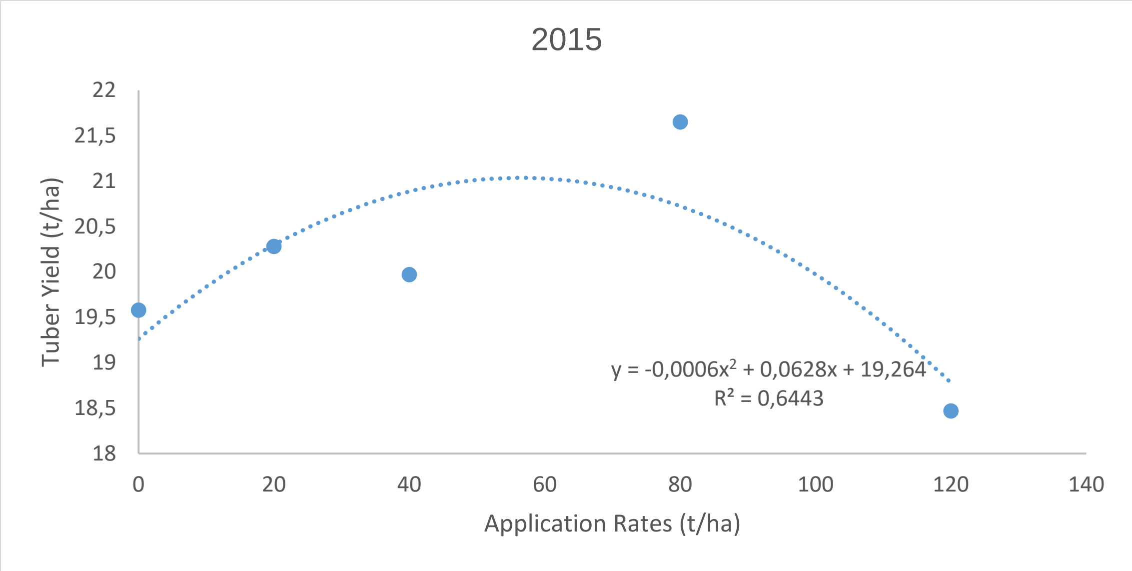
Table 15: Pearson correlation matrix for plant growth and yield parameters

Parameters	Tuber yield (t/ha)	Dry matter	No. stems/ plant	No. leaves/ plant	Plant height	Chlorophyll content
Tuber Yield (t/ha)	1.00*					
Dry matter %	0.90*	1.00*				
No. stems/plant	-0.52*	-0.43*	1.00*			
No. leaves/plant	-0.45*	-0.38*	0.79*	1.00*		
Plant height	0.57*	0.48*	-0.74*	-0.77*	1.00*	
Chlorophyll content	0.59*	0.52*	-0.85*	-0.78	0.71*	1.00*

Table 16: Polynomial regression analyses on plant growth parameters

Predictor variables	Coefficient	Std error	T	p-values	VIF
Constant	21.9539	1.56103	14.06	0.0000	
Plant height	0.59152	0.19877	2.98	0.0036	3.7
No. stems/plant	-0.43491	1.32960	-0.33	0.7442	8.6
No. leaves/plant	-0.04606	0.07665	-0.60	0.5491	8.4
Plant height^2	0.06550	0.02977	2.20	0.0299	5.2
No. stems/plant^2	-0.21260	0.61433	-0.35	0.7300	2.7
No. leaves/plant^2	0.0025	0.0027	0.94	0.3487	7.3
Plant height*No. stems/plant	-0.09337	0.24702	-0.38	0.7062	8.4
Plant height*no. leaves/plant	0.01908	0.01370	1.39	0.1667	9.8
No. stems/plant*no. leaves/ plant	0.02857	0.06157	0.46	0.6435	4.2

Std error= Standard error, T= T statistics, p= p-value and VIF= Variance inflation factor



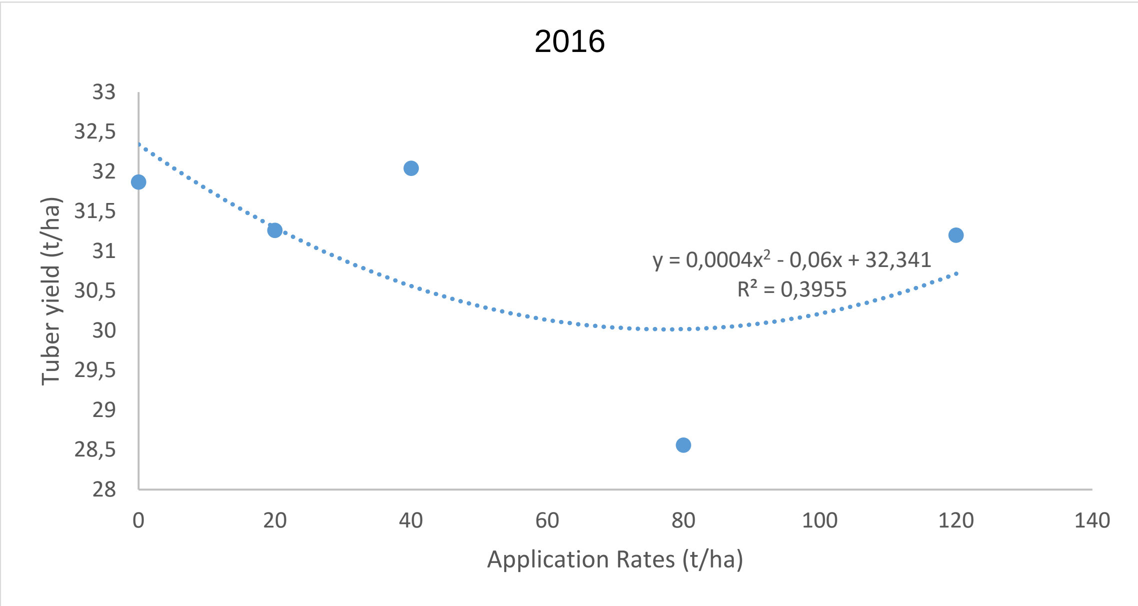


Figure 7: Effect of phospho-compost application rates on tuber yield

4.4. Effect of phospho-compost types and application rates on tuber grading

4.4.1. Tuber grading according to size.

The baby tubers in 2015 and 2016; and small tubers in 2015 tuber percentages were highly significantly ($p<0.001$) influenced by the application of the phospho- compost types (Appendix 10 & 11). The baby tuber percentages ranged from 32 - 47% (Table 17) with CV% of 22.32 in 2015 and 7 - 17% with CV% of 68.20 (Table 18) in 2016. It was apparent from the data that the highest baby tuber percentage of 64.77% was distributed in the PM8:2 compost type in 2015. The lowest tuber percentage was found in the CM8:2 treatment. The highest and lowest baby tubers of 16.87% and 7.08%

were further found in the CM8:2 and PM7:3 phospho-composts respectively. 39% of small tubers were distributed in the CM8:2 compost type in 2016. In 2016, medium tuber percentage was also significantly ($p<0.05$) influenced by the phospho- compost types application with a CV% of 3.05. The percentage ranged from 36 – 25% with the highest percentage in the PM7:3 and lowest in CM8:2 compost types applied. Although the phospho-compost types applied had non- significant ($p<0.05$) effects on the size distribution of the medium, large medium and large tubers in 2015 figure suggested that there was decreasing relationship between the tuber percentages with increase in tuber size distribution. However, as shown in figure 8 tuber percentages were almost equally distributed in the small and large medium tuber sizes in 2016. There were no significant influences on the tuber size distribution between the rates applied and the compost types x application rates interaction.

4.4.2. Tuber grading according to class

Analysis of variance showed a highly significant ($p>0.005$) variation between the compost types applied on the distribution percentages of class 1 and class 2 in 2015 and no significant ($p<0.05$) influence on class 3. The data presented in table 13 show higher tuber percentage of 76% in the PM7:3 plots and the lowest tuber percentages of 66% were found in the CM8:2 treatments. A non- significant relationship was observed between the compost types on the various tuber classes. The variable application rates and the interaction between the compost types and rates applied had no significant ($p>0.05$) influence on the distribution of class percentages. Figure 9 further shows the decrease in class distribution with the lowest percentage of tubers in class 3 in 2015. However, it was evident that the highest percentage of tubers in the PM7:3 was obtained in class 2 and the percentage of tubers distributed equally between class 1 and 2. Although there were no significant ($p>0.05$) differences between the compost types applied, observations in Figure 9 show the decreasing trend in class with tuber distribution in 2016.

Table 17: Effect of phospho- compost types and application rates on percent tuber grading according to size and class in 2015

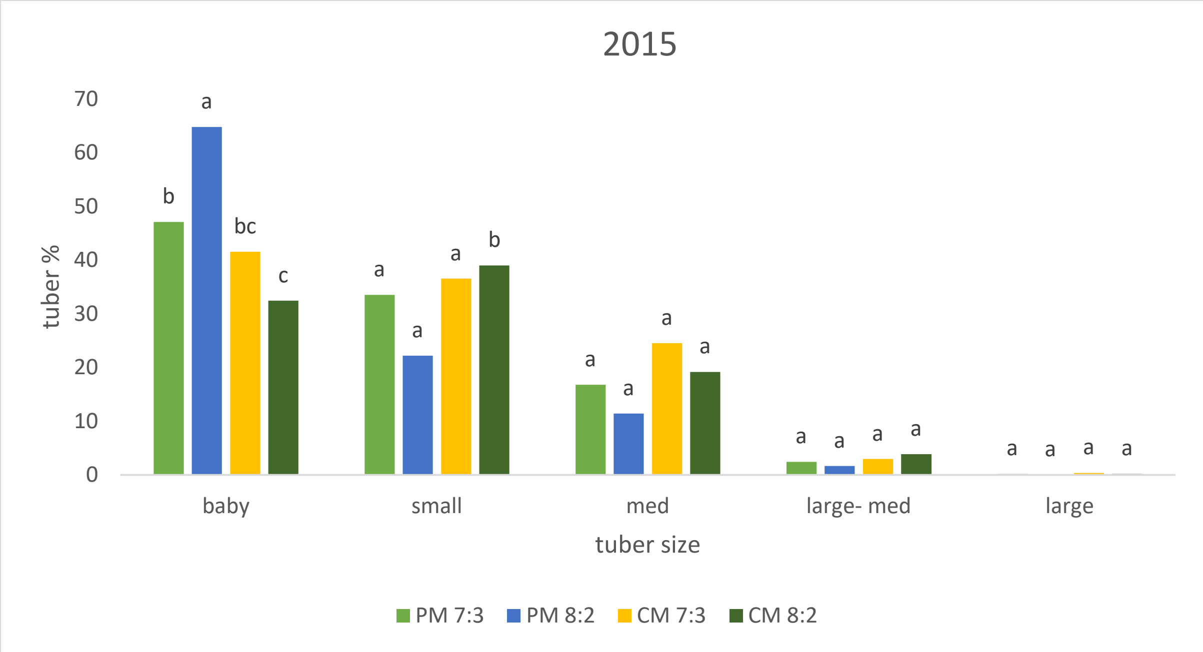
Treatment	Baby	Small	Medium	large-medium	Large	Class 1	Class 2	Class 3
Compost types								
PM 7:3	47.09b	33.52a	16.77	2.42	0.19	76.36	17.23	6.44
PM 8:2	64.77a	22.18a	11.41	1.64	0.00	69.90	20.40	9.02
CM 7:3	41.53bc	36.02a	24.50	2.94	0.37	73.88	19.74	6.43
CM8:2	32.42c	39.01b	19.15	3.88	0.19	65.88	24.30	9.85
F-value	***	***	NS	NS	NS	NS	NS	NS
CV(LSD p≤0.05)	(9.26)	(5.83)	58.09	163.04	494.77	11.22	20.31	56.21
Phospho-compost rates (t ha^{-1})								
0	41.200	34.73	20.44	3.40	0.00	70.10	21.64	8.28
20	50.17	30.41	19.70	1.85	0.00	74.26	19.25	6.53
40	42.24	33.40	17.58	4.65	0.23	71.65	23.27	7.13
80	46.09	35.31	16.86	1.49	0.23	69.06	23.27	7.68
120	52.550	29.57	15.21	2.21	0.48	72.46	17.56	10.04
F-value	NS	NS	NS	NS	NS	NS	NS	NS
CV(LSD p≤0.05)	35.90	36.19	41.28	128.37	363.82	17.55	42.33	57.54

Treatment means in columns sharing the same letters are not significantly different at P≤0.05 according to LSD test. *= significantly different, ns= non-significant

Table 18: Effect of phospho- compost types and application rates on the percent tuber grading according to size and class in 2016

Treatment	Baby	Small	Medium	large-medium	Large	Class 1	Class 2	Class 3
Compost types								
PM 7:3	7.08b	22.52	36.32a	22.32	11.73	72.99	16.53	10.49
PM 8:2	8.04b	26.54	31.99ab	24.19	9.25	71.38	18.14	10.49
CM 7:3	12.67ab	23.87	28.33b	25.93	9.17	66.05	20.82	13.14
CM8:2	16.87a	22.67	24.80b	26.29	9.39	67.07	19.26	13.67
F-value	***	NS	*	NS	NS	NS	NS	NS
CV(LSD p≤0.05)	(6.80)	27.23	(3.05)	40.01	68.76	17.37	45.44	31.25
Phospho-compost rates (t ha^{-1})								
0	12.95	26.57	29.58	22.10	8.83	67.61	19.86	12.53
20	10.08	24.21	29.68	26.10	9.93	68.88	19.95	11.17
40	10.01	23.13	32.42	24.97	9.46	68.57	17.68	13.76
80	9.45	21.87	32.89	24.15	11.65	68.72	18.76	12.52
120	13.33	23.73	27.23	26.08	9.63	73.07	17.17	9.75
F-value	NS	NS	NS	NS	NS	NS	NS	NS
CV(LSD p≤0.05)	48.18	38.04	34.50	40.26	82.81	11.15	31.69	37.80

Treatment means in columns sharing the same letters are not significantly different at P≤0.05 according to LSD test. *= significantly different, ns= non-significant



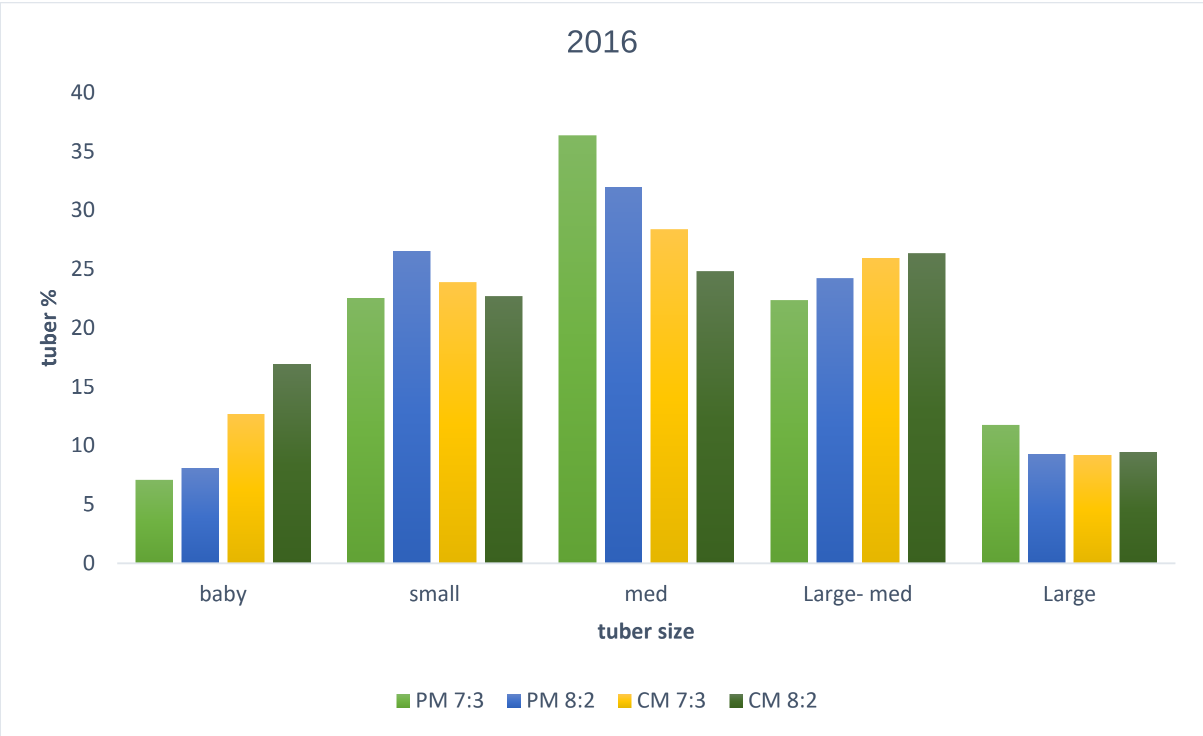
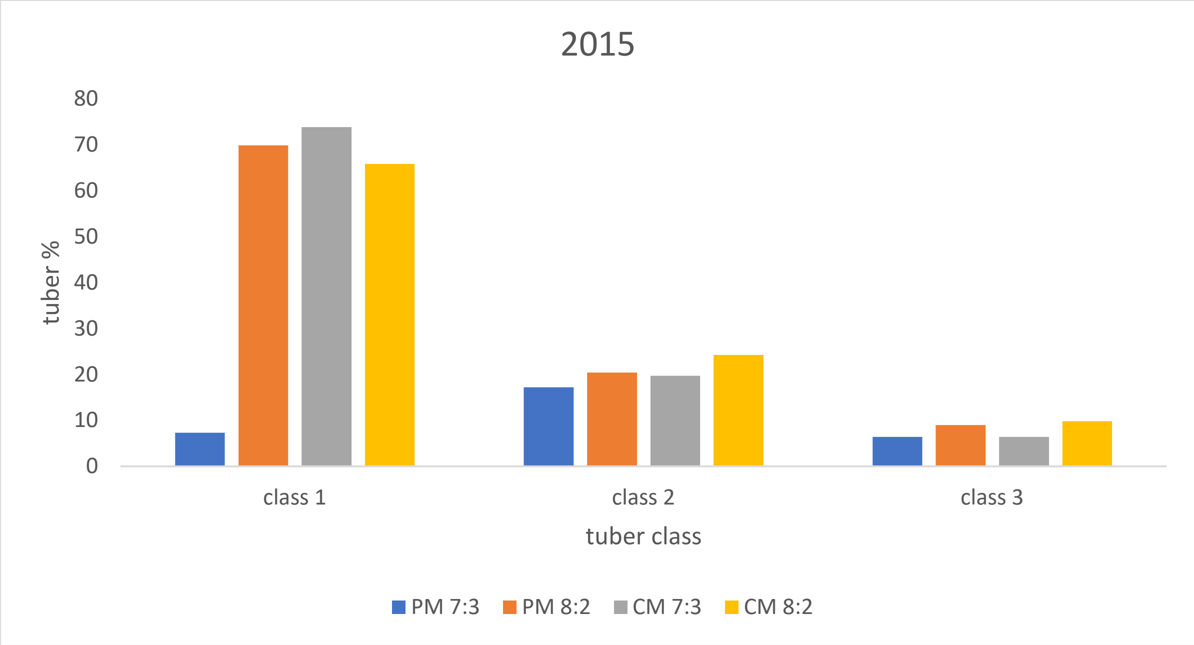


Figure 8: Tuber size distribution as affected by phospho- compost types in 2015 and 2016



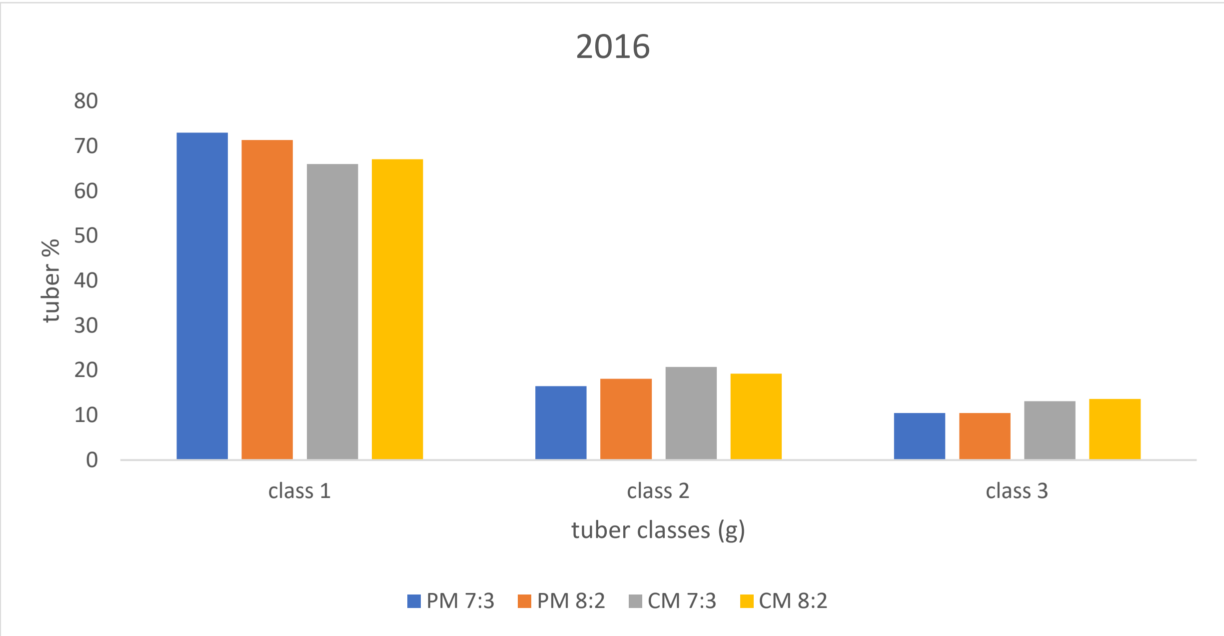


Figure 9: Tuber class distribution as affected by phospho- compost types in 2015 and 2016

4.5 Effect of different treatment factors on nutrient concentrations in potato

Planting season exerted highly significant ($p \leq 0.01$) effect between different plant parts (leaves and tubers) on nutrient concentrations except for Ca and Na (Appendix 13). The mean contents of total N, Mg, crude protein and Ca measured in 2015 were higher than 2016 (Table 19). The highest concentrations of TN, crude protein and Ca measured 2.21, 13.78 and 2.98% in 2015, respectively. In 2016, the concentrations of TN, crude protein and Ca were 1.56, 9.74 and 0.30%. However, significantly ($p<0.001$) higher P, K, Fe, Mn and Cu concentrations were obtained in the different plant parts in 2016 than 2015. The highest P concentration of 0.30% was found in 2016 and the lowest (0.26%) in 2015. Similarly, higher concentrations of K (1.17%), Fe (813.68mg/kg), Mn (37.62mg/kg) and Zn (38.40mg/kg) were measured in 2016.

The difference in concentration of total N, crude protein, Mg, Na, Cu, Fe, and Mn among the two plant parts (leaves and tubers) was highly significant ($p<0.001$). A significant difference ($p<0.05$) was also observed between the plant parts on K concentration. Although no significant ($p>0.05$) difference in the measured P and Ca concentrations among the two plant parts, higher percentages were recorded in tubers. The highest TN and crude protein concentrations were measured from the leaves while the lowest concentrations were measured from the tubers respectively. However, the concentrations of Mg and K were higher in the tubers while the difference in Na concentration between leaves and tubers was abrupt, with higher concentration in the tubers. The potato leaves had higher Fe concentration (933.47 mg/kg) than the tubers (268.23 mg/kg). Higher concentrations of Mn and Zn were found in the leaves and the lowest in the leaves. The leaves contained 48.03% and 33.36% of Mn and Zn respectively. The lowest concentration of Mn (14.98%) and Zn (23.39%) were recorded.

Compost types had no significant effect ($p>0.05$) on the measured nutrients content while only Na concentration was significantly ($p<0.05$) affected by the phospho-compost application rates. The highest Na concentration was found from treatments that received 120 t/ha.

Table 19: Effect of the different treatment factors on total P and other nutrient concentrations in potato leaves and tubers

Treatments	%TN	%Crude Protein	%P	%Ca	%Mg	%K	Na (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)
Season											
2015	2.21a	13.78a	0.26b	2.98	0.97a	1.00b	128.36	13.43a	388.02b	25.40b	18.35b
2016	1.56b	9.74b	0.30a	6.06	0.62b	1.17a	121.11	10.18b	813.68a	37.617a	38.40a
F- value	***	***	**	NS	***	**	NS	***	***	***	**
LSD (≤0.05)	0.17	1.05	2.3	-	0.11	0.12	-	1.40	136.12	6.02	11.68
Plant parts											
Leaves	2.41a	15.06a	0.29	4.82	1.21a	1.03b	71.10b	13.64a	933.47a	48.03a	33.36a
tubers	1.35b	8.47b	0.27	4.22	0.37b	1.15a	178.37a	9.98b	268.23b	14.98b	23.39b
F-value (0.05)	***	***	NS	NS	***	*	***	***	***	***	
LSD (≤0.05)	0.17	1.05	-	-	0.11	0.12	29.34	1.40	136.12	6.02	ns
Compost types											
PM 8:2	2.00	12.51	0.29	2.51	0.76	1.10	131.10	12.38	548.87	31.17	32.82
PM 7:3	1.77	11.09	0.27	9.46	0.74	1.06	146.38	12.68	648.47	35.87	25.33
CM 7:3	1.95	12.18	0.29	3.09	0.82	1.08	121.29	11.53	653.45	32.98	29.55
CM 8:2	1.81	11.28	0.27	3.02	0.84	1.10	100.17	10.63	552.62	26.01	25.80
F-value (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LSD (≤0.05)	-	-	-	-	-	-	-	-	-	-	-
Phospho-compost rates (t ha^{-1})											
0	1.83	11.87	0.26	3.18	0.70	1.02	87.15b	10.92	526.60	26.25	20.10
20	1.76	10.99	0.27	2.79	0.78	1.19	106.83ab	11.12	570.56	31.15	23.92
40	1.84	11.44	0.28	2.48	0.88	1.07	131.02ab	12.04	621.06	32.63	40.90
80	1.90	11.46	0.29	2.99	0.84	1.14	146.08ab	12.19	656.94	33.04	28.08
120	2.09	13.05	0.30	11.17	0.75	1.01	152.59a	12.77	629.08	34.48	28.88
F-value (0.05)	NS	NS	NS	NS	NS	NS	***	NS	NS	NS	NS
LSD (≤0.05)	-	-	-	-	-	-	64.54	-	-	-	-
CV	35.22	35.19	34.79	576.12	55.05	92.95	46.74	89.53	75.45	162.68	41.68

Treatment means in column sharing the same letters are not significantly different at p<0.05 according to LSD test; *= significantly different, ns= non-significant

Season x plant parts interaction exerted significant (p<0.001) effect on P, K, Mg, Na, Cu and Mn (Appendix 13, Table 20). The highest tissue P (0.34%) and K (1.15%) concentrations were observed in potato leaves from 2016 trial. The highest concentration of Na (218.45 mg/kg) was measured from potato tubers in 2015 and the lowest (38.27 mg/kg) from the leaves in 2015. Potato leaves contained the highest Mg (1.61%), Cu (18.08 mg/kg) and Mn (48.53 mg/kg) concentrations in 2015 while the least Cu concentration (8.78 mg/kg) was recorded in tubers from 2015 trial.

Table 20: Season x plant parts interaction effect on total P, K and Mg (%) as well as Na, Cu and Mn (mg/kg) concentration

Season	Plant parts	P	K	Mg	Na	Cu	Mn
2015	Leaves	0.23c	0.85b	1.61a	38.27c	18.08a	48.53a
2015	Tubers	0.28b	1.15a	0.32c	218.45a	8.78b	2.27c
2016	Leaves	0.34a	1.20a	0.82b	103.94b	9.20b	47.53a
2016	Tubers	0.26bc	1.14a	0.41c	138.28b	11.17b	27.70b
F-value (0.05)		***	**	***	***	***	***
LSD (≤0.05)		0.05	0.21	0.21	54.37	2.59	11.15

Mean within the same column with the different letter(s) are significantly different

A highly significant (p<0.001) plant parts x compost types interaction effect on Na concentration was also observed (Figure 10) with higher concentration in tubers than in leaves. The highest Na concentration (245 mg/kg) was obtained from PM7:3 treated tubers while the lowest (48 mg/kg) was obtained from PM7:3 compost type in leaves. However, the concentration of Na in tubers from CM8:2 compost ratio is statistically comparable to the leave Na concentration obtained from CM7:3 phospho-compost.

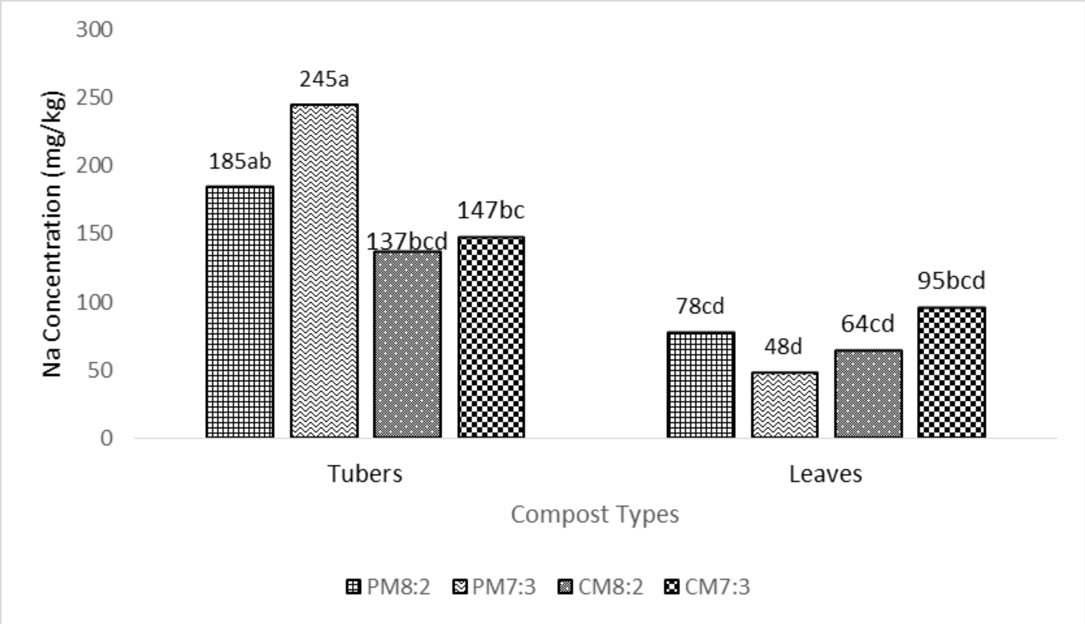


Figure 10: Compost types X plant parts interaction effect on total Na (mg/kg) concentration in potato tubers and leaves

A significant season x plant parts x compost types interaction ($p<0.05$) effect was observed on total P, Na and Mn concentrations (Appendix 13, Table 21). The highest P concentration of 0.38% was detected in potato leaves from plots that received PM8:2 compost type in 2016 while the lowest P concentration was recorded in leaves from plots that received from CM8:2 in 2015. The highest Na concentration (260.27 mg/kg) was obtained from CM7:3 treated potato tubers in 2016 while the lowest Na (28.47 mg/kg) concentration was recorded from CM8:2 treated potato leaves in 2015. The lowest Mg (1.20 mg/kg) concentration was obtained from potato tubers in 2015 from CM7:3 compost type. The highest Mn concentration in the leaves was however found from PM7:3 (60.60 mg/kg) compost types in 2015.

Table 21: Total P, Na and Mn concentrations as affected by season x plant parts x compost types interaction effect

season	Plant parts	Compost types	%P	Na (mg/kg)	Mn (mg/kg)
2015	Leaves	PM 8:2	0.22c	41.27ef	57.27a
2015	Leaves	PM 7:3	0.21c	28.47f	60.60a
2015	Leaves	CM 8:2	0.20c	44.60ef	32.33abcd
2015	Leaves	CM 7:3	0.28abc	38.73ef	43.93abc
2015	Tubers	PM 8:2	0.31abc	250.13ab	1.60f
2015	Tubers	PM 7:3	0.28abc	229.53abc	2.13ef
2015	Tubers	CM 8:2	0.27abc	177.74abcde	4.13def
2015	Tubers	CM 7:3	0.29abc	216.40abcd	1.20f
2016	Leaves	PM 8:2	0.38a	113.93bcdef	49.33ab
2016	Leaves	PM 7:3	0.36a	67.27ef	41.93abc
2016	Leaves	CM 8:2	0.35ab	82.80def	43.40abc
2016	Leaves	CM 7:3	0.28abc	151.76abcdef	55.47a
2016	Tubers	PM 8:2	0.26abc	119.07abcdef	16.47cdef
2016	Tubers	PM 7:3	0.23c	78.27def	38.80abc
2016	Tubers	CM 8:2	0.23bc	95.53cdef	24.20bcdef
2016	Tubers	CM 7:3	0.31abc	260.27a	31.33abcde
F-value (0.05)			**	*	*
LSD (≤0.05)			0.12	145	29.73

Mean within the same column with the different letter(s) are significantly different

Total P and Mg showed significant ($p<0.05$) responses to season x plant parts x compost rates interaction (Table 22). Zero treated (0t/ha) leaves contained the lowest P concentration of 0.20% in 2015. The highest percentage of 0.28% was found in 80 t/ha treated leaves in 2015. A partly similar trend was recorded in 2016 with the lowest percentage of 0.31 found in 0 t/ha treated leaves. However, the highest concentration of 0.44% was obtained from 120 t/ha treated leaves. The highest Mg concentration (1.86%) was found from 0t/ha leaves in 2015. The lowest Mg content of 0.21% was measured from 40t/ha leaves in 2015.

Table 22: Season x plant parts x applications rates interactions on percent total phosphorus (P) and magnesium (Mg) concentrations

season	Plant parts	Application Rates t/ha	P	Mg
2015	Leaves	0	0.20c	1.86a
2015	Leaves	20	0.23bc	1.69abc
2015	Leaves	40	0.22bc	1.50abcd
2015	Leaves	80	0.28bc	1.75ab
2015	Leaves	120	0.22bc	1.22bcde
2015	Tubers	0	0.29bc	0.42gh
2015	Tubers	20	0.29bc	0.29gh
2015	Tubers	40	0.26bc	0.38gh
2015	Tubers	80	0.29bc	0.24h
2015	Tubers	120	0.31abc	0.27gh
2016	Leaves	0	0.31abc	0.88defg
2016	Leaves	20	0.31abc	0.64efgh
2016	Leaves	40	0.35ab	0.71efgh
2016	Leaves	80	0.32abc	0.79efgh
2016	Leaves	120	0.44a	1.09cdef
2016	Tubers	0	0.23bc	0.37gh
2016	Tubers	20	0.27bc	0.49fgh
2016	Tubers	40	0.28bc	0.21h
2016	Tubers	80	0.28bc	0.57fgh
2016	Tubers	120	0.24bc	0.43gh
F-value (0.05)			*	*
LSD (≤0.05)			0.14	0.63

Mean within the same column with the different letter(s) are significantly different

CHAPTER 5

GENERAL DISCUSSION

5.1. Effect of phospho-compost application on soil mineral composition and its effect on P dissolution.

Soil pH levels range from 0 to 14 with neutral levels at pH 7 (Slessarev *et al*., 2016). The results of the study revealed pH levels above 7, these are considered alkaline. Furthermore, an increase in pH with growing stages relative to the pH recorded before planting was observed. The highest pH was observed from the CM8:2 plots across the two sampling stages in 2015. However, high pH values were observed in 2016 than in 2015. Phosphorus availability in soil is adversely affected by the soil pH (Ekelof, 2007) and other spatial variation factors such as soil carbon and organic matter levels (Phefadu and Kutu 2016), soil microbial biomass content (Bhat et al 2017) and soil colloid chemistry (Turner et al., 2004; Jiang et al., 2017). Most potato production soils tend to increase acidity over time due to leaching of cations from the root zone (Rosen and Bierman, 2008). According to Qureshi *et al*., 2014, alkaline and acidic soils favour the decomposition of applied organic materials which release acids that react with soluble salts or increase solubility. The organic acids released during the decomposition further solubilizes the rock phosphate releasing phosphate and calcium. However, acidic conditions are favourable for potato production because it minimizes invasion of common scab which mostly spreads on soil pH above 5.5. The influence of pH was due to the presence of Ca, Fe and Al which influence soil available P (Ekelof, 2007). Soils with low pH are usually dominated by the Fe and Al compounds which affect the phosphate solubility by reverting to even more stable or insoluble compounds (Busman *et al*., 2009). However neutral pH (6-7.5) as observed from the results in 2015 and 2016 accommodate the orthophosphate forms of P which are available for plant. However, this is in contrast with Lorion (2004) stating that neutral and slightly alkaline pH may retain P in Ca complexes which become in excess with high pH. (Rosen and Bierman, 2008) suggested that once pH drops below 4.9 nutrient deficiencies and toxicities may become evident particularly of Mn.

Significantly higher available P content values were obtained from the PM8:2 treated plots across both sampling stages in 2015. The results further showed an increase in P content from the PM8:2 plots, which were significantly affected by the compost type addition relative to the available P content measured before planting (100 mg/kg) in 2015. This aligned with reports from studies by Chauke (2014) and Mokase (2016) who indicated the highest available P concentration in PM8:2 compost mix ratio. A decrease in available P content was observed from the cattle manure- based phospho-compost treatments across the two sampling stages. The relative decrease of available P from the soil indicates utilization by the crop. However, no significant effects were observed between the application rates and compost types x application rates interactions. Furthermore, higher available P content was higher in 2015 than in 2016. The higher total P content in the PM-based than CM-based phospho-composts reported in this study may be attributed to the higher P content in poultry manure. This was supported by a study by Dikinya and Mufwanzala (2010) reporting that the need for and utilization of poultry manure has overtaken the use of other animal manures such as pig and kraal manures due to its higher N, P and K contents. From literature, it is known that phosphate ions precipitated by elements such as Ca, Mg, Al and Fe form solid compounds that become unavailable for plant use (Busman *et al*., 2009).

In 2015 signs of nutrient imbalances were visually observed from the potato plant leaves after flowering. Symptoms of K deficiency with black pigmentation and necrotic edges appeared on crinkle leaves. General chlorosis which is associated with N deficiency that was also clearly visible on the leaves immediately after flowering. Gumede (2015) also suggests that N deficiency in the growing season leads to early canopy senescence that indirectly resulted in lower tuber yields. Furthermore, this may have led to the crop being susceptible to early blight infestation in 2015. Once tuber initiation has commenced, more assimilates are partitioned to the reproductive parts (tubers) and less to the canopy which may have resulted in the deficiency symptoms after tuber initiation (Steyn, 2008). From a study by Gathungu *et al.* (2000) integration of soil moisture, N and P fertilization increases potato yield. Therefore, a balance in the three factors is vital in maintaining higher growth and yield.

Soil exchangeable K was significantly affected by compost type application in 2016 and no significant differences 2015. However, more K contents were observed in 2015. This however, was not supported by Gumede (2015) reporting that the high K requirement of the tuber plays an important role in determining high yields, quality and the plant size. High K is necessary to prevent blackspot bruising, shattering, good storage quality and induces Mg deficiencies since K and Mg compete for uptake

(Rosen and Bierman, 2008). Potassium source generally have no effect on total yield alone (Panique *et al*., 1997). Furthermore, Potato plants are known to take up 40-50% K prior tuber bulking and 50- 60% during tuber bulking. Halder *et al*. (2011) indicated that the application of N fertilizer might also increase the available N in the soil solution. Further suggesting that phospho- compost together with N and K fertilizers can enhance the optimum growth and yield of crops. The immediate termination of the 2015 experiment due to blight infestation may have been the result of the low nutrient imbalances in the soil solution.

The same N deficiency was also evident in 2016, however a steep decrease in the nutrient contents of K and Ca were observed from 2016 trial which completely affected the growth and yield of the tubers. Even though tuber yields are not directly affected by applied Ca, Gumede (2015) suggested that tuber yields increase with Ca increase to medium levels, which further enhances tuber quality. Soil Ca content was significantly affected by compost type application in 2016 and non-significant in 2015 with higher Ca contents. Although, the content of Ca in the soil solution has been shown to be inversely related to the dissolution of rock phosphate, in the current study a direct relationship was observed. The study further shows that P is largely held by the insoluble forms dominated by the Ca-P (Lorion, 2004) which is mostly found in pH greater than 7. Therefore, the low levels of Ca found in the soil solution had less impact on the dissolution of P in 2016. The PM 8:2 compost with the highest Ca content also had the highest available P content. Acidic sandy soils that are low in organic matter require supplementary addition of Ca and Mg for optimum tuber yield and quality (Lorion, 2004). Under these soil conditions Ca becomes deficient to a level that it reduces tuber yield and quality. Significant differences were evident between the rates of application in 2016 which showed an increase on Ca content with increasing application rates.

A study on Minnesota soils reported increases in potato yields with Zn applications but not with Mn applications (Rosen and Bierman, 2008). In the current study, higher Zn contents were observed in the PM-based phospho-composts and lower in CM-based. In acid soils, they should be in adequate amounts to meet crop needs and pesticide sprays often contain enough Zn to meet plant demands for nutrients. (Rosen and Bierman, 2008)

5.2. Potato growth and yield as affected by phospho- compost types and variable rates.

There was no clear evidence of (positive or negative) effect of the phospho-compost application on plant population, the number of stems per plant, the number of leaves, the chlorophyll content and the plant height. However, the effect of phospho-compost application was highly significant between fresh and dry weight leaves samples. This shows that the weight of the leaves was highly depend on the type of compost that was applied in the field. Temperature, photoperiod and water supply are the most important abiotic factors affecting the growth and yield of potatoes (Steyn, 2008). Both photoperiod and temperature influence the rate of crop growth and development. Temperature determines the onset and duration of the different growth stages namely seedling emergence, tuber initiation, bulking and senescence; and partitioning of assimilates to different plant parts of leaves, stems, roots and tubers (Steyn, 2008).

Evidence of significant and relatively high effect of the phospho-compost application on potato growth from the two season trial abounds through the current study. A highly significant difference was observed in the number of stems and leaves per plant, which was higher in 2015 than 2016. This may be due to various factors including differences in the cultivars used (Gumede, 2015). Mondial cultivars takes about 90- 110 days to attain maturity from the date of emergence; and is highly susceptible to early blight that severely infested the field leading to early termination of the trial in 2015. The different cultivars (Valor) planted in 2016 thus influenced the growth and yield response of this crop. The cultivar Valor thus appears an ideal cultivar with high yield, drought and heat stress tolerant, and resistant to tuber blight thus suitable for the semi-arid regions of Limpopo province. About 38% of South African potato farmers cultivate mondial while Valor cultivation presently stands at 4.46% (Gumede, 2015).

However, the significant increase in chlorophyll content in the leaves in 2016 than in 2015 may have been stimulated by increased N availability. This was supported by Guler (2009) who reported a significant effect of N on chlorophyll content in potato cultivars. As observed from the results, there was a higher plant population in 2016 with high chlorophyll content as well. However, this contradicts Aminifard *et al.* (2012) who revealed that lower plant populations associated with higher chlorophyll content due to less completion for nutrients and less shading. Although there was no significant effect of phospho-compost application on plant population in the current study, Masarirambi *et al*. (2012) reported that plant population affects the number of tubers, the number of leaves and the number of stems, which were also evident from the results obtained in the current study. This is possibly attributed to enhanced root and tuber development following increase nutrients availability following phospho-compost application and better light interception. Another interesting aspect of this study is the significant interaction between the year of planting and the compost type applied on harvested fresh leaf weight and dry leaf weight. The highest fresh leaf weight was recorded from poultry manure treatments (PM 7:3) in 2015 and 2016 trial years. The number of fresh leaf is an important aspect that allows plants to trap more radiant energy leading to increased photo assimilates needed to increase tuber bulking (Guthungu *et al*., 2015).

5.3. Potato tubers yield and grading quality as affected by the applied phospho-compost

High tuber yields were obtained in 2016 than in 2015. significantly different tuber yields in 2015 ranged from 16 to 22.14 t/ha and non-significant tuber yields in 2016 ranged from 27.54 to 33.04 t/ha. With highest tuber yields obtained from the PM-based phospho-composts. Most potatoes grown under irrigation in south Africa produces on average 40 t/ha which were relatively lower in this study. However, it is important to note the differences in soil available P content which was higher in 2016 than in 2015. This in contrast with results observed from Hakoomat *et al*. (2004) who suggested that tuber yields increased with P fertilization. However, maximum yield obtained from 80t/ha application rates in 2015 support Lorion (2004) suggesting that greater application rates were needed to increase significant response of the compost application rates over the control treatments. The observations were made under low rainfall conditions which were similar in this experiment. Further explaining the lower tuber yields obtained by suggesting that increases in soil moisture could highly influence the dissolution of rock phosphate.

Tuberization highly depends on many factors which amongst others include the availability of nutrients during tuber initiation stage, the number of stems per plant, irrigation moisture supplied, diseases, temperature and the type of cultivar planted. Furthermore, it has been concluded that phosphorus highly affects tuberization and increases the number of tubers produced per stem (Hakoomat *et al*., 2004) supported by a positive correlation report between the P content and potato tuber number from a study by Ekelof (2007). The study indicated that the number of tubers highly correlated with the minimal absorption of P during the 1st week of planting. However, in the current study, higher number of tubers were observed in low available P 2016 than in 2015. It is important to note that P can be responsible for the size and percentage of the dry matter, however from the results reported a non- significant relationship between the compost types application on dry matter was found. This was further supported by Guthungu *et al.* (2014) suggesting that P affected tuber set and a general relationship between stem number and tuber numbers. Although the number of tubers per stem were not significantly different, the positive relationship observed from the results show higher number of tubers with higher number of stems in 2016.

The application of the compost types did not have a significant effect on the grading of the tubers into size. Although a significant effect was found on the percentage of small tubers found between the different compost types in 2015. High percentage yield was highly distributed in the small tubers. According to Gumede, 2015 heat stress results in higher number of small and medium tubers which is evident from the 2015 and 2016 results. There was a decrease in tuber percentages with increasing size of tubers in 2015. The highest percentages of small and medium tubers where found in the PM-based treatments. The percentage of bigger size tubers was higher in 2016 which supports the effect of potato cultivars on yield. Mondial is highly recommended for producing predominantly medium to Large sized tubers and has short tuberization/ maturing days (Fernandes *et al*., 2017). However, the reduced tuber sizes observed in the current study could be affected by the premature harvesting of the field which limited the tuber bulking period from the reported duration of 60-120 days tuber bulking (Gumede, 2015). Hence, the rate and duration of tuber bulking may have affected the yield. This is further supported by Guthungu et al. (2014) who suggested that photo assimilates transported from the vegetative part into the tubers increases tuber bulking and enlargement, which in this case, the process was inhibited by early termination of the field in 2015.

The minimum percentages of large and medium tubers in both trials may be influenced by the plant population observed. The observation was further supported by Zheng *et al*., (2016) reporting a significant decrease in percentage tubers above 80g with increasing plant density. Furthermore, it was concluded that higher plant population were significantly associated with higher tuber yields which were observed in 2016 than in 2015. The degree of influence however, depends on different growing seasons (Zheng *et al*., 2016).

The exposure of the potato to direct sunlight could have also reduced the growth of the potato tubers and may have led to the greening of tubers that was observed during 2015. The exposure was caused by the destruction of ridges during manual weeding using hoe. The greening may have also adversely affected the grading of the tubers into class. This is supported by Olsen (2005) who indicated that greening increases chlorophyll and solanine levels in potato tubers resulting in major marketing and retailing problems such as undesirable appearance for consumers that drastically reduces class. Higher greening effect was recorded in class one among the different compost types with PM-based phospho-compost yielding the maximum number of class one tubers. This is in agreement with previous work by Rosen and Bierman (2008) who revealed increased percentage of class 1 tubers and total tuber yield due to P fertilization.

5.4. The optimum rate required for the application of phospho-compost for increased yield of potato tubers.

The relative effectiveness of the Phosphate rock depends considerably on the application rates (Lorion, 2004). However, In the 2015 there was no effect of the phospho-compost rates application on the soil mineral content, except for K in harvest. The highest content of K was observed from the 120 t/ha application rate. There was no significant effect of the rates on available P, however highly significant differences were evident on K and Ca contents in the 2016. Both K and Ca showed a positive correlation between rates applied. There was a direct increase in contents with increasing rates of application. The fresh tuber weight collected in 2016 trial year was highly affected by the phospho-compost addition with the highest tuber weight found in the 120 t/ha treatment while the minimum tuber weight as expected was found in the control treatment with no phospho-compost application. This indicates the linear relationship between phospho-compost rates applied and the fresh tuber weight. The increase in the rates of the phospho-compost increased the tuber weight. Furthermore, a high significant effect was found between the interaction of compost type and rates applied between flowering and harvest on the Mg and exchangeable acidity.

5.5. Effect of phospho-compost application on tuber mineral concentrations

Mineral balance is vital for the progression of higher tuber quality and yields (Rosen and Bierman, 2008). The production of marketable potatoes is highly dependent on their visual and nutritional content which are strongly influenced by the addition of nutrients to the soil solution (Fernandes *et al*., 2015). Additionally, the chemical composition of the tuber may vary depending on other factors such as cultivar type, plant maturity, climate, etc. Mineral concentration in tubers is highly dependent on the phyto-available minerals needed by the crop resulting from complex interactions between minerals and tissue mineral composition (White, 2009).

The results showed acceptable range of mineral concentrations for potato tubers as supported by Modisane (2007). Mahamad *et al*. (2015) presented mineral nutrients adequate in potato tubers for N (1.00- 2.19%), P (0.12-0.47%), K (1.45-2.58%) and Ca (>0.15%). The concentrations of N, P and K fell within the suggested range and higher mineral concentration of Ca was observed from the current study. The increase in Ca content in the tubers can be elucidated by Lorion (2004) who reported Ca complex increase with increasing soil pH. Therefore, the neutral slightly alkaline soils observed in the study created favourable Ca uptake conditions for the leaves and tubers. Additionally, Singh and Kaur (2016) suggested required nutrient concentration ranges for Cu (11-23 mg/kg), Fe (3-23 mg/kg) and Mn (12–84 mg/kg) in potato tubers. However, results from the current study revealed higher concentration of Fe compared to the required range. Stark *et al*. (2004) reported nutrient concentration ranges for P (>0.22%), K (>8.0%), Ca (>0.6%) and Mg (>0.3%) in potato leaves; and that these vary according to growth stages and cultivar. The percent K content was however very low and below the threshold value in the current study. Furthermore, Reis Jr and Monnerat (2000) reported the threshold level of Cu (6-30 mg/kg), Mn (21-200 mg/kg) and Zn (21-705 mg/kg) in potato leaves. The concentrations of Cu, Mn and Zn observed in the current study were therefore adequate from the leaves on all treatments including the control in the current study.

Phosphorus fertilization has been reported to increase the concentrations of ascorbic acid, N and protein as well as the dry matter production of potato (Fernandes *et al.,* 2017). This statement agrees with the increase in total N and crude protein in the current study. The results showed higher total N and crude protein concentrations in the two plant parts in 2015 than 2016. Westerman (2005) reported large amounts of total N and K in potato plants, followed by Ca and Mg after P fertilization. However, the current study revealed low concentrations of K compared to the required content in both leaves and tubers. The difference in N and crude protein contents with season may be attributed to the differences in cultivar types planted. This statement was supported by Fernandes *et al.* (2017) who reported differences in the uptake and removal of most nutrients, growth and tuber yield increase with P fertilization in various evaluated potato cultivars including Agata and Mondial. Modisane (2007) also revealed that variation in cultivar types exert significant influence on the percent protein and other nutrient contents in potato tubers. Hence, it was expected that different potato cultivars would respond differently to phospho-compost application as seen from the high significance effect of the season to the mineral concentrations in the current study. The significant effect of season on K, Mg, Mn, Cu, Fe and Zn concentrations was further supported by Wekesa *et al*. (2014) who reported a significant difference with production site, potato varieties and treatment of seed potatoes on the measured tuber nutrients.

Balanced P supply can affect the spread of nutrient concentrations in different plant parts of the potato plant. However nutritional concentration in the plant varies with plant organs and time of harvest (Reis Jr and Monnerat, 2000). The results show significant influence of the plant parts on the distribution of chemical nutrients in the tubers and leaves. Although the effect was not significant, higher P and Ca concentrations were measured in potato leaves than tubers. Furthemore, higher calcium than total N and P concentrations in the current study contradicts Modisane (2007) findings who reported lower calcium concentrations than N and P in potato leaves after Ca fertilization. The high increase in Ca was supported by Qureshi *et al*. (2014) suggesting the release of phosphates and calcium, during the solubilization of rock phosphate through decomposition with organic acids in the soil solution. The current findings agree with Fernandes et al. (2017) who revealed marginal increase in total N, K, Ca, Mg, P, Mn and Zn in potato leaves after P fertilization. Although the rates of phospho-compost applied did not significantly affect the P and other mineral concentrations in the tubers, P concentration showed quantitative increase following increase in phospho-compost application rates. Hence, the highest total N, crude protein, P, Ca, Na, Cu and Mn concentrations were obtained from the 120 t/ha treatments. Similarly, Ozturk *et al*. (2010) reported a non-significant effect of P fertilization rates on N, P and other nutrient qualities of potato while significant only on percentage protein and crisp oil content.

CHAPTER 6:

CONCLUSION AND RECOMMENDATIONS

The use of phospho-compost as a cheaper P fertilizer alternative can be supported from the results in this current study. A predominant significant difference between the compost types on the available P concentration was observed across the two trial years in all soil sampling stages. Therefore the increase in available P reveals that the amendment of poultry manure and cattle manure with Phalaborwa ground phosphate rock increases solubility of the rock. Furthermore, PM 8:2 and PM 7:3 plots showed higher significant levels of available P contents than the CM 8:2 and CM 7:3 based plots. This was an expected trait because poultry manure generally has higher nutrient content than the cattle manure (Irshad et al., 2013). Soil pH was significantly affected by compost types and the trial year X compost types interaction at flowering and harvest stages, with alkaline pH ranges. The rates of application, however did not have any significant effect on the available P content in the soil solution, except for exchangeable K and Ca contents at flowering stages. K concentration increased significantly with increasing phospho-compost rates, with the highest K content in the 120t/ha plots and the lowest in the control treatments. Ca content was significantly affected by compost type application in 2016 and non-significant in 2015.

The direct increase in contents of K and Ca as affected by the increasing rates strongly suggest that the highest rate of application (120 t/ha) was more effective. There was no significant effect of phospho compost application on plant population, the number of stems per plant, the number of leaves, the chlorophyll content and the plant height. However, the effect of phospho-compost application was recorded from the collection of fresh and dry weight leaves samples in 2015. High tuber yields were obtained in 2016 than in 2015. However, it was important to note the difference in available P content higher in 2015 than 2016, which may be related to the differential responses in cultivars planted to the phospho-compost types. Therefore, further studies can be directed to the different cultivars which better utilize P from the composted rock phosphate. The application of the compost types did not exert any significant effect on the tuber grades but significant difference was recorded in the percentage small tubers obtained across the different compost types in 2015.

Phospho-compost types and their application rates had inconsequential effects on the nutrient concentrations of the two plant parts (leaves and tubers) evaluated. Nonetheless, variation in planting seasons and plant parts showed significant effect on the nutrient concentrations. The addition of P fertilization known to increase other nutrient quantities in both leaves and tubers was supported from the observed results from the current study except for percent K. The low K concentration can be corrected by the addition of K sources to the soil. Plant residues left for example, are important organic sources of K which can be returned to the soil (Lorion, 2004). Therefore, it can be of significant advantage to use the phospho-compost in soils that have a history of massive P deficiency.

Together with P, the availability of N is also very important aspects to consider during further research for the optimum nutrient balance needed in the soil (Guler, 2009). Deficiencies that are evident early in the season like Nitrogen in this case, may lead to early canopy senescence which may result in reduced tuber yields. Incorporation of nitrogen sources such as urea to the soil may be beneficial together with the phospho-compost application. Legumes may also be able to progressively trigger rock phosphate dissolution with the rhizosphere acidification during N_2 fixation by converting it into available forms (Lorion, 2004). Therefore, crop rotations following a legume crop can be very beneficial in making the P available for plant uptake.

The rates of application may have been significantly low, therefore increasing the rates of Phospho-compost may be applicable to increase tuber growth and yield. Although the rates of application had no significant effect on the nutrient concentrations across the plant parts, increase in nutrient concentration with increasing phospho-compost rates reveal high tuber nutrient quality with high application rates.

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Appendices

Appendix 1: p-values for soil pH and mineral content at flowering stage in 2015

Sources of variation	DF	pH_{KCl}	Avail P	K	Ca	Mg	Ex. acidity	Tot cation	Zn
Compost (C)	3	0.005**	0.036*	0.455^{NS}	0.159^{NS}	0.279^{NS}	0.84^{NS}	0.179^{NS}	0.067^{NS}
Rates (R)	4	0.055^{NS}	0.793^{NS}	0.044*	0.322^{NS}	0.272^{NS}	0.048*	0.227^{NS}	0.311^{NS}
C x R	12	0.824^{NS}	0.63^{NS}	0.339^{NS}	0.195^{NS}	0.687^{NS}	0.574^{NS}	0.159^{NS}	0.767^{NS}

*, ** and *** implies significant at 5%, 1% and 0.1% probability level, respectively while NS implies non-significant

Appendix 2: p-values for soil pH and mineral content at harvest stage in 2015

Sources of variation	DF	pH_{KCl}	Avail P	K	Ca	Mg	Ex. acidity	Tot cation	Zn
Compost (C)	3	0.148^{NS}	0.027*	0.221^{NS}	0.260^{NS}	0.350^{NS}	0.626^{NS}	0.113^{NS}	0.022*
Rates (R)	4	0.299^{NS}	0.234^{NS}	0.162^{NS}	0.117^{NS}	0.222^{NS}	0.431^{NS}	0.032*	0.541^{NS}
C x R	12	0.167^{NS}	0.567^{NS}	0.731^{NS}	0.271^{NS}	0.364^{NS}	0.429^{NS}	0.144^{NS}	0.340^{NS}

* implies significant at 5% probability level, while NS implies non-significant

Appendix 3: p-values for soil pH and mineral content at flowering stage in 2016

Sources of variation	DF	pH_{KCl}	Avail P	K	Ca	Mg	Ex. acidity	Tot cation	Zn
Compost (C)	3	0.034*	0.029*	0.011*	0.013*	0.896^{NS}	0.025*	0.445^{NS}	0.121^{NS}
Rates (R)	4	0.357^{NS}	0.079^{NS}	0.005**	0.015*	0.203^{NS}	0.439^{NS}	0.431^{NS}	0.849^{NS}
C x R	12	0.435^{NS}	0.107^{NS}	0.211^{NS}	0.586^{NS}	0.023*	0.008**	0.458^{NS}	0.376^{NS}

*, ** and *** implies significant at 5%, 1% and 0.1% probability level, respectively while NS implies non-significant

Appendix 4: p-values for soil pH and mineral content at harvest stage in 2016

Sources of variation	DF	pH_{KCl}	Avail P	K	Ca	Mg	Ex. Acidity	Tot Cation	Zn
Compost (C)	3	0.022*	0.015*	0.021*	0.015*	0.472^{NS}	0.001**	0.627^{NS}	0.047*
Rates (R)	4	0.534^{NS}	0.325^{NS}	0.833^{NS}	0.348^{NS}	0.418^{NS}	0.744^{NS}	0.545^{NS}	0.878^{NS}
C x R	12	0.551^{NS}	0.704^{NS}	0.286^{NS}	0.645^{NS}	0.209^{NS}	0.577^{NS}	0.407^{NS}	0.821^{NS}

*, ** and *** implies significant at 5%, 1% and 0.1% probability level, respectively while NS implies non-significant

Appendix 5: P-values comparison across two years soil sampling for soil pH

Source	DF	Flowering	Harvest
Year	1	0.0578^{NS}	0.000***
Compost	3	0.000***	0.428^{NS}
Rates	4	0.337^{NS}	0.620^{NS}
Year* compost	3	0.002**	0.000***
Year* rates	4	0.545^{NS}	0.419^{NS}
Compost*rates	12	0.990^{NS}	0.469^{NS}

*, ** and *** implies significant at 5%, 1% and 0.1% probability level, respectively while NS implies non-significant

Appendix 6: p-values for soil pH and other measured parameters as affected by various treatment factors and their interactions at flowering and harvest stages in 2016

Sources of variation	DF	pH_{KCl}	Avail P	K	Ca	Mg	ExAcidity	Tot cation	Zn
SS	1	0.17^{NS}	0.37^{NS}	0.11^{NS}	0.75^{NS}	0.36^{NS}	0.23^{NS}	0.81^{NS}	0.68^{NS}
C	3	0.05*	0.00***	0.01*	0.00***	0.64^{NS}	0.00***	0.23^{NS}	0.00***
R	4	0.57^{NS}	0.03*	0.16^{NS}	0.01*	0.15^{NS}	0.31^{NS}	0.31^{NS}	0.81^{NS}
SS*C	3	0.96^{NS}	0.77^{NS}	0.07^{NS}	0.53^{NS}	0.98^{NS}	0.57^{NS}	0.89^{NS}	0.89^{NS}
SS*R	4	0.03*	0.74^{NS}	0.69^{NS}	0.95^{NS}	0.51^{NS}	0.95^{NS}	0.70^{NS}	0.89^{NS}
C*R	12	0.33^{NS}	0.33^{NS}	0.20^{NS}	0.85^{NS}	0.00***	0.01*	0.78^{NS}	0.32^{NS}
SS*C*R	12	0.83^{NS}	0.36^{NS}	0.20^{NS}	0.37^{NS}	0.52^{NS}	0.55^{NS}	0.17^{NS}	0.87^{NS}

*, ** and *** implies significant at 5%, 1% and 0.1% probability level, respectively while NS implies non-significant

Appendix 7: p-values for growth and yield parameters as affected by compost types, rates of application and their interaction in 2015

Sources of variation	DF	Plant population	No. stems plant	No. leaves	Fresh leaves (g)	Dry leaves (g)	Plant height (cm)	Chlorophyll content	No. tubers/ plant	No. tubers/ stem	Dry matter (%)	Tuber yield (t/ha)
Compost (C)	3	0.21^{NS}	0.16^{NS}	0.33^{NS}	0.00***	0.00***	0.98^{NS}	0.18^{NS}	0.16^{NS}	0.19^{NS}	0.00***	0.01*
Rates (R)	4	0.37^{NS}	0.47^{NS}	0.54^{NS}	0.78^{NS}	0.56^{NS}	0.94^{NS}	0.47^{NS}	0.60^{NS}	0.28^{NS}	0.63^{NS}	0.58^{NS}
C x R	12	0.75^{NS}	0.33^{NS}	0.36^{NS}	0.74^{NS}	0.69^{NS}	0.39^{NS}	0.54^{NS}	0.58^{NS}	0.72^{NS}	0.49^{NS}	0.47^{NS}

*, ** and *** implies significant at 5%, 1% and 0.1% probability level, respectively while NS implies non-significant

Appendix 8: p-values for growth and yield parameters as affected by compost types, rates of application and their interaction in 2016

Sources of variation	DF	Plant pop/plot	No. Stems/ plant	No. leaves/ plant	Plant height	Chlorophyll content	Fresh leaves	Dry leaves	No. tubers/ stem	Yield (t/ha)	Dry matter (%)
Compost (C)	3	0.77^{NS}	0.12^{NS}	0.24^{NS}	0.90^{NS}	0.77^{NS}	0.37^{NS}	0.10^{NS}	0.58^{NS}	0.40^{NS}	0.66^{NS}
Rates (R)	4	0.59^{NS}	0.68^{NS}	0.72^{NS}	0.44^{NS}	0.59^{NS}	0.84^{NS}	0.87^{NS}	0.96^{NS}	0.91^{NS}	0.70^{NS}
C x R	12	0.33^{NS}	0.81^{NS}	0.26^{NS}	0.67^{NS}	0.33^{NS}	0.36^{NS}	0.89^{NS}	0.16^{NS}	0.61^{NS}	0.68^{NS}

NS implies non-significant.

Appendix 9: p-values for growth and other measured parameters as affected by various treatment factors and their interactions across two years

Sources of variation	No. stems/ plant	Plant height/ plant	No. leaves/ plant	Fresh leaves (g)	Dry leaves (g)	Chlorophyll content (cci)	Plant population	# tubers/ stem	Dry matter %	Tuber yield (t/ha)
Year (TT)	0.00***	0.00***	0.00***	0.00***	0.03*	0.00***	0.02*	0.12NS	0.00**	0.00**
Compost types(C)	0.04*	0.79NS	0.31NS	0.00***	0.00***	0.14NS	0.24NS	0.22NS	0.26NS	0.67NS
Rates (R)	0.29NS	0.97NS	0.94NS	0.65NS	0.68NS	0.68NS	0.32NS	0.12NS	0.98NS	0.99NS
TT*C	0.56NS	0.85NS	0.23NS	0.00***	0.00***	0.35NS	0.37NS	0.06NS	0.11NS	0.05NS
TT*R	0.83NS	0.96NS	0.86NS	0.91NS	0.51NS	0.44NS	0.60NS	0.82NS	0.42NS	0.67NS
C*R	0.21NS	0.60NS	0.95NS	0.67NS	0.79NS	0.72NS	0.55NS	0.84NS	0.39NS	0.42NS
TT*C*R	0.69NS	0.91NS	0.99NS	0.58NS	0.61NS	0.32NS	0.44NS	0.63NS	0.95NS	0.79NS

*, ** and *** implies significant at 5%, 1% and 0.1% probability level, respectively while NS implies non-significant

Appendix 10: p-values for tuber grading as affected by phospho-compost application in 2015

Sources of variation	DF	Baby %	Small %	Medium %	large-medium %	Large %	Class 1 %	Class 2 %	Class 3 %
Compost	3	0.00***	0.00***	0.07^{NS}	0.60^{NS}	0.77^{NS}	0.05*	0.02*	0.17^{NS}
Rates	4	0.40^{NS}	0.69^{NS}	0.43^{NS}	0.18^{NS}	0.41^{NS}	0.87^{NS}	0.55^{NS}	0.40^{NS}
Compost* Rates	12	0.76^{NS}	0.87^{NS}	0.74^{NS}	0.85^{NS}	0.48^{NS}	0.42^{NS}	0.57^{NS}	0.17^{NS}

*, ** and *** implies significant at 5%, 1% and 0.1% probability level, respectively while NS implies non-significant

Appendix 11: p-values for tuber grading as affected by phospho-compost application in 2016

Sources of variation	DF	Baby %	Small %	Medium %	large-medium %	Large %	Class 1 %	Class 2 %	Class 3 %
Compost	3	0.04*	0.38^{NS}	0.04*	0.69^{NS}	0.69^{NS}	0.40^{NS}	0.60^{NS}	0.11^{NS}
Rates	4	0.26^{NS}	0.78^{NS}	0.67^{NS}	0.85^{NS}	0.94^{NS}	0.47^{NS}	0.71^{NS}	0.26^{NS}
Compost* Rates	12	0.26^{NS}	0.77^{NS}	0.73^{NS}	0.91^{NS}	0.37^{NS}	0.91^{NS}	0.10^{NS}	0.35^{NS}

* implies significant at 5% probability level, while NS implies non-significant

Appendix 12: ANOVA for regression analyses on growth parameters.

Source	DF	SS	MS	F	P
Regression	9	4595.5	510.611	8.63	0.000
Lack of fit	107	6442.7	60.2122	6.50	0.0730
Pure Error	3	27.8	9.26400		
Total	119	11066.0			

Appendix 13: p-values for nutrient concentrations in potato tissues as affected by various treatment factors and their interactions

Source	DF	TN	Crude Protein	P	K	Ca	Mg	Na	Cu	Fe	Mn	Zn
Season (S)	1	0.000***	0.000***	0.001**	0.005**	0.36^{NS}	0.000***	0.629^{NS}	0.000***	0.000***	0.000***	0.001**
Plant parts (PP)	1	0.000***	0.000***	0.31^{NS}	0.039*	0.86^{NS}	0.000***	0.000***	0.000***	0.000***	0.000***	0.10^{NS}
Compost types (CT)	3	0.16^{NS}	0.17^{NS}	0.21^{NS}	0.96^{NS}	0.41^{NS}	0.56^{NS}	0.18^{NS}	0.17^{NS}	0.56^{NS}	0.15^{NS}	0.79^{NS}
Compost rates (CR)	4	0.16^{NS}	0.15^{NS}	0.21^{NS}	0.22^{NS}	0.42^{NS}	0.30^{NS}	0.033*	0.44^{NS}	0.78^{NS}	0.49^{NS}	0.24^{NS}
S*PP	1	0.11^{NS}	0.12^{NS}	0.000***	0.002**	0.15^{NS}	0.000***	0.000***	0.000***	0.20^{NS}	0.000***	0.95^{NS}
S*CT	3	0.50^{NS}	0.55^{NS}	0.57^{NS}	0.50^{NS}	0.44^{NS}	0.18^{NS}	0.43^{NS}	0.09^{NS}	0.38^{NS}	0.21^{NS}	0.99^{NS}
S*CR	4	0.58^{NS}	0.59^{NS}	0.34^{NS}	0.26^{NS}	0.33^{NS}	0.022*	0.15^{NS}	0.51^{NS}	0.51^{NS}	0.30^{NS}	0.19^{NS}
PP*CT	3	0.33^{NS}	0.31^{NS}	0.59^{NS}	0.38^{NS}	0.35^{NS}	0.38^{NS}	0.004**	0.74^{NS}	0.21^{NS}	0.13^{NS}	0.73^{NS}
PP*CR	4	0.48^{NS}	0.43^{NS}	0.49^{NS}	0.25^{NS}	0.43^{NS}	0.81^{NS}	0.10^{NS}	0.60^{NS}	0.85^{NS}	0.41^{NS}	0.77^{NS}
CT*CR	12	0.62^{NS}	0.67^{NS}	0.82^{NS}	0.65^{NS}	0.41^{NS}	0.84^{NS}	0.27^{NS}	0.09^{NS}	0.98^{NS}	0.73^{NS}	0.73^{NS}
S*PP*CT	3	0.27^{NS}	0.28^{NS}	0.006**	0.29^{NS}	0.30^{NS}	0.08^{NS}	0.025*	0.39^{NS}	0.06^{NS}	0.048*	0.38^{NS}
S*PP*CR	4	0.13^{NS}	0.10^{NS}	0.018*	0.18^{NS}	0.51^{NS}	0.024*	0.46^{NS}	0.86^{NS}	0.96^{NS}	0.89^{NS}	0.87^{NS}
S*CT*CR	12	0.32^{NS}	0.30^{NS}	0.70^{NS}	0.47^{NS}	0.49^{NS}	0.52^{NS}	0.27^{NS}	0.74^{NS}	0.98^{NS}	0.83^{NS}	0.71^{NS}
PP*CT*CR	12	0.54^{NS}	0.52^{NS}	0.99^{NS}	0.90^{NS}	0.55^{NS}	0.09^{NS}	0.23^{NS}	0.91^{NS}	0.81^{NS}	0.70^{NS}	0.11^{NS}

*, ** and *** implies significant at 5%, 1% and 0.1% probability level, respectively while NS implies non-significant