Effect of Organic Based Soil Fertility Management Strategies on Soil Nutrient Status And Marketable Quality Of Kales (*Brassica Oleracea* Var. *Acephala*) In Kabete, Kenya

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DECLARATION

This thesis is my original work and has not been presented for award of a degree in any other university.

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DEDICATION

This work is dedicated to my son Christian Abisha and husband Anthony Hillary.

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GENERAL ABSTRACT

Demand for uncontaminated and safe agricultural products in Kenya for the last two decades has created a major shift from the use of conventional farming practices to organic based techniques. However, there remains a challenge of poor quality and yield of vegetables. This study aimed to enhance the quality and yield of kale (*(Brassica oleracea* var. *acephala*) in Kabete - Kenya, through use of organic inputs and integration of chickpea (*Cicer arietinum)* either as an intercrop or in rotation with kale. The experimental layout was a randomized complete block design with a split plot arrangement. The main plots were cropping systems; crop rotation (Chickpea – Kale), monocropping (sole Kale) and intercropping (chickpea/Kale). The split plots were organic inputs (FYM and Minjingu rock phosphate). The preferred kale quality attributes were also assessed during the study through a survey targeting 70 farmers. To ascertain the sustainability of the imposed treatments, partial and full nutrient balances (N, P and K) were determined using NUTMON. Parameters collected for the survey included the major vegetable produced by the farmers and the quality attributes they aim for in production, challenges that they face and coping strategies adopted. Organic carbon, N, P, K and kale yield were measured for the on station experiments. About 78% of farmers produced kale with the major quality attributes preferred being large size (76%) and produce free from disease and pest signs (52%) such as black rot and diamond back moth. The production challenges were; unpredictable rains (85%), lack of standardized input application rates (66%) and lack of irrigation equipment (43%). Organic C (3.2%), N (0.45%) and K (1.5 mg/kg) were significantly ($P<0.05$) higher in the rotation system with application of FYM. P content was significantly ($P<0.05$) higher in the intercropping systems with application of Rock P (32 mg/kg). The kale yields followed a similar trend as for the nutrients C, N and K with highest yield (1.62 t/ha) obtained in the rotation system with application of FYM. The control (0.45 t/ha) of the intercrop had the lowest Kale yield. Positive full N balances were realized in the crop rotation systems with application of FYM whereas the partial N balances were all negative across cropping systems and organic inputs except for the monocropping system with application of FYM. Positive full and partial P balances were realized in all the cropping systems with the application of Rock P. Negative full P balances were realized in all cropping systems with application of FYM and control. Negative full and partial K balances were realized across cropping systems and organic inputs. Kales grown in rotation with chick pea and application of FYM are a sustainable strategy for enhanced kale production in Kabete.

Key Words; Chickpea; Crop Rotation; Farm Yard Manure; Intercropping; Monocropping; NUTMON; Rock Phosphate.

ACRONYMS AND ABBREVIATIONS

FAO	**Food and Agricultural Organisation**
FYM	**Farm Yard Manure**
IFOAM	**International Federation of Organic Agricultural Movement**
KARI	**Kenya Agricultural Research Institute**
KOAN	**Kenya Organic Agriculture Network**
NUTMON	**Nutrient Monitoring**
Rock P	**Rock Phosphate**
WHO	**World Health Organisation**

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CHAPTER ONE

1.0 GENERAL INTRODUCTION

Kale *(Brassica oleracea* var. *acephala*) is the most consumed green vegetable in both urban and rural areas of East Africa (Mose *et al*., 2003). In Kenya it is grown by 90% of small holder farmers thus providing employment, mostly, for women and youth who are involved in its production. According to Mariga (2001), kale is much easier to produce compared to other vegetables, and requires fewer chemical inputs and labour. The lower production costs translate into lower selling prices in the market, thus making it affordable even to households with less income (Maina and Mwangi, 2008). Although kale is the most popular leafy vegetable in Kenya, its economic production is limited by several factors including poor soil fertility and weed interference (Anyango, 2005). To increase kale productivity there is need for improvements in soil fertility and disease control through, perhaps, use of agrochemicals. However, due to escalating levels of poverty, small scale farmers cannot afford these agrochemicals while many consumers are frowning at excess use of agrochemicals. This calls for alternative, innovative and sustainable methods of kale production. Organic based soil fertility management strategies is one such approach.

Organic based soil fertility management strategies which avoid the use of synthetic fertilizers; instead it relies on crop rotations, legume cultivation, animal and green manure and off-farm organic wastes and mineral-bearing rocks to feed the soil and supply plant nutrients, in order to maintain sustainable yield production (IFOAM, 2005). All this is in an effort to increase soil organic matter content, which can support microorganisms that help in improving soil fertility and structure and also destroy potential weed seeds in the soils. The use of organic soil fertility management strategies has been associated with desirable soil properties including higher plant available water holding capacity, cation exchange capacity (CEC), lower bulk density and can foster beneficial micro-organisms (Drinkwater *et al.*, 1995). These soil properties enhance productivity and quality of kale crops.

However, a large proportion of kale sold in urban areas poses a number of food safety risks including microbial pathogens, heavy metals, heavy pesticide and fertilizer residues to consumers (Mburu et al., 2007). This is in a bid to improve the physical marketable kale quality but in return it totally diminishes the safety and health aspects of quality. Marketable quality in general is the totality of features and characteristics of a product such as kale that bear on its ability to satisfy stated or implied needs (FAO 2003). Shewfelt (1999) points out that quality is often defined from either a product orientation or a consumer orientation. According to the East African standard for specification and grading (2010), grade 1 which is the highest quality of kale, is produce that is of one type which is well trimmed, not stunted, free from decay and from damage caused by yellow or discoloured leaves, seed stems, wilting, bud burn, freezing, dirt, disease, insects, or mechanical or other means of damage. Thus the principles of organic based farming which apply clean water and no chemical strategy would ensure that the kale produced are both aesthetically and nutritionally safe for consumer consumption. These organic based strategies will hence work well under kale production that is grown by 90% of the smallholder farmers in Kenya (Mariga, 2001). This will reduce the food safety risk by ensuring improved soil fertility, soil health and kale yields and quality, and subsequently raise the farmers' economic returns. Against this backdrop, the current study was carried out at the Kabete on station field to determine the effect of organic based soil fertility management strategies on soil nutrient status, soil nutrient balances and marketable quality and yield of kale.

1.1 STATEMENT OF THE PROBLEM

Kale production is limited by poor soil fertility and weed interference. Poor soil fertility management and especially the excessive use of inorganic fertilizers and pesticides by commercial farmers has led to degradation of soils thus rendering them unproductive due to soil contamination with chemical residues, nutrient depletion and soil structure destruction. (Halberg et al.,2006). Agriculture relies on roughly one meter of topsoil, and that is being depleted ten times faster than it is being replaced (Seattle, 2008).This depletion occurs as a result of excessive use of chemicals and intensive farming techniques that destroy and weaken the soil structure. On the contrary the potential to increase crop production by smallholder farmers is also limited due to very minimal use of nutrient sources (FAO, 1995). This is because in most Sub-Saharan African countries, fertilizer is not readily available and when available the cost is often limiting to small scale resource poor farmers (Smestad et al., 2002). These challenges affect the soil nutrient status and especially the nutrient balances, causing negative N,P and K balances and this in turn results in low vegetable yields and quality hence food insecurity and reduced livelihoods. Production of vegetables that do not meet consumer and food safety standards subsequently becomes a challenge and this leads to poor marketability (Mariga 2011).

1.2 JUSTIFICATION

Since kale production is hampered by low soil fertility, improving the soil status in terms of quality and health is crucial and fundamental in determining productivity of kale. This was done through the implementation of site specific cropping systems such as crop rotation and intercropping with legume (chickpea), with application of organic based fertilizer (Farm yard manure and Rock phosphate). These techniques improved soil fertility and soil health by improving water holding capacity, increasing the cation exchange capacity, lowering bulk density and by fostering beneficial microorganisms. This hence increased productivity and quality of kale crops. To ensure/ascertain the sustainability of this system, a NUTMON analysis was carried out. NUTMON is a tool used to ascertain the nutrient balances (amount of nutrients that go in to the soil vis a vis the ones that go out). Thus farmers can establish when to intervene so as to ultimately take measures that improve soil nutrient balances and hence improve kale production. Once the objective of increased productivity is realized, supply to the markets will increase so as to meet the demands of organic vegetable consumers. However, if shortage is not addressed promptly and efficiently, a crisis of food insecurity to this group of consumers may evolve. Furthermore unless strict adherence to the protocol of growing kale using organic based technologies is adhered to, food safety related concerns will rise from fear of contaminated food produce.

1.3 OBJECTIVES

1.3.1 BROAD OBJECTIVE

To assess the challenges of smallholder vegetable farmers and hence the contribution of organic based soil fertility management strategies on soil nutrient status and kale performance.

1.3.2 SPECIFIC OBJECTIVES

- To assess the challenges and coping strategies of smallholder vegetable producers.
- To assess preferred quality attributes of kale leaves by farmers.
- To evaluate the effects of organic inputs and cropping systems on soil nutrients status and balances
- To determine the effects of organic inputs and cropping systems on kale yield and quality.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Kale production

Kale *(Brassica oleracea* var. *acephala*) is one of the oldest forms of the cabbage family. It has origins in the eastern Mediterranean (Nieuwhof, 1969; Balkaya and Yanmaz, 2005). Farmers generally allocate the tenderer leaves for human consumption and older ones for forage. Kale is the most consumed green vegetable in both urban and rural areas of East Africa (Mariga, 2011).

In Kenya, kale vegetable is popular in many smallholder households because it is consumed together with ugali as the staple food for majority of Kenyans (Mose *et al*., 2003). According to Mariga 2001, kale is much easier to produce compared to other vegetables, and requires fewer chemical inputs and labor. Another advantage is that when kale is sufficiently nourished with compost manure and well watered, it produces huge volumes of leaves, which can be harvested repeatedly (several times a week from the same plant). The lower production costs translate into lower selling prices in the market, thus making it affordable even to households with less income (Maina and Mwangi, 2008).

Overall kales have the potential to transform African economies and contribute to poverty reduction and it is for this reason that its production should be increased. In Kenya it is grown by 90% of small holder farmers thus providing employment mostly for women and youth who are involved in their production. They also provide a positive spillover effect upon a range of other industries like transport and trade. Another reason for its popularity is that kale is rich in numerous health benefiting polyphenolic flavonoid compounds such as lutein, zeaxanthin, and beta-carotene, and vitamins than found in any other green leafy vegetables (USDA, 2005). The consumption of Brassica vegetables such as kale improves human health and reduces the risk of certain cancers and cardiovascular diseases (Francisco et al., 2010; Sies and Stahl, 1995; Traka and Mithen, 2009; Verhoeven, et al., 1997). Numerous studies have indicated that a high intake of plant products such as kale results in a reduced risk of a number of chronic diseases and cancer (Podsedek, 2007; Gosslau and Chen, 2004; Gundgaard et al., 2003; Hashimoto et al., 2002; Kris-Etherton et al., 2002; Law and Morris, 1998; Temple, 2000). The high nutritional value of kale derives from its intense chemical composition (Rosa and Heaney, 1996).

However, though kale is the most popular leafy vegetable in Kenya, its economic production is limited by several factors including poor soil fertility and weed interference (Anyango, 2005). According to KARI (2004), growing requirements are about the same as those for cabbage: fertile soil, neutral pH, plenty of calcium, and water as needed. Excess nitrogen will cause sappy, frost-sensitive tissues. Well-drained loams relatively high in organic matter are suitable. Cover crops may be incorporated to maintain organic matter. The desirable pH is between 5.5 and 6.5. If the pH is too high, manganese is frequently unavailable which results in a chlorotic condition of the leaves. If the pH is too low, an application of lime is recommended. Botrytis (head rot) and black rot are among diseases that affect kale. Both diseases are seed-borne and spread by spores on the wind or in the soil. Thus the seed being propagated should be certified and free from any pathogens (KARI, 2004).

2.2 Organic based farming systems

According to WRI (2007) the area covered by agriculture in Kenya is about 19% of the total land surface. Agriculture remains the mainstay of the Kenyan economy with important vertical and horizontal linkages to other sectors such as manufacturing and service sector. The sector accounts for 60-65% of the country's export earnings and 45% of government revenue (Republic of Kenya 2005). However, according to Kimemia and Oyare (2006), a lot of the farming has limited access to external inputs due the cost factor.

In Kenya as in most Sub-Saharan African countries, fertilizer is not readily available and when available the cost is often limiting to small scale resource poor farmers (Smestad et al., 2002). This leads to non-use or use of suboptimal quantities of fertilizer to avoid crop failure which in turn affects negatively on the soil fertility and thus posing a threat to food security. Agricultural systems have in addition become addicted to the soluble acidic-based NPK fertilizers and this addiction, supported with the then required pesticides and herbicides, leads to soil degradation; thus keeping producers on the production treadmill with "more on‟ farming (Pettit 2006). These current practices continue with the ecessive use of chemicals and ignore the delicate balance of humus, microbes, trace minerals and nutrients in the soil. Such management has resulted in marked losses in soil organic carbon (including humus) and greatly reduced diversity and abundance of microbes (algae, bacteria, fungi, nematodes, protozoa) and larger organisms (*e.g.* mites, ants, beetles, worms) in the soil food web (Ingham 2006). Disruption of soil biological and chemical processes usually leads to physical problems, such as reduced infiltration, compaction and erosion. As a result, conventional farming is now searching for answers to increasing soil organic matter and microbial biomass (Bell 2005, Fisher 2005, Kirkby *et al.* 2006) so as to improve soil health and fertility. This has led to the adoption of organic based soil fertility management strategies. Soil fertility is fundamental in determining the productivity of all farming systems. Soil fertility is most commonly defined in terms of the ability of a soil to supply nutrients to crops. It is viewed as an ecosystem concept integrating the diverse soil functions, including nutrient supply, which promote plant production (Swift and Palm, 2000). This view is appropriate to organic based farming, as it recognizes the complex relationships that exist between different system components and that the sustainability of the system is dependent upon the functioning of a whole integrated and inter-related system (Atkinson and Watson 2000).

Organic based farming system is an example of a low external-input system which avoids the use of synthetic fertilizers; instead it relies on crop rotations, legume cultivation, animal and green manure and off-farm organic wastes and mineral-bearing rocks to feed the soil and supply plant nutrients, in order to maintain sustainable yield production (IFOAM 2005). All this is in an effort to increase soil organic matter content, which can support microorganisms that help in improving soil fertility and structure and also can destroy potential weed seeds in the soils. Improving soil fertility management among smallholder farmers is widely recognized as a critical aspect in addressing food insecurity and poverty, especially in Sub-Saharan Africa, where the majority of the populations in most countries earn their livelihood as smallholder farmers (Donovan and Casey 1998; Freeman and Omiti 2003). Sustained soil fertility management has been an important factor in increasing productivity, but this has been a challenge in Sub-Saharan Africa where on average, the rate of input intensity is estimated at between 8-12 $kgha^{-1}$ compared to over 83 $kgha^{-1}$ for all developing countries (Stoorvogel and Smaling 1990; Mwangi 1997).

Among the most promising organically based soil nutrient management practices include use of animal manure, incorporation of crop residues and improved legume fallows (Place et al., 2003). Short term improved legume fallow technology is characterized by deliberate planting of fast growing nitrogen fixing legume species in rotation with crops of a different family (Niang et al., 2002). Efficient legume growth and nitrogen fixation is highly dependent on an adequate supply of phosphorus. Minjingu rock phosphate (MRP) which costs about 50% of processed P fertilizers, on elemental P basis, is suitable for use under organic based nutrient management systems (Okalebo and Nandwa, 1997; Lelei, 2004).

As the world enters an era in which global food production is likely to double, it is critical that agricultural practices be modified to minimize environmental pollution and degradation (Tilman 1999). Majority of the world population are greatly concerned about the deterioration of the world's land resources and our capacity to produce food for the ever-increasing world population. It is in this context that organic based soil fertility agriculture has slowly been evolving as a solution to these emerging issues.

The use of organic soil fertility management strategies has been associated with desirable soil properties including higher plant available water holding capacity, CEC and lower bulk density, and can foster beneficial microorganisms (Drinkwater et al., 1995). This is among the reasons for use in kale production by smallholder farmers in Kenya. This will ensure soil fertility and health in these farms is improved thus improving yields and consequently improving the economic standards and causing poverty reduction. Examples of soil fertility management strategies used in kale production include the following.

2.2.1 Cropping systems

2.2.1.1 Intercropping

Intercropping refers to the growing of two or more crops at the same time on a single field (Machado, 2009). The cropping system has four general subcategories, namely; mixed, row, strip and relay intercropping (Machado, 2009). Intercropping is more stable than monocropping due to the partial restoration of diversity that is lost under monocropping. Other advantages of the system include; suppression of weeds, soil erosion control and reduced damage from pests and diseases (Machado, 2009). These improved factors lead to production of high quality and yield of crops such as kale.

Cultural benefits are derived when kale is intercropped with two or more plant species (onion, nasturtium, marigold, asparagus, carrot, parsley, cucumber) in close proximity. The benefits include pests and disease control, higher yield, and an increase in the biodiversity of ecosystems (Kuepper and Dodson, 2001). Intercropping of kale may lead to reduction in flea beetles and diamondback moth. Intercropping with plants that attract more natural enemies and that search for preys (Anderson, 2000), helps in controlling pests. Cover crops such as Tepary beans (*Phaseolus acutifolius*), Wedelia (*Wedelia trilobata*) and Sun hemp (*Crotalaria juncea*) have a protective effect against whiteflies. These cover crops serve as a refuge for the natural enemies of whiteflies and soybean looper, thus lowering their population densities (Pantoja and Cabrera, 1999). Planting dill and lovage as trap crops lures hornworms away from the plants (Ellis and Bradley, 1996). According to Anyango (2005), intercropping kale with legumes such as cowpea or mungbean results to weed reduction and hence substantial kale yield increase. This is because weeds cause substantial yield reduction in kale.

2.2.1.2 Crop rotation

Crop rotation is a critical feature of all organic cropping systems because it provides the principal mechanism for building healthy soils, a major way to control pests, and a variety of other benefits (Mohler, 2009). This extrapolates into improved marketable quality and yield. A rotation is a temporal arrangement of crops on the same piece of land (Anderson, 2010). Crop rotation means changing the type of crop grown on a particular piece of land from year to year. The term includes both cyclical rotations, in which the same sequence of crops is repeated indefinitely on a field, and noncyclical rotations, in which the sequence of crops varies irregularly to meet the evolving business and management goals of the farmer (Mohler, 2009).Farmers practice crop rotation in order to build and maintain soil health and to break the lifecycle of pests, thus reducing the need for synthetic fertilizer and pesticide applications (Rodale, 1971). This in turn improves on the kale yield and marketable quality. Rotation design should avoid preceding kale with other Brassica species, thus reducing the potential for pest, disease and weed carryover (Anderson, 2010). Rotation of kale to non-brassica crops for three years is usually recommended to avoid pest problems common to this group of vegetables (Neeson, 2004). Kale planted in rotation with short term improved legume fallow technology which is characterized by deliberate planting of fast growing nitrogen fixing legume species in rotation with kale is beneficial to both the soil and kale crop (Niang et al., 2002). Rotation of kale crops is the most effective means yet devised for keeping land free of weeds. No other method of weed control, mechanical, chemical, or biological, is so economical or so easily practiced as a well-arranged sequence of tillage and cropping (Anderson, 2010).

2.2.2 Organic based fertilizers

2.2.2.1 Green manure/cover crops

This is a crop that is grown then plowed into the soil or left to decompose for the purpose of soil improvement. These crops supply mainly nitrogen to the soil. Examples of cover crops used for green manure include soybeans, clover, rye, and others (Rodale, 1971). Green manures are frequently used in vegetable crop production including kale (FAO, 2002). They are incorporated or plowed into the soil to add organic matter and nutrients for the kale crops. Green manures can be managed to disrupt plant disease cycles or to suppress nematodes. Generally they grow very quickly, are very herbaceous, decompose rapidly, and release nutrients quickly (FAO, 2002).

2.2.2.2 Farm yard manure

Manure offers a natural means to cycle plant nutrients. As such, animal manure forms an important part of organic soil fertility programs. Manure either on its own or blended with crop residues, makes up much of the raw material for the compost used on organic farms (Baker et al, 1990). The most common kinds of farmyard manures are horse, cow and pig manure. Of these three kinds, horse manure has the best balance of nutrients. Cow manure has relatively little phosphate. Pig manure is usually rich in mineral salts but has relatively little potassium. Manure from goat and sheep is also good organic manure (Wageningen 2005). The quantity of nutrients in manures varies with type of animal, feed composition, quality and quantity of bedding material, length of storage and storage conditions (Dewes and Hunsche 1998; Shepherd et al.,1999). Composting of FYM is recommended as an organic based management tool for controlling weeds, pests and diseases especially in kale production. True composting of manures, i.e. aerobic decomposition at temperatures of around 60^0C, results in fundamental physical and chemical changes, causing a significant reduction in nutrient availability, particularly of nitrogen. Composted manure thus has a more long-term role in building soil fertility, and has been shown to be more effective in building soil microbial biomass and increasing activity than uncomposted manure (Fließbach and Mäder 2000). Fresh manure may have an effect on the occurrence of diseases such as root knot nematodes. However, some studies report that adding fresh organic matter such as poultry manure, cattle manure and different kinds of green manure greatly reduced infestations of root knot nematodes (FAO, 2005).

2.2.2.3 Compost

Compost is easy to make from all kinds of organic materials. Examples of materials that can be used are crop residues, kitchen wastes, garden cuttings and manure. Compost is a rich source of macro- and micronutrients. It supplies nutrients at the right time in required quantities (Wageningen, 2005). It is especially useful for improving the soil structure and fertility. Composts have been shown to reduce disease severity (Kim et al. 1997; Abawi and Widmer 2000). In kale production, to help control fungal disease, compost tea made from mature-based compost si applied. The microorganisms present in the compost tea attack the fungi that cause disease in kale (Abawi and Widmer 2000).

2.2.2 4 Phosphorite, phosphate rock or rock phosphate

This is a non-detrital sedimentary rock which contains high amounts of phosphate bearing minerals. The phosphate content of phosphorite is at least 15 to 20% which is a large enrichment over the typical sedimentary rock content of less than 0.2% (Blatt et al., 1996). Phosphorus (P) is very important for vigorous kale plant growth and development. According to Lelei et al., (2009), RP led to efficient legume growth thus more efficient nitrogen fixation which in turn increased yields under intercropping with legumes.

Besides the organic based soil fertility management strategies, other organic based strategies that improve the quality and yield of kale need also be applied. Such practices include those used in crop protection.

Other recommended organic based technologies include the use of non-synthetically processed minerals such as limestone, green sand and rock dust to improve the soil's tilth.

2.2.3 Crop protection

Many researchers have suggested that increasing insect pest and disease pressure in agro ecosystems is due to changes that have occurred in agricultural practices such as the usage of fertilizers and pesticides which have increased rapidly since World War II (Conway and Pretty, 1991). Evidence suggests that such excessive use of agrochemicals in conjunction with expanding monocultures has exacerbated pest problems (Conway and Pretty, 1991). On the other hand, proponents of alternative agricultural methods contend that crop losses to insects and diseases are reduced with organic based farming techniques (Merrill, 1983; Oelhaf, 1978). The organic based approach to crop protection is essentially a biological rather than a chemical one. This is done by developing and enhancing some of a whole range of natural, biological processes and cycles that occur in and around the farm ecosystem and by combining these with a variety of cultural controls and the use of bio degradable pesticides (George McRobie,1990). The few conducted studies suggest reduced susceptibility to pests may be a reflection of differences in plant health, as mediated by soil fertility management (Phelan et al., 1995). Many researchers and also practicing farmers have observed that fertility practices that replenish and maintain high soil organic matter and that enhance the level and diversity of soil macro and micro biota provide an environment that through various processes enhances plant health (McGuiness, 1993). Weeds cause substantial yield reduction in kale (Anyango, 2005), thus weed management practices need be put in place to reverse this effect. Organic based weed management promotes weed suppression, rather than weed elimination, by enhancing crop competition and phytotoxic effects on weeds (Delate and Hartzler, 2003). Kale growing farmers integrate cultural, biological, mechanical, physical and chemical tactics to manage weeds without synthetic herbicides (Delate and Hartzler, 2003). These include; selection of competitive crop varieties, high-density planting, tight row spacing and late planting into warm soil to encourage rapid crop germination (Delate and Hartzler, 2003). Increasingly, new research is showing that the ability of kale crop to resist or tolerate insect pests and diseases is tied to optimal physical, chemical and mainly biological properties of soils (Magdoff and van Es, 2000). Soils with high organic matter and active soil biology generally exhibit good soil fertility as well as complex food webs and beneficial organisms that prevent infection. On the other hand, farming practices that cause nutrition imbalances can lower pest and disease resistance (Magdoff and van Es, 2000) of kale crop. Crop protection strategies that are both sustainable, safe and effective such as use of phytotoxic effect, will lead to production of marketable quality kale and higher yields that would have otherwise been affected by the pests and diseases.

2.3 Food quality

Food quality is the totality of features and characteristics of a product that bear on its ability to satisfy stated or implied needs whereas food safety is the assurance that food will not cause harm to the consumer when it is prepared and/or consumed according to its intended use (FAO, 2001). In most cases food safety falls under the food quality. The demand for produce with specific physical attributes such as, color, shape, size and spotlessness by consumers has encouraged farmers to produce with these attributes in mind (Thrupp et al., 1995; Okello and Swinton 2010). As consumers' lifestyle changes, so are the changes in demand for products with a bundle of specific attributes that often include the safety of the produce (Freidberg, 2003; Henson and Reardon, 2005).

Kale is the most common green leafy vegetables consumed by households in Nairobi and play an important role in nutritional balance (FAO/ WHO, 2005). However, a large proportion of kale sold in urban areas poses a number of food safety risks, including microbial pathogens, heavy metals, and pesticide and fertilizer residues to urban consumers. KEMRI (2004) found that there was a high level of lead in kale grown and sold along the roads with heavy traffic. Due to high perishability a significant proportion of kale sold in Nairobi emanate from the urban and peri-urban areas. At the same time, to keep it fresh and attractive, most retailers sprinkle or moisten it with unclean and sometimes polluted water (Mburu et al., 2007).

Consumer concerns about the safety of vegetables such as kale arise from the increase in the food borne illnesses. In the policy arena, pesticide and fertilizer residues in food are at top among the food safety concern (Okello and Swinton, 2007). Use of sewage water also results in excessive accumulation of heavy metals in soils which in turn leads to elevated heavy metal uptake by crops, which may affect food quality and safety (Muchuweti et al., 2006). Throughout developed countries, food quality and safety have become increasingly important attributes driven by consumers' lifestyle changes and income among other factors (Okello et al, 2009; Mergenthaler et al., 2009). At the same time, the demand for aesthetic attributes (e.g., spotlessness and good looking produce) by urban consumers has encouraged excessive use of pesticides and chemical fertilizers (Karanja et al., 2010). This in turn causes food safety concerns due to the pesticide residues. A balance thus should be created between producing foods of good quality and producing foods that are safe for consumption and use. This is where organic techniques of food production come in. However, challenges still emerge that lead to production of low yields and substandard vegetable marketable quality.

2.4 Challenges of smallholder farmers with respect to vegetable production

Challenges that face smallholder farmers in the sub-Saharan Africa limit the production of crops and heighten the poverty levels of those who depend on agriculture as their sole or major source of livelihood. In Kenya, smallholder farmers are the main food producers but paradoxically, they are also the most food insecure (Nyikal, 2003; Omiti *et al*., 2006; Salasya, *et al.*, 2007; Ogada *et al*., 2011). IPCC (2001) noted that challenges include population pressure, problems associated with land use such as erosion/siltation and possible ecological consequences of land use change on the hydrological cycle. In Kenya, low and declining soil fertility is a major constraint to kale production in smallholder farming systems. Kale (*Brassica oleracea* var. *acephala* D.C.) though being the most popular leafy vegetable in Kenya, has its economic production limited by several factors including poor soil fertility and weed interference. The potential to increase crop production in these systems is limited due to very minimal use of nutrient sources in the form of inorganic fertilizers (FAO, 1995). This is because in most Sub-Saharan African countries, fertilizer is not readily available and when available the cost is often limiting to small scale resource poor farmers (Smestad et al., 2002). This leads to non-use or use of suboptimal quantities of fertilizer to avoid crop failure, thus posing a threat to food security. Weeds also cause substantial yield reduction in kale. Hand weeding is the main method used by most farmers to control weeds. This method has several disadvantages in that it is labour intensive, time consuming and impacts negatively on soil conditions (Anyango, 2005). Smallholders use a wide range of strategies and local innovations to manage and respond to ecological and socio-economic challenges (Milton and Obote, 2007). Adaptive strategies and innovations intrinsic to communities of rural smallholder farmers are often disregarded by research and development efforts (Fenta and Assefa, 2009; Milton and Obote, 2007). This is, in spite of the growing acknowledgement that local strategies and innovations lead to better understanding of socio-cultural, economic and environmental circumstances of specific communities; support the capacities of farmers to cope with and manage food insecurity situations and encourage linkages with appropriate research and policy options (Brooks and Loevinsohn, 2011).

Practices and strategies that improve vegetable production should also be sustainable so as to ensure continuous production of kale. The sustainability of any system is determined by monitoring the nutrient inflows and outflows.

2.5 Nutrient monitoring

Knowledge of status of nutrient management in agricultural production systems is critical in the development of sustainable improvement options (Mubiru et al., 2011) that ensure sustainable fertility and productivity of our soils.

Judicious nutrient management is generally based on thorough understanding of nutrient inflows and outflows, their net balances and management within farming systems. An understanding of these phenomena is crucial for identifying appropriate strategies for systems nutrient management improvement (Mubiru et al., 2011). In Sub-Saharan Africa, considerable efforts to highlight the nutrient management deficiencies in kale production for example have been made (Stoorvogel and Smaling, 1990; Smaling et al., 1993; Stoorvogel et al., 1993; Smaling et al., 1996; De Haan et al., 1996). Based on the nutrient monitoring (NUTMON) concept, Stoorvogel and Smaling (1990) concluded that agriculture in most of SSA is unsustainable. Limited use of nutrient inputs among smallholder farmers exerts pressure on soil nutrient deficiency. The estimated nutrient losses due to erosion, leaching and crop harvests are sometimes staggering, at over 60–100 kg of N, P, and K per hectare each year in Western and Eastern Africa (Stoorvogel and Smaling, 1990; De Jager *et al*., 1998). In many areas of Kenya and especially areas where kale and vegetables in general are produced, low soil fertility tends decline further, as farmers remove many nutrient outputs in crops, crop residues and through losses by processes such as leaching, volatilization and soil erosion. Nutrient mining has thus led to negative nutrient balances (Van den Bosch *et al*., 1998; Lesschen *et al*., 2003). For this reason, sustainable organic based soil nutrient management strategies should be employed to create an increase in the nutrient balance trends. This will in turn improve the marketable quality and yield of kale.

CHAPTER THREE

3.0 GENERAL MATERIALS AND METHODS

3.1 Site description

The study was undertaken in Kabete, Nairobi County. Kabete is situated about 15 km to the West of Nairobi city and lies at Latitude 1° 15′S and Longitude 36° 44′E, and at altitude 1940 m above sea level (Sombroek et al., 1982). Kabete has a bimodal distribution of rainfall, with long rains from early March to late May and the short rains from October to December (Jaetzed and Schimdt 2007). The mean annual temperature is 18°C. The soils in Kabete are characterized as nitisols (Kenya soil survey, 2004).

Socioeconomic status

The Agricultural activities in Kabete are coffee, beans, carnations, peas, maize, tomatoes, kales and dairy production. Kabete is located near the central market for organic produce which is Nairobi. Its accessibility to the market greatly reduces farm losses which may occur due to storage and transportation. The region is also known for housing a large group of organic based farmers.

3.2 Survey

3.2.1 Farmer selection for survey

A total of 70 smallholder farmers from Ngong', Dagoretti, Limuru and Murang'a were selected for interviews on the challenges and coping strategies of vegetable production. These are the regions where organic vegetable farming is widely practiced. A list of the smallholder farmers in these areas was obtained from the Kenya Organic Agricultural Network (KOAN). A computer random number generator was employed to select the number of households in each location. These farmers were then contacted through contact data provided for by KOAN and meetings set up for interviews using structured questionnaires and farm visits.

3.2.2 Questionnaire administration

The questionnaire (appendix 1) aimed at determining the major crop grown by the farmers and their preferred quality attributes. It also assessed the challenges, coping strategies, farming practices and general livelihoods of smallholder vegetable producers. To ensure the questionnaire's ability to accurately measure and capture the intended objectives, it was subjected to review by experts, supervisors and peers. The questionnaires were pre-tested to check on content and clarity of questions before being administered to the farmers. In addition, farm visits were undertaken for direct observation on the practices undertaken on the farm fields.

3.3 On farm experimental designs and treatments

The field experiment trials were conducted at the University of Nairobi field station, Kabete Campus during the long rain season (March - June) and short rain season (October –December) of 2012.

The experimental design was a Randomized Complete Block Design with a split plot arrangement. The main plots were the cropping systems (monocropping, intercropping and crop rotation) with a legume component (chickpea) while the sub- plots were incorporated with organic inputs (farm yard manure and rock phosphate) (table 3.1). The rock phosphate was applied at a rate of 480 $kgha^{-1}$, with the FYM being applied at the rate of 10 tons/ha applied during planting. The experiment had nine treatments replicated three times.

Table 3.1: Experimental layout for one replicate

Monocrop FYM	Monocrop Rock P	Monocrop control	Intercrop FYM	Intercrop Rock P	Intercrop control	Rotation FYM	Rotation Rock P	Rotation control

3.3 Agronomic practices

The crops were planted in March and October of the long and short rains respectively of the year 2012.

Direct sowing of kale and chickpea seeds was done on the farms with backup kale seed beds being prepared at the sites. Three kale seeds were planted per hole while for the chickpea; two seeds were planted per hole. The organic inputs were incorporated into the soils during planting. Seeds were planted at 2 cm deep and thinned when plants were in the trifoliate stage (had three true leaves). Plants removed at thinning were then transplanted to adjacent areas (gapping) leaving only one plant per hole.

For pest and disease control, Eucalyptus tree ash was used to control cut worms and pyrethrum extracts to control aphids and diseases. The fields were surrounded by Mexican marigold plants to act as a pest-repelling barrier.

Weeding was done at interval of three weeks from the time of planting to harvesting. Selective hand weeding was done.

Kale was harvested at 12 weeks. Older leaves were generally stripped off the plants to allow the young leaves to continue to grow.

3.4 Statistical Analysis

3.4.1 Survey: Descriptive statistics (means, frequencies and percentages) were calculated for key categories for the survey results. Socio-economic data was entered into a spreadsheet and analyzed using SPSS for Windows version 14.02 (SPSS Inc., ©1989-2005).

3.4.2 Field experiments: The measured soil nutrients and plant yield and quality parameters were subjected to Analysis of variance (ANOVA) using Genstat 6.2 (Lawes Agricultural Trust, Rothamstead, UK) package in accordance with the split plot design. The significance of differences at different harvests between main-plot effects (cropping systems), sub-plot effects (organic inputs) and their interactions were determined using standard error of the difference in means (SED) values at 5% ($P<0.05$).

RESULTS AND DISCUSSION

CHAPTER FOUR

4.1 Challenges and coping strategies in production of preferred kale quality attributes by smallholder farmers

4.2 Abstract

Smallholder farmers face numerous challenges that lead to low production. Current organic based soil fertlity management strategies have not facilitated bridging the demand- supply gap for uncontaminated and safe agricultural products in Kenya for the last two decades. A survey was carried out to determine the cause of low organic based kale production among the smallholder farmers of central Kenya. The study's objective was to determine the major vegetables grown by the smallholder farmers, quality attributes they strived to produce for the market, challenges faced and coping strategies adopted by these farmers to enhance production. A total of 63 farmers from Ngong', Dagoretti, Limuru and Murang'a counties were selected for a survey through questionnaires. Of the farmers interviewed, 67% were female and 33% male. About 48% of farmers had achieved post-secondary education, with 16% having primary level education. The mean age of the farmers interviewed was 52 years. Of the farmers interviewed; 63% grew kales and 32% spinach. The farmers listed the kale quality attributes they strived to produce as; produce free from disease and pest signs (76%), and size (52%). The challenges faced in production included; unpredictable rains (85%), lack of irrigation equipment (43 %,) lack of standardized input application rates (66%) and lack of proper soil testing and analysis facilities (37%). Coping strategies adopted by the farmers included irrigation (64%), mass application of manure (45%) and use of traditional weather forecasting methods (16%). The study revealed need for research, extension and credit services to help curb the problems faced by the farmers. This will hence improve quality and yield of produce, and thus bridge the supply demand gap.

Key words: Challenges; Coping Strategies; Quality Attributes; Kale

4.3 INTRODUCTION

Food production in Kenya relies heavily on smallholder agricultural production (Maina 2012). Among the crops produced by these smallholder farmers, vegetables are the most grown. They are rich in mineral nutrients such as calcium, iron, vitamin A and C (Mwangi *et al.,* 1994). Vegetables play an important role in the diet of many households in Kenya both in the urban and rural areas. Consequently, uncontaminated and safely produced vegetables are in increasing demand. These are vegetables grown using organic based techniques such as use of organic inputs in combination with cropping systems that enhance the performance of both the soil and crop without the application of synthetic fertilizers. The demand for such vegetables has increased tremendously over the last decade especially in East Africa (Bouagnimeck, 2009). The reasons for the rapid increase in demand include safety, positive effect on environment, flavor, freshness, health benefits and nutritional value (Bourn and Prescott, 2002; Smith 1993).

In Kenya, the smallholders are the main food producers but, they are also the most food insecure (Nyikal, 2003; Omiti *et al*., 2006; Salasya, *et al.,* 2007; Ogada *et al*., 2011). Challenges that face smallholder farmers in the sub-Saharan Africa including Kenya limit the production of crops and heighten the poverty levels of those who depend on agriculture as their sole or major source of livelihood. The potential to increase crop production is further limited due to very minimal use of inorganic fertilizers as nutrient sources (FAO, 1995). This is because in most Sub-Saharan African countries, fertilizer is not readily available and when available the cost is often limiting to small scale resource poor farmers (Smestad et al., 2002) leading to food insecurity.

However, smallholders use a wide range of strategies and local innovations to manage and respond to ecological and socio-economic challenges (Milton and Obote, 2007). Adaptive strategies and innovations intrinsic to communities of rural smallholder farmers, (Fenta and

Assefa, 2009; Milton and Obote, 2007) can support the capacities of farmers to cope with and manage food insecurity (Brooks and Loevinsohn, 2011). The innovations can also be used to address food safety and quality issues. These issues have been summarized in the organic produce quality standards as desired quality attributes that supply should seek to fulfill (Abbott, 1998; Shewfelt, 1999) so as to meet sensory properties (appearance, texture, taste and aroma), nutritive values, chemical constituents, mechanical properties and functional properties (Abbot, 1999). However, supply of vegetables of theses specifications still falls short of demand. This study aimed at determining the major vegetables grown by the smallholder farmers, the quality attributes they strive to meet for the market, the challenges faced and coping strategies adopted for production.

4.4 MATERIALS AND METHOD

4.4.1 Study approach

The study was carried out in Ngong', Dagoretti, Limuru and Murang'a areas. The study involved a survey which targeted smallholder vegetable farmers. The survey aimed at assessing the challenges and coping strategies of these farmers and also the preferred quality attributes of kale leaves that they aim for in production.

4.4.2 Farmer selection for survey

A total of 70 smallholder farmers from Ngong', Dagoretti, Limuru and Murang'a were selected for interviews on the challenges and coping strategies of vegetable production. These are the regions where organic vegetable farming is widely practiced. A list of the smallholder farmers in these areas was obtained from the Kenya Organic Agricultural Network (KOAN). A computer random number generator was employed to select the number of households in each location. These farmers were then contacted through contact data provided for by KOAN and meetings set up for interviews using structured questionnaires and farm visits.

4.4.3 Questionnaire administration

The questionnaire (appendix 1) aimed at determining the major crop grown by the farmers and their preferred quality attributes. It also assessed the challenges, coping strategies, farming practices and general livelihoods of smallholder vegetable producers. To ensure the questionnaire's ability to accurately measure and capture the intended objectives, it was subjected to review by experts, supervisors and peers. The questionnaires were pre-tested to check on content and clarity of questions before being administered to the farmers. In addition, farm visits were undertaken for direct observation on the practices undertaken on the farm fields.

4.4.4 Statistical Analysis

Descriptive statistics (means, frequencies and percentages) were calculated for key categories. Socio-economic data was entered into a spreadsheet and analyzed using SPSS for Windows version 14.02 (SPSS Inc., ©1989-2005).

4.5 RESULTS AND DISCUSSION

4.5.1 Demographics

Majority (67%) of the farmers interviewed were female which was almost double the number of male farmers (34%) (Table 4.1).

Table 4.1: Characteristics of the households involved in vegetable production

Demographics		**Percentage %**
Gender	Male	34
	Female	67
Age	Below 30	7
	31 – 40	21
	41 -50	11
	51 – 60	28
	61 – 70	30
	71 and above	3
Level of education	Primary	16
	Secondary	36
	Post-secondary	30
	University	18
Source of income	Farming	62
	Business	28
	Employed	10

This may be due to the fact that more women are being empowered to start enterprises that improve their economic status through self-help groups and funding from government and nongovernmental programmes aimed at improving the woman's standing in society and national development. They are thus making their own decisions as to which practices are safe, healthy and productive for their families and society at large. These findings are similar to those of Foeken et al. (2000) who found that the majority of smallholder farmers are women. In addition, this vegetable serves as a source of cash for small-scale farmers, particularly women and youth in rural and peri-urban areas (Lohr and Gathu, 2002).In most parts of Africa, women have traditionally been responsible for household food provision and farming is relatively easy to combine with the care of children.

About 30% of the farmers interviewed were between the ages of 61 to 70 years old, followed closely by 28% who were between ages 51 to 60 years old. This shows that about 61% of farmers were aged above 50 years, with 39% aged below 50 years. This may be due to the fact that the youth mainly seek white collar jobs in towns, leaving behing the older generation who have mostly retired to the rural areas to take up farming. The conclusion that majority of farmers constitute the older generation may also be due to the fact that this age group is mostly retired and are taking up farming as a means to alternative livelihood from white collar jobs in the city. These results are similar to those of Mwabo (1998) who studied the Effects of agricultural extension on farm yields in Kenya and found that majority of farmers in Kenya are above 45 years.

Nearly 84% of farmers had an secondary level education and higher. Only 16% did not complete their secondary education. This shows that most of the farmers were educated with an impressive 48% having received higher education in post-secondary colleges and universities. These are well read people and this fact is assuring that organic based farming is being embraced by people who can comprehend the significance of this particular method of farming. However, these results are contrary to findings of Muchai et al., (2012), who found that majority of the farmers had attained primary education (59.6%) while 25.8% and 9.2% had attained secondary and post-secondary education, respectively

Of the respondents, 62% generated their income solely from farming. Another 28% supplemented their farm income with personal businesses. Only 10% of the farmers were in full employment and thus practiced farming in their free off-work hours .This shows that most of the farmers derived their income solely from farming and thus farming as an enterprise sustained their livelihoods. These findings are similar to those of Nyambiro (2012) who found that in Kenya, a large percentage of households (33.4%) derive their income from the sale of farm produce, another 20.7 % derive their livelihoods from small trade and 14.2% derive livelihood from remittances. The other respondents derived their incomes from sale of livestock (9.4%), formal employment (3.3%), pensions (3.3%), interests and savings (1.5%), house rentals (0.7%) and dividends (0.3%). This shows that farming onits own can sustain livelihoods.

4.5.2 Farmer prioritization of crops grown.

Farmers termed crops as being high value based on their market demand and high price value in the markets. They then listed the crops grown in their farms (Figure 4.1).

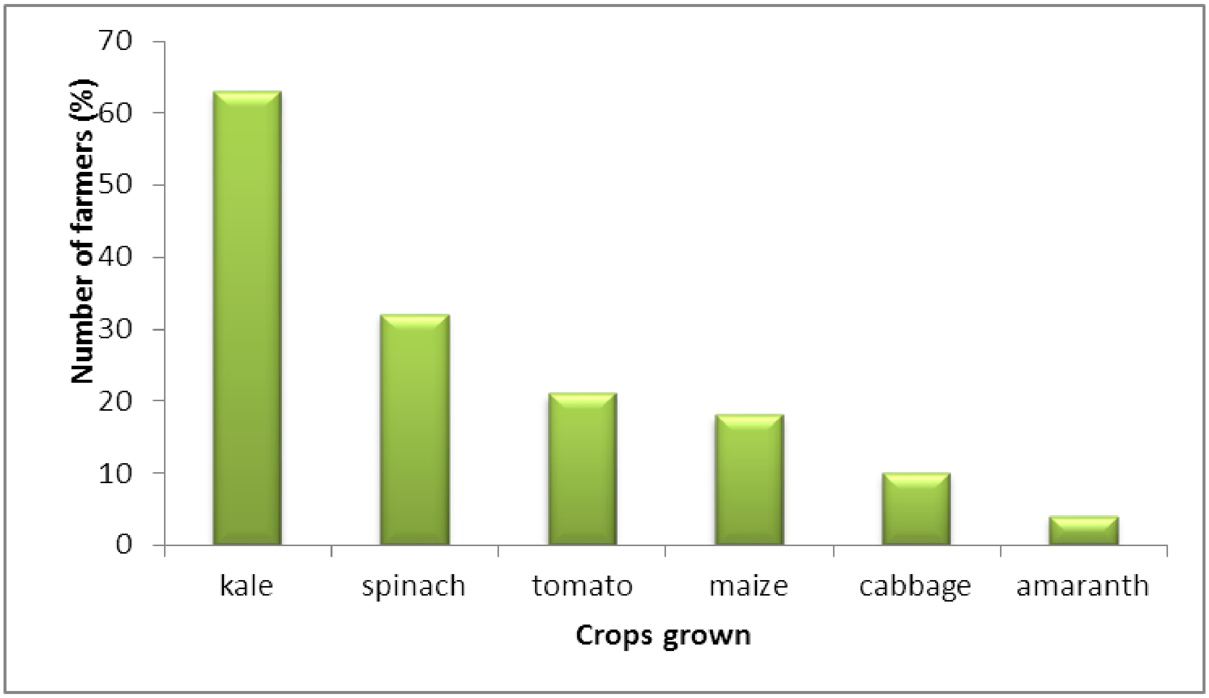

Figure 4.1: Major high value crops grown by smallholder farmers.

Most (63%) of the farmers produced kales since this product had highest demand in the local markets (Figure 4.1).About 32% of the farmers produced spinach. 21% produced tomatoes, making these three crops the predominantly grown crops by the farmers (Figure 4.1). Another contributing factor to the order of crops may be because a big percentage of the first three crops (kale, spinach and tomato) are also produced for daily home consumption. Maize though a staple crop may have fallen short in the listing because most of the maize is produced conventionally using synthetic fertilisers. This finding is similar to those of a study conducted by Salasya (2005) of Kiambu district which neighbours Nairobi, which found kale to be the most popular green vegetable consumed by almost every household in Kenya, because it had the highest returns and thius a major source of cash for many households.

4.5.3 Kale quality attributes that farmers produce for the market

The farmers stated that consumers were interested in physical attributes of produce to determine their quality and worth. This in turn determines how much the farmer gains in terms of sales and profits. About 76% of the farmers reported that the consumers mostly looked at presence of signs and symptoms of disease and pests in the produce before buying (Figure 4.2).

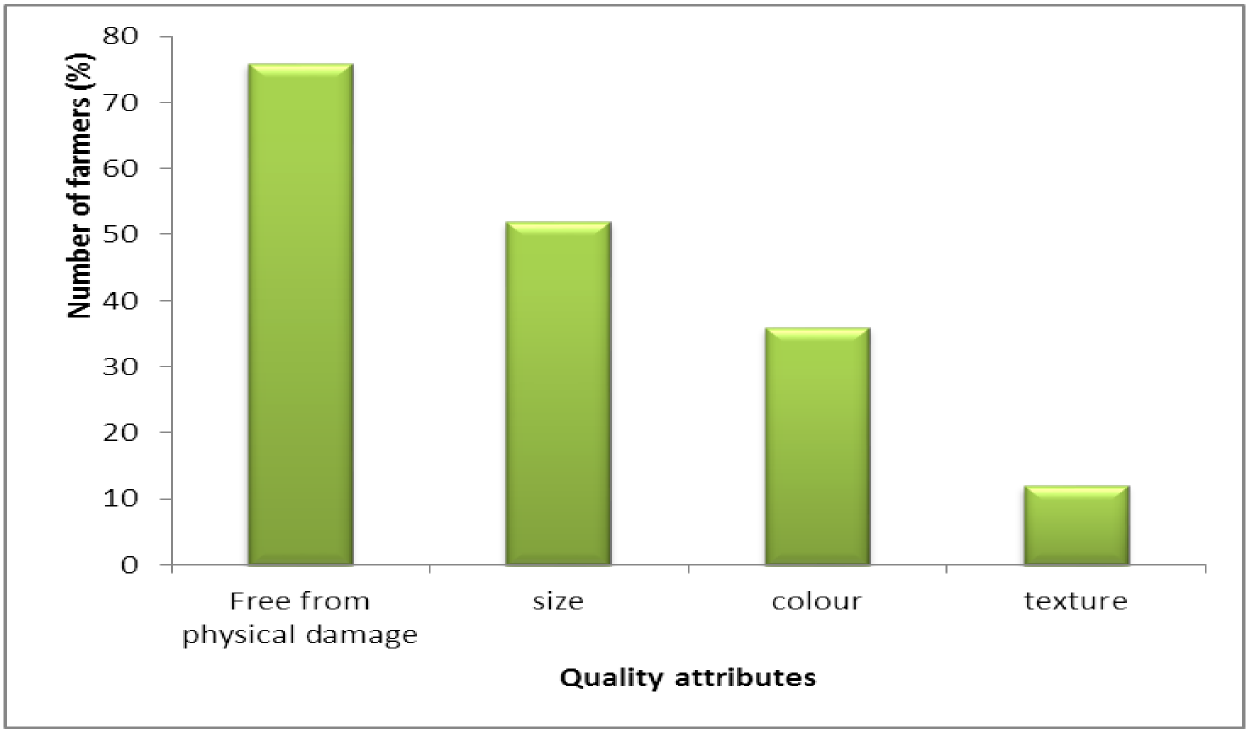

Figure 4.2: Vegetable quality attributes that farmers produce for the market

Consumers consider the absence of such signs and symptoms as the best sign that the produce is of high quality. In their production therefore, the farmers paid keen attention to ensure that they produced pest and disease free produce. This was achieved by using organic based techniques such as planting certified seeds, early planting, and use of biopesticide and pest repellant crops in the cropping systems. Another 52% of the farmers mentioned size as a major consideration in production of the vegetables for market consumption (Figure 4.2). Though size is mostly a characteristic of the specific vegetable variety, soil and environmental factors may contribute to size of the vegetables. Poor soil fertility and adverse environmental conditions can reduce size of produce. Thus farmers paid keen attention on the above factors by choosing specific varieties and ensuring that the soils were healthy so as to meet market requirements. This is because consumers may regard cleanliness and bigger produce as a direct reflection on the farming practices and thus health and safety of the produce. These results are similar to those of a study on quality attribute conducted by Rubzen and Correia, (2012), who found that the most important attribute consumers are seeking when buying vegetables is freedom from physical damage and defects. This is followed by freedom from pest and disease and freedom from chemical residues.

4.5.4 Challenges and constraints faced by smallholder vegetable farmers.

The challenges (Figure 4.3) faced in production of kale and other key vegetables included unpredictable rains (85%), which affected timing of production due to late planting and decreased yields.

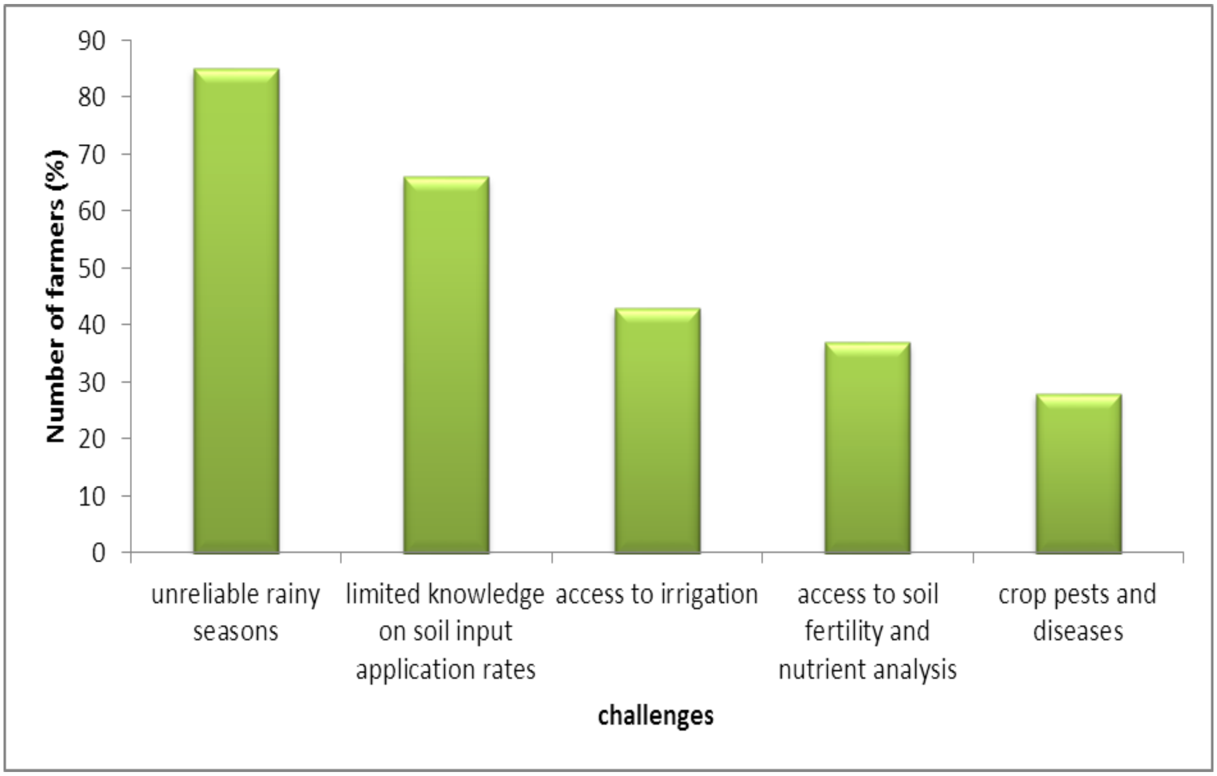

Figure 4.3: Challenges and constraints of vegetable production by smallholder farmers

Lack of irrigation equipment and water (43%) to supplement the unreliable and unpredictable rains also adds up to production challenges. Crop pest and diseases (28%) were mainly a challenge due to lack of information on specific control strategies and due to high cost of bio pesticides. This resulted in significant reduction in yields and quality of crops which were infested by pests and disease. Lack of access to proper soil testing and analysis facilities (37%) and inadequate knowledge on input application rates (66%), led to application of improper quantity and quality of the same and thus hindered optimum production. The challenges mentioned may be due to and/or further heightened by lack of funds to make available essential inputs such as irrigation equipment, soil testing facilities and bio pesticides that would otherwise increase quality and quantity on production. The farmers in Kenya are faced by difficulties in gaining access to formal credit, since they do not have the requisite collateral to obtain credit and also due to the fact that the financial institutions do not recognize the differences between organic based and conventional agriculture. However the leading challenge is unreliable rainfall. This may be due to climate change which has affected the rainfall calendar. Rainfall delays and sometimes unexpected floods cause damage to crops and this is reflected on losses to the farmers and food insecurity in the country at large. The results (figure 4.3) are similar to those of a study conducted by Owuor (2002) which showed that farmers faced various constraints such as irregular rainfall, drought, flooding, water logging, poor soils, pests and disease, and the destruction of crops by animals. However, an analysis on the organic based smallholder farming sector undertaken by Bett and Freyer (2007), summarized the main challenges and opportunities in the sector as policy based. This was because the government though had put in place policies and legislation that protected farmers in general, no extension of such policies addressed organic farmers. The policies failed to recognize that organic production was unique and needed specialized effort to promote it.

4.5.5 Coping strategies adopted by farmers in response to the vegetable production challenges.

Farmers had devised coping strategies so as to protect their interests. Out of the farmers who stated unreliable rains as a challenge 64% mentioned irrigation and 36% mentioned late planting as strategies they used so as to cope (Table 4.2).

Table 4.2: coping strategies adopted by farmers to reduce losses caused by the challenges in production

CHALLENGES	COPING STRATEGIES	%
Unreliable rainfall	Irrigation	64
	Late planting	36
Limited knowledge on soil input application	Mass application	55
	Indigenous techniques	45
Access to irrigation	Only plant during the rainy seasons	84
	Credit facilities	16
Access to soil fertility and nutrient analysis	Blanket recommendations for all soil types	74
	Rely on outdated information	26
Pest and disease management	Bio pesticide	11
	Indigenous techniques	76
	No coping strategy	13

Other coping strategies e.g. mass application of inputs to cope against lack of specific recommended rates and resulting to use of indigenous techniques (techniques passed down from generation i.e. application on three handfuls of FYM per hole), have however not always worked well or efficiently towards the improvement of quality and yield of produce. To cope with the unreliable rainfall, 64% of the farmers could afford to set up irrigation facilities on their farms. Access to credit facilities to dig boreholes and buy irrigation equipment was the reason as to why 36% of the farmers practiced late planting. Farmers could not get loans from credit institutions such as banks and or SACCOs due to lack of collateral since most of these farmers had hired the land they farmed on. Use of bulk/mass application (55%), where farmers believe in applying loads of fertilizer and blanket recommendations of organic inputs (74%) was the coping strategy for inadequate information on application rates and lack of access to soil nutrient and fertility analysis respectively. Only 11% of the farmers could afford biopesticide due to cost and limited information made available to them. About 76% of the farmers made use of traditional knowledge passed on to them for generations while 13% did not make any efforts to manage pests and disease. The coping strategies adopted by the farmers are inadequate and only add to the problems/challenges and not to the solution thus low production. Devereux and Guenther (2007) sated that coping strategies that include water harvesting, conserving and managing resources, irrigating are only sustainable if government and stakeholders work with farmers.

4.6 Conclusion

Female farmers almost double the number of male farmers. Kale and spinach were the crops grown by majority of the farmers making them high value both in production and demand. However, challenges of unreliable rainfall, lack of information on input application and pests and diseases were at the top of the disadvantaging factors leading to low production of vegetables.

This coupled with the coping strategies used to mitigate the effects of the challenges which are neither scientific nor efficient such as; mass application of fertilizer and waiting for the unpredictable rains so as to commence planting, only stall the need for improving production quality and yield of the vegetables by the farmers. From the study findings, farmers need more assistance from agricultural organic based stakeholders, researchers and extension officers to work with them and help in improving the organic based vegetable production sector.

4.7 Recommendations

- Organic agriculture institutes in the given areas should focus their attention to soil analysis, irrigation, greenhouse production and recommendations on site specific input rate application.

- More research needs to be conducted to avail information on pest and disease control strategies that are affordable to small holder farmers.

- Credit should be extended to farmers who embrace organic based farming as a business venture. This would enable them access inputs such as irrigation equipment and organic based fertilizer.

CHAPTER FIVE

5.1 EFFECTS OF ORGANIC INPUT APPLICATION AND CROPPING SYSTEMS ON SOIL NUTRIENTS STATUS

5.2 Abstract

Soil fertility has been on the decline over the past years in sub Saharan Africa due to continuous and sub optimal use of synthetic fertilizers. Soils then become a major constraint to crop production in smallholder farms especially in Kenya hence food insecurity. This study investigates the effect of three cropping systems; sole kale, kale in rotation with chickpea and kale intercropped with chickpea in combination with organic inputs (farm yard manure and phosphate rock), on the soil nutrient status and hence performance of kale. An on station field experiment was conducted at upper Kabete field station of the University of Nairobi for two seasons (long and short rains 2012). The experimental design was a Randomized Complete Block Design (RCBD) with a Split-plot, arrangement replicated three times. The main plots consisted of the cropping systems while the split plots consisted of the organic inputs. Soil Carbon, Nitrogen, Phosphorous and Potassium were measured. Organic Carbon was highest in the rotation system with application of FYM (3.18%). Nitrogen was highest in the rotation system with application of FYM (0.45%). Phosphorus content was highest in the intercropping system with application of Rock P (32.5 mg/kg). Potassium was highest in the rotation system with application of FYM (1.49 mg/kg. The results indicated that either intercropping or rotation with continuous application of both FYM and Rock P would significantly increase the soil nutrient content.

Key words: Carbon, Cropping Systems, Nitrogen, Organic Inputs, Phosphorous, Potassium

5.3 Introduction

In sub saharan Africa including Kenya, low soil fertility, particularly nitrogen (N) and phosphorus (P) deficiencies, is recognized as one of the major biophysical causes for declining per capita food production (Sanchez et al., 1997). Most soils in Kenya have been degraded and depleted of essential nutrients thus rendering them unsuitable for crop production (Drinkwater *et al.*, 1995). For many cropping systems in the tropics, application of N and P from inorganic sources is essential to maximize high crop yield potential in continuous cultivation systems (Hartemik et al., 2000). However, prolonged application of these inorganic fertilizers on the other hand has resulted in negative environmental impacts such as accumulation of heavy metals in soil, crop and water (Halberg *et al*., 2006). These inorganic fertilizers have also proven to be quite costly especially for the smallholder farmers in Sub-Saharan Africa including Kenya and thus majority of farmers apply very little amounts of fertilizer or none at all (Gyaneshwar et al., 2002; Darzi et al.,2011) leading to low yields.

Organic based nutrient management (ONM) which emphasizes use of biodegradable material, is a sustainable alternative for the high cost of fertilizer and soil nutrient depletion in the sub Saharan Africa (Lelei et al., 2008). ONM avoids the use of synthetic fertilizers; instead they rely on crop rotations, legume cultivation, animal and green manure and off-farm organic wastes and mineral-bearing rocks to feed the soil and supply plant nutrients, in order to maintain sustainable yield production (IFOAM 2005). Various types of organic materials have been found to have similar effects on soil physical properties (Barzegar et al., 2002), and almost all studies indicate that application of organic materials improves soil properties (Celik et al., 2004; Mando et al., 2005). Among the most promising organically based soil nutrient management practices include use of organic inputs such as farm yard manure and phosphate rock (Place et al., 2003).

Cattle manure is a good source of nutrients if available in sufficient quantity and quality (Dewes and Hunsche 1998; Shepherd *et al.* 1999). Bahremand et al., 2003 and Mosaddeghi et al. (2000) reported that application of farm yard manure to the soil counteracted soil compaction, and decreased soil compactibility. Phosphate Rock (PR) is a raw material that contains phosphate mineral for making super-phosphate fertilizers. It can be utilized as direct application fertilizer in acid soils because of the low input cost and slow release of P to the soil (Sale and Mokwunye, 1993).

Soil fertility depletion in addition can also be addressed through incorporation of crop residues and integration of legumes into cropping systems through improved legume fallows (Place et al., 2003). The use of these legumes in many parts of the tropics is limited and it has been shown that farmers tend to adopt them when they have other benefits in addition to soil fertility improvement (Versteeg et al., 1998). Legume managed as green manures has the potential to furnish all or part of the N needed by a succeeding non-legume crop (Bowen et al., 1993). In addition, conservation tillage as a component of organic based soil fertility management system has the potential to bring soil quality to a high stage and reduce soil loss by providing protective crop residue on soil surface and improving water conservation by decreasing evaporation losses (Unger and McCalla, 1980). Therefore the above mentioned organic based soil fertility management systems can be used to meet the objective of improving soil quality and soil health which have been over the years continuously degraded by careless and excessive use of synthetic fertilizers and poor agricultural techniques.

5.4 Materials and methods

5.4.1 Experimental design and treatments

The field experiment trials were conducted at the University of Nairobi field station, Kabete Campus during the long rain seasons (March - June) and short rains (October –December) of 2012. The experimental design was a Randomized Complete Block Design with a split plot arrangement. The main plots were the cropping systems (monocropping, intercropping and crop rotation) with a legume component (chickpea) while the sub- plots were incorporated with organic inputs (farm yard manure, rock phosphate and a control). The rock phosphate was applied at a rate of 480 kgha^{-1}with the FYM being applied at the rate of 10 tha^{-1}. Both RP and FYM were applied during planting. The experiment had nine treatments replicated three times.

5.4.2 Agronomic practices

Kale and chickpea were planted in March and October of the long and short rains of the year 2012 respectively.

Direct sowing was done on the farms with backup seed beds being prepared at the sites. The organic inputs were incorporated into the soils during planting. Seeds were planted at 2cm deep and thinned when plants had three to four true leaves. Plants removed at thinning were then transplanted to adjacent areas (gapping), leaving only one plant per hole.

For pest and disease control, Eucalyptus tree ash (500kgha$^{-1)}$ was sprayed on the crops to control cut worms and pyrethrum extracts (200litresha^{-1}) also sprayed to control aphids and diseases. The fields were surrounded by Mexican marigold plants to act as a pest-repelling barrier.

Weeding was done at interval of three weeks from the time of planting to harvesting. Selective hand weeding was done, with the weeds being incorporated as green manure into the soil.

Kale was harvested at 8and 12 weeks. Older leaves were generally stripped off the plants to allow the young leaves to continue to grow.

The experimental design was a Randomized Complete Block Design with a split plot arrangement. The main plots were the cropping systems (monocropping, intercropping and crop rotation) with a legume component (chick pea) while the sub- plots were incorporated with organic inputs (farm yard manure and rock phosphate).). The rock phosphate was applied at a rate of 100kgacre^{-1} with the FYM being applied at the rate of 10 tons/ha applied during planting. The experiment had nine treatments replicated three times.

5.4.3 Soil sampling and Analysis

Initial soil sampling was done before planting. At the end of the season, soils were sampled again. Soil samples were taken from each plot in a systematic random manner at 0 – 15 cm depths.. Soil samples were air-dried by spreading the soil out in a clean, warm, dry area, for two days. The sample were packed, labelled and later taken to the laboratory for analysis. Soil samples were analyzed for N, P, K and Carbon nutrient contents using the methods described by Okalebo *et al*. (2002).

Soil pH: The procedure for determining soil pH was a 1:1 (soil: water) suspension (Mc keague, 1978, McLean, 1982).The soil pH was arbitrarily described as follows: strongly acidic (pH <5.0), moderately acid (5.0-6.5), neutral (6.5 and 7.5), moderately alkaline (7.5-8.5) and strongly alkaline (>8.5).

Organic Carbon: The method used to analyse organic matter was wet combustion which involved reduction of potassium dichromate ($K_2Cr_2O_7$) by OC compounds and subsequent determination of the unreduced dichromate by oxidation-reduction titration with ferrous ammonium sulphate (Walkey, 1947; FAO, 1974).

Total Nitrogen: The procedure involved digestion and distillation. The soils were digested in concentrated H_2SO_4 with a catalyst mixture that raised the boiling temperature and promoted the conversion from organic-N to ammonium-N. Ammonium-N from the digest was obtained by steam distillation, using excess NaOH to raise the pH. The distillate was collected in saturated H`3BO3; and then titrated with dilute H2SO4 to pH 5.0 (Bremner and Mulvaney, 1982).

Extractable Phosphorus**:** The sodium bicarbonate procedure of Olsen et al. (1954) was used to measure P in the soil.

5.4.4 Statistical Analysis

The measured soil values were subjected to Analysis of variance (ANOVA) using Genstat 1.2 (Lawes Agricultural Trust, Rothamstead, UK) package in accordance with the split plot design. The significance of differences at different harvests between main-plot effects (cropping systems), sub-plot effects (organic inputs) and their interactions were determined using standard error of the difference in means (SED) values at 5% ($P<0.05$).

5.5 RESULTS AND DISCUSSION

5.5.1 Effect of organic inputs and cropping systems on soil organic carbon

In season one there was no significant difference in OC between monocropping and intercropping systems. However, OC percentage was highest in the monocropping systems with application of FYM (2.89%) followed by intercropping system with application of FYM (2.87%), (Figure 5.1).

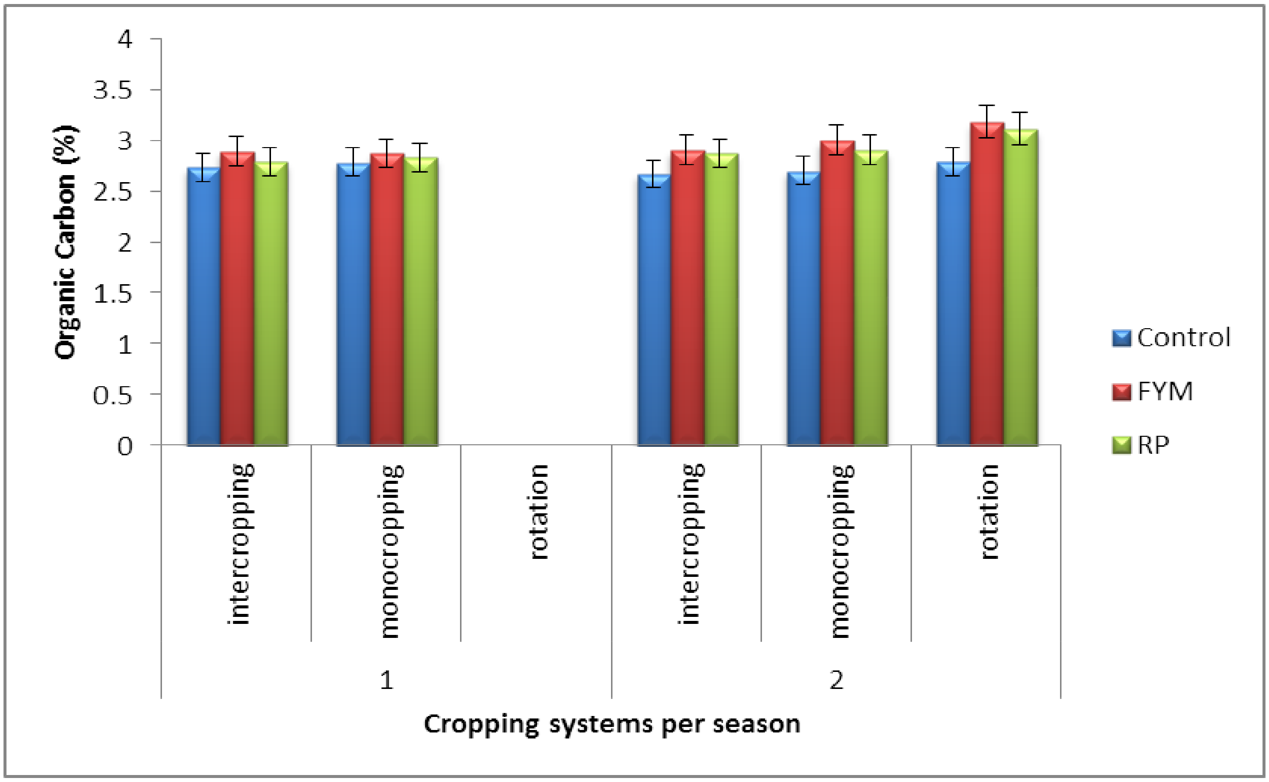

Figure 5.1:Effect of organic inputs and cropping systems on soil organic carbon at kabete season one and two

OC levels in seasonone were moderate. In season two, significant difference was observed in the cropping systems but not in the organic inputs. In season two, rotation system with application of FYM had the highest C (3.18) followed by rotation system with application of Rock P (3.11%), (Figure 5.1). Theseadequate levels of OC may be due to the legume forages from the first season that were incorporated into the soil hence raisong the OC content. These findings are similar to those of K. Banger (2008), who found that continuous application of FYM to the soil lead to increase in soil organic carbon (SOC) in all the soil fractions. Sudhir and Siddaramappa (1995) and Janzen et al. (1998) also found increased SOC under the FYM treatments and attributed the same to addition of organic materials and continuous return of large amount of crop residues in the form of roots and stubbles to the soil. Lal et al. (1999); Hao et al. (2002) and Desjardins et al. (2001) also stated that incorporation of forage legumes in the crop rotation cycles were strategies for SOC increase and restoration.

5.5.2 Effect of organic inputs and cropping systems on soil nitrogen

In season both seasons there was significant difference in the cropping systems but not in the organic inputs. In season one intercropping system with application of FYM had the highest N (0.38%) followed by intercropping system with application of Rock P (0.36%), (Figure 5.2).

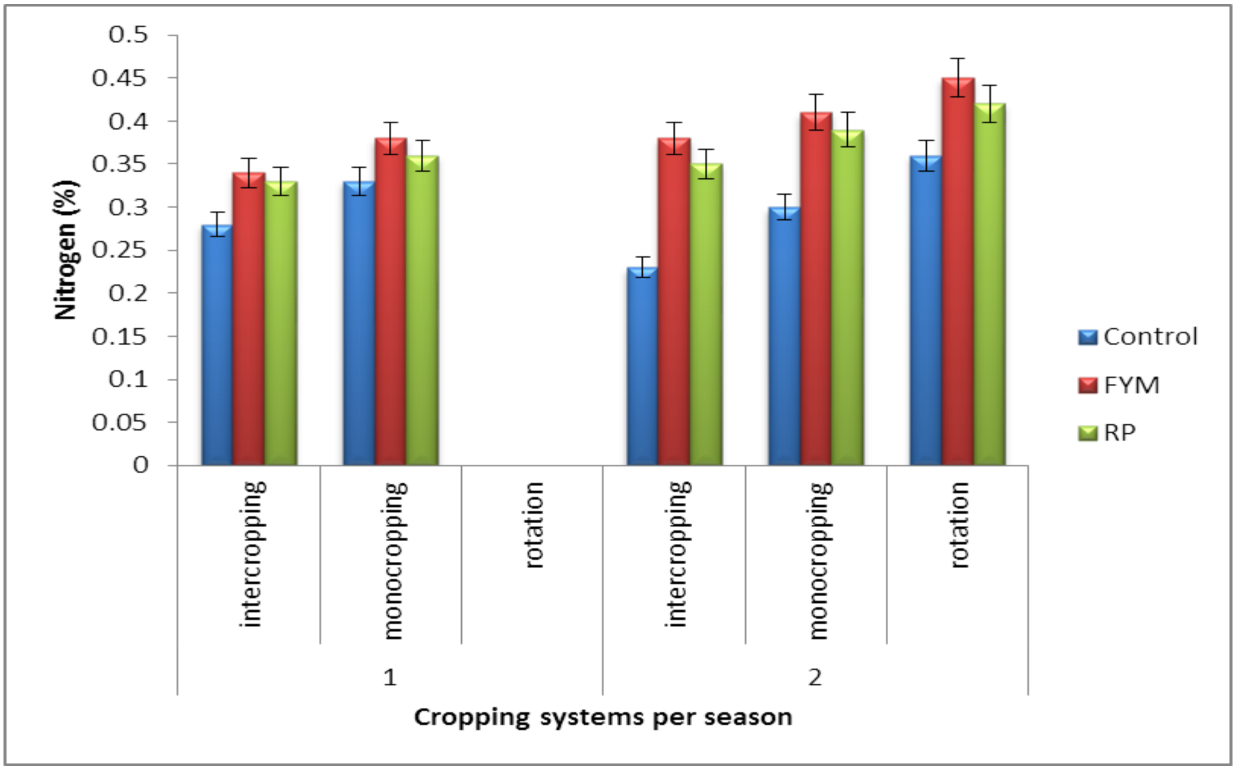

Figure 5.2:Effect of organic inputs and cropping systems on soil nitrogen at kabete season one and two

This may be due to N fixation through the legume that increased the N amount in the rhizosphere.

In season two, rotation system with application of FYM had the highest N (0.45%) followed by rotation system with application of Rock P (0.42%). This may be because FYM contains N and application into the soil may have resulted to an increaes in soil N as compared to application of RP which does not contain N. These findings are similar to those of K. Banger (2008), who found that continuous application of FYM to the soil lead to increase in total N in all the soil fractions. Brar et al. (1989) also reported that an increase in the levels of applied N such as FYM causes an increase in the total nitrogen (TN) content of the soil. These findings are also similar to those conducted by Anyango (2005) who found that kale-legume intercrop had the highest soil nitrogen content in both seasons in the absence of rotation. In a study conducted by Defra as well, legume intercrops and organic rotations were found to often provide a supplementary boost of N during the fertility depleting phase by the growing of a leguminous crop, such as field beans or peas.

5.5.3 Effect of organic inputs and cropping systems on soil phosphorous

In both seasons, there was significant effect and difference in both the cropping systems and organic inputs. In season one intercroping system with application of Rock P had the highest P (24.51mg/kg) followed by monocropping sytsem with application of Rock P (22.5 mg/kg), (Figure 5.3).

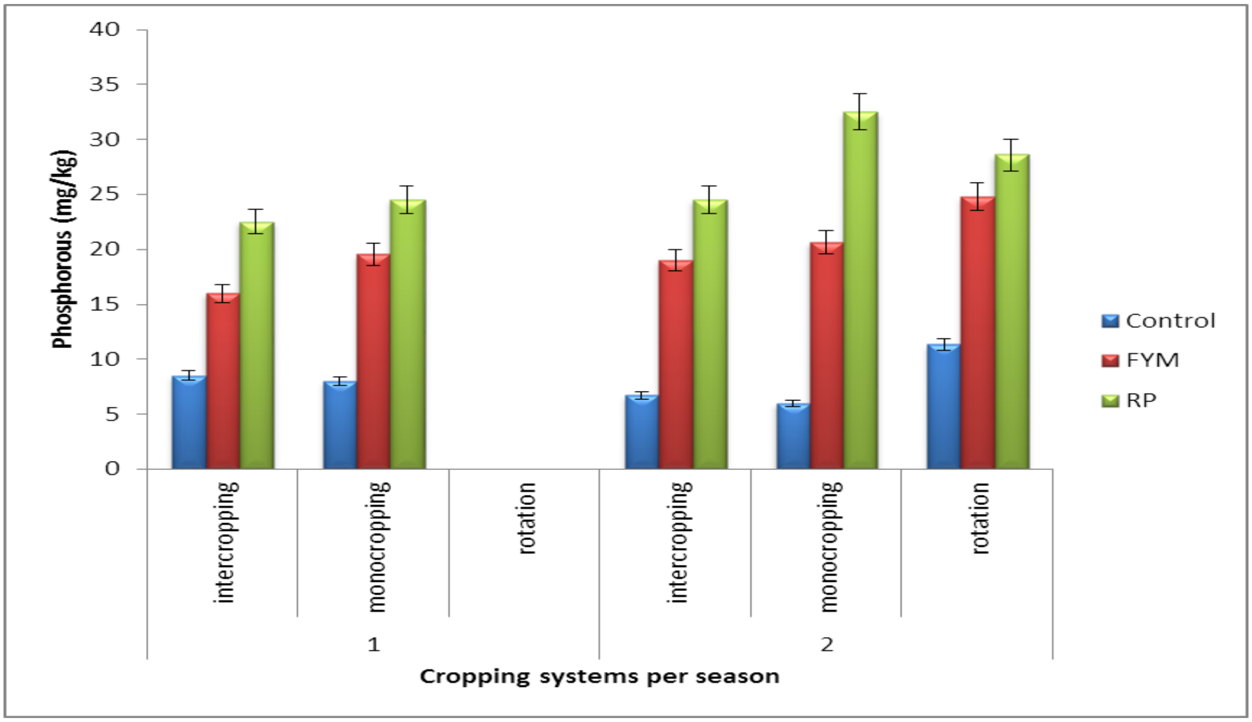

Figure 5.3;Effect of organic inputs and cropping systems on soil phosphorous at kabete season one and two

This may be attributed to addition of RP which increasdthe amounts of P in the soil, coupled with the effect of legumes (legumes acidify soils during N fixation and the protons lead to solubilisation of R (Marscher 1995)). In season two intercropping system with application of Rock P had the highest P (32.5mg/kg) followed by roattion system with application of Rock P (28.6mg/kg), (Figure 5.3). These findings relate to those of a study on the effect of legume incorporation on solubilisation of phosphate rock carried out by Adesanwo et al. (2012) which showed that decomposition of legume biomass from legume intercrops and legume based rotation enhanced rate of P release from Phosphate Rock.

5.5.4 Effect of organic inputs and cropping systems on soil potassium

In season one there was significant difference in the cropping systems but not in the organic inputs. Intercropping system with application of FYM had the highest K (1.46 mg/kg) followed by intercropping system with application of Rock P (1.39 mg/kg), (Figure 5.4).

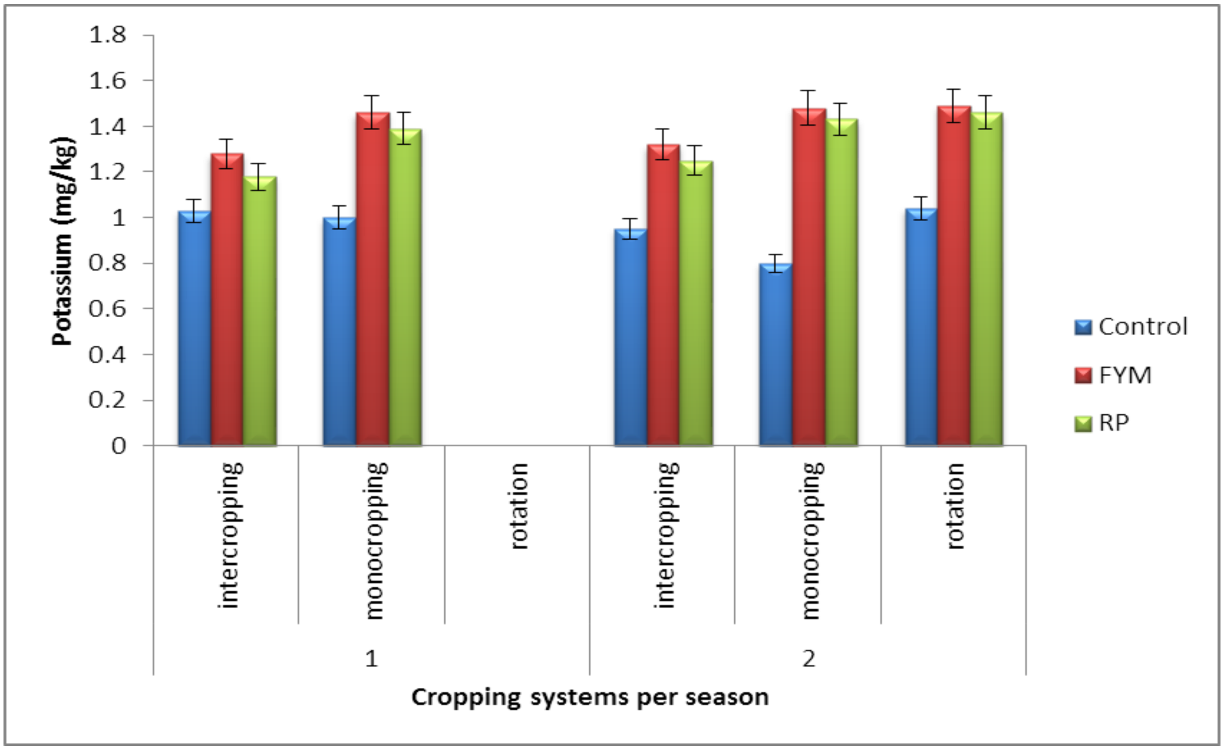

Figure 5.4; Effect of organic inputs and cropping systems on soil potassium at kabete season one and two

In season two rotation and intercropping systems had no significant differences. However, there was significant difference between mocropping-rotation and monocropping–intercropping.

Rotation system with application of FYM had the highest K (1.49 mg/kg) followed by intercropping system with application of FYM (1.48 mg/kg), (Figure 5.4). this may be because FYM had significant amount of K which may have lead to an increase in K in the soil while RP had no K levels at all. These findings are similar to those of a study on the Effect of farmyard manure on K-Mg exchange by S.R Poonia et al. (2007), who found that application of FYM caused a small but consistent increase in the K. In another study conducted by Abou.et al. (2012) on the effect of farmyard manure and potassium fertilization on some soil properties, application of FYM at any rate improved the soil properties and markedly increased available soluble ions of K+. In a study of forms of soil potassium as influenced by long-term application of FYM conducted by Dhanorkar *et al. (*1994) it was further observed that FYM alone increased total K by 40 percent.

5.6 Conclusion

OC, N, P and K are all important elements in determining the soil nutrient status and hence productivity of soils. Legume as an intercrop or as a rotational crop increase levels of N through; N fixation and also increase soil OC from the legume forages that are incorporated into the soil. Addition of RP coupled with the solubilisation effect of legumes on RP ensures availability of P in the soil and hence uptake by plants. K is made available through application of FYM. However this is not sufficient because K levels in FYM are relatively low.

5.7 Recommendations

- Farmers should be encouraged to produce their own farm yard manure and compost since this assures them that the manure has no synthetic chemicals in it for the purpose of fulfilling the organic based practices.

- More organic based sources of K should be made available and affordable e.g. bone meal.

CHAPTER SIX

6.1 EFFECTS OF ORGANIC INPUTS AND CROPPING SYSTEMS ON YIELD AND QUALITY OF KALE (Brassica oleracea)

6.2 Abstract

Kale being the most popular leafy vegetable is a major source of cash for many households in Kenya. However, its production has been hampered by poor soil fertility and weed interference. This study examines the impact of three cropping systems; sole kale, kale in rotation with chickpea and kale intercropped with chickpea in combination with organic inputs (farm yard manure and phosphate rock), on the performance of kale. An on station field experiment was conducted at upper Kabete field station of the University of Nairobi for two seasons. The experimental design was a Randomized Complete Block Design (RCBD) with a Split-plot, arrangement replicated three times. The main plots consisted of the cropping systems while the split plots consisted of the organic inputs. Quality and yield attributes such as disease and pest prevalence, leaf size and yield of kale were measured at the first harvesting stage of the kale. In the rotation system, disease incidence was nil with application of FYM and rock P. Pest prevalence was lowest (7%) with the application of FYM. The sizes of the leaves were largest in the FYM and Rock phosphate plots under crop rotation. Yield was highest in the rotation system with application of (1.629 tha^{-1}) and lowest in the intercropping system with no inputs applied (0.468 tha^{-1}). The best soil fertility management strategy for production of marketable quality kale and improved yield is the crop rotation system with application of FYM and rock P.

Key words: Cropping Systems, Kale, Organic Inputs, Quality Attributes, Yield

6.3 Introduction

Kale being a popular green vegetable is consumed by almost every household in Kenya and has been shown to be a major source of cash for many households (Mariga, 2001). As a vegetable in general, kale offers variety in family diets and helps to ensure household food security (Luchen and Mingochi, 1995), since it is affordable to most families. It is known as a source of many nutrients, vitamins, antioxidants, minerals and important proteins (Akula et al., 2007). Among fresh leafy greens, kale is the most important source of nutrients in the diet followed by spinach in total carotenoids and folate (Holden et al., 1999; USDA 2003) and second in total antioxidant capacity behind only garlic (Cao et al., 1996). Kale has no fat, is high in vitamin A and vitamin C, is a good source of calcium and iron and is considered one of the most nutritious vegetables (USDA 2005). It is also a good source of vitamin B6, manganese, copper, potassium and dietary fiber (Maina and Mwangi, 2008). Though kale is the most popular leafy vegetable in Kenya, its economic production is limited by several factors including poor soil fertility and weed interference. These factors not only hamper the amount of kale produced, but also the quality. Quality of produce encompasses sensory attributes, nutritive values, chemical constituents, mechanical properties, functional properties and defects (Shewfelt, 1999). Food quality in general is the totality of features and characteristics of a product that bear on its ability to satisfy stated or implied needs (FAO 2003). Shewfelt (1999) points out that quality is often defined from either a product orientation or a consumer orientation. According to the East African standard for specification and grading (2010), grade 1 which is the highest quality of kale should have produce that is of one type which are well trimmed, not stunted, free from decay and from damage caused by yellow or discoloured leaves, seed stems, wilting, bud burn, freezing, dirt, disease, insects, or mechanical or other means of damage. Leaf size is also a key component in quality determination (Shewfelt, 1999).

Due to the low soil fertility particularly nitrogen and phosphorus deficiency, quality and quantity of kale produced is compromised (Anyango, 2005). This ultimately leads to lower economic returns and eventually heightened poverty levels of small scale farmers who are dependant on sale of kale. At the same time, the demand for aesthetic attributes (e.g. spotlessness and good looking produce) by urban consumers has encouraged excessive use of pesticides and chemical fertilizers (Karanja et al., 2008). This is extremely costly and in turn causes food safety and environmental concerns due to the pesticide residues. It is for this reason that organic inputs and cropping system regimes are employed to increase production and quality of kale. Among the most promising organically based soil nutrient management practices include use of animal manure, incorporation of crop residues and improved legume fallows (Place et al., 2003). Short term improved legume fallow technology which is characterized by deliberate planting of fast growing nitrogen fixing legume species in rotation with kale (Niang et al., 2002) is among the practices that ensure sustainable soil resource management. Use of cropping systems such as intercropping with legumes and crop rotation are an example of low external-input systems as is the use of organic inputs so as to avoid the use of synthetic fertilizers. In addition, organic nutrient management (ONM), based on biodegradable material is the safest and most effective alternative for the high cost and excessive/sub optimal use of fertilizer in the sub Saharan Africa. This will ensure an increase in both quality and yield of kale.

6.4 Materials and methods

6.4.1 Experimental design and treatments

The field experiment trials were conducted at the University of Nairobi field station, Kabete Campus during the long rain seasons (March - June) and short rains (October –December) of 2012. The experimental design was a Randomized Complete Block Design with a split plot arrangement. The main plots were the cropping systems (monocropping, intercropping and crop rotation) with a legume component (chickpea) while the sub- plots were incorporated with organic inputs (farm yard manure, rock phosphate and a control). The rock phosphate was applied at a rate of 480kgha^{-1} with the FYM being applied at the rate of 10 tha^{-1} applied during planting. The experiment had nine treatments replicated three times.

6.4.2 Agronomic practices

Kale and chickpea were planted in March and October of the long and short rains of the year 2012 respectively.

Direct sowing was done on the farms with backup seed beds being prepared at the sites. The organic inputs were incorporated into the soils during planting. Seeds were planted a quarter of an inch deep and thinned when plants had three to four true leaves. Plants removed at thinning were then transplanted to adjacent areas (gapping).

For pest and disease control, Eucalyptus tree ash (500kgha$^{-1)}$ was sprayed on the crops to control cut worms and pyrethrum extracts (200litresha^{-1}) also sprayed to control aphids and diseases. The fields were surrounded by Mexican marigold plants to act as a pest-repelling barrier (George McRobie, 1990).

Weeding was done at interval of three weeks from the time of planting to harvesting. Selective hand weeding was done.

Kale was harvested at 8and 12 weeks. Older leaves were generally stripped off the plants to allow the young leaves to continue to grow.

6.4.3 Plant sampling and analysis

The plants were sampled both for quality attributes and yield. Sampling was done on the three middle rows of each plot leaving two rows on the sides acting as guard rows. From the three middle rows, ten plants were randomly selected and tagged for plant sampling.

Plant Sampling: from each plot containing 7 rows, plant sampling of leaf quality attributes and dry yield matter was done only on the three middle rows leaving two rows on the sides acting as guard rows. The plants were sampled for leaf size, plant height, disease incidence, pest prevalence and dry weight (table 5.1).

Table 6.1 Quality attribute determination of kale

Quality attribute	**How measured**
Leaf size	Leaf size was measured by the diameter of the largest circle that can be drawn inside the leaf surface. This is referred to as functional leaf size (Parkhurst and Loucks 1972).
Leaf height	This was measured from the soil surface to the tallest tip/branch of the kale crop.
Disease incidence	Appendix 2
Pest prevalence	Appendix 3
Dry weight	The sampled kale yield was oven dried at 60^0C to a constant weight and weighed (Parkinson and Allen, 1975).

6.4.4 Statistical Analysis

The measured kale quality and leaf yield were subjected to Analysis of variance (ANOVA) using Genstat 1.2 (Lawes Agricultural Trust, Rothamstead, UK) package in accordance with the split plot design. The significance of differences at different harvests between main-plot effects (cropping systems), sub-plot effects (organic inputs) and their interactions were determined using standard error of the difference in means (SED) values at 5% ($P<0.05$).

6.5 Results and discussion

6.5.1 Leaf size

In season one; there was significant difference in intercropping system with application of FYM and intercropping with application of RP (Figure 6.1).

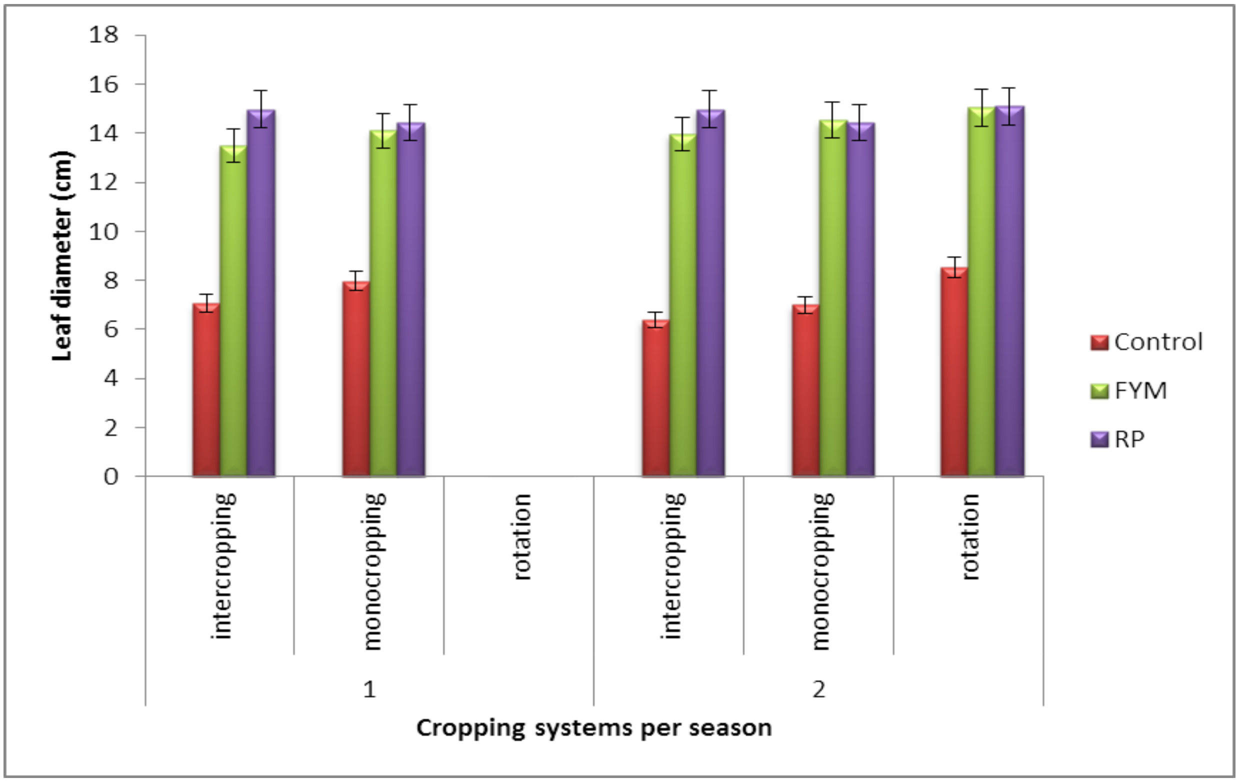

Figure 6.1:Effect of organic inputs and cropping systems on leaf size of kale at kabete season one and two.

Kale leaves were bigger in the intercropping system with application of rock P (14.9 cm) followed by the monocropping system with application of rock P (14.4 cm), (Figure 6.1). This may be because the legume intercrop contributed to the larger leaves because on N fixation thus making available more N for the kale crop which assists in growth and development. Legumes also acidify soils during N fixation and the protons may lead to solubilisation of RP hence making the RP readily available to the crop. These results are similar to those of Davis and

Westfall (2009) who stated that as a nutrient, P is the second in importance only to nitrogen. Thus where the kale crop gets both nutrients in a readily available form and in sufficient quantities, vital processes such as photosynthesis, root development and maturation take place and lead to healthy and large leaves (Uchida, 2000).

In season two the rotation system with application of Rock P had the largest leaf size (11.1 cm) followed by rotation with application of FYM (15.0 cm), (Figure 6.1). . Lal et al. (1999); Hao et al. (2002) and Desjardins et al. (2001) stated that incorporation of forage legumes in the crop rotation cycles were strategies for N and SOC increase and restoration. This thus led to the increased vegetative growth and hence larger leaves.

Also in the second season, intercropping with application of FYM had larger leaves as compared to the same treatment in the first season. The increase may also be due to the effect of the FYM being more readily available over time. This is because FYM is a slow releasing fertilizer and thus as time goes by, the nutrients from the manure become available to the crops (P. Miller, 1994).

However in season two the leaf size for the controls under intercropping system were smallest (6.2 cm). This is because no organic inputs were added thus causing nutrient depletion. hence competition between the intercrops These results are similar to those of Anyango 2005 who found that intercropping reduced the kale yield in leaf size and numbers, fresh leaf weight and unit leaf weight as compared to monocropping and rotation.

6.5.2 Height of kale crop at harvest (12 weeks)

In season one intercropping system with application of Rock P had the tallest kale plants (23.43 cm) followed by monocropping with application of RP (18.27 cm), (Figure 6.2).

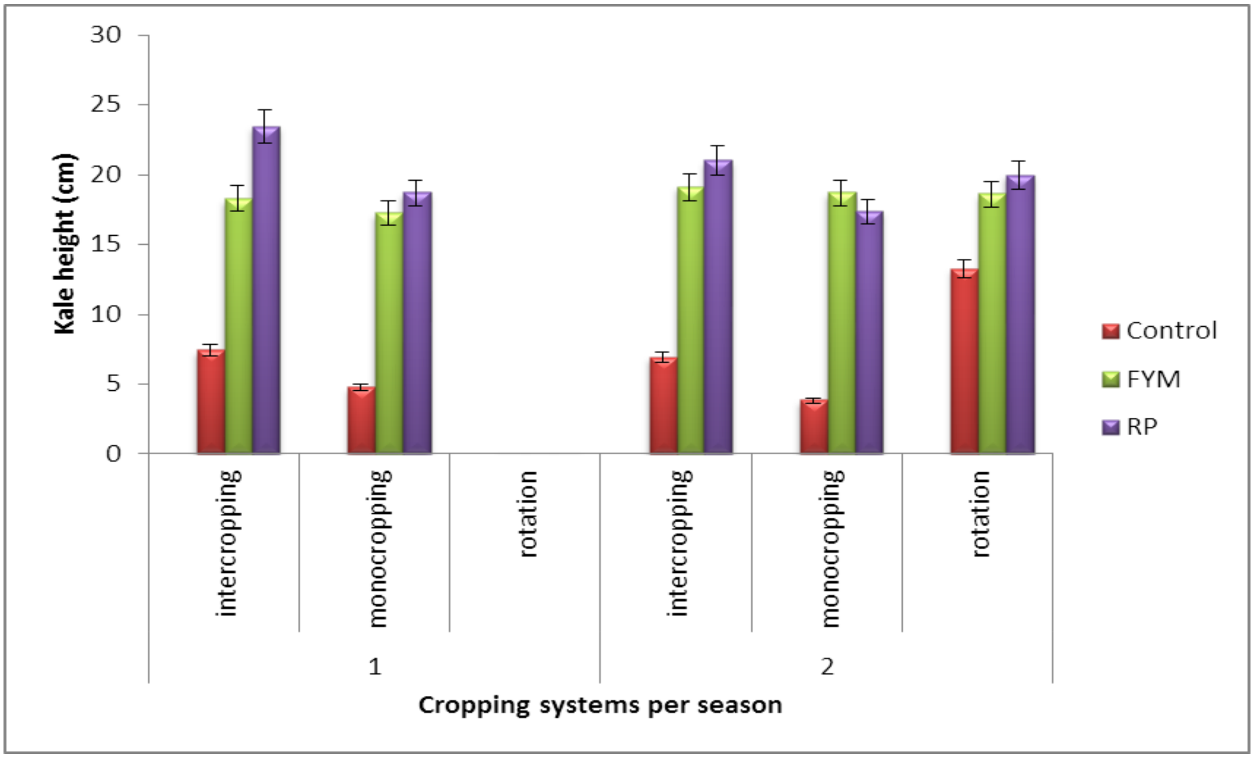

Figure 6.2:Effect of organic inputs and cropping systems on height of kale crop at kabete season one and two

In season two, there was no significant difference between intercropping system and the rotation system. However significant difference was observed between monocropping-intercropping and monocropping-rotation. Intercropping with application of Rock P had the tallest plants (21 cm) followed by rotation system with application of Rock P (19.97 cm), (Figure 6.2). This may be due to the fact that in the intercrops might have been in competition for growth parameters and more specifically light and thus the upward thrust in growth. This is because the legume chick pea was of a bushy type and would have otherwise crowded the kale crops. These results are also similar to those of Anyango (2005) who found that intercropping increased the kale plant height as compared to monocropping. However the results are contrary to those of S. M. Shakya (1999) who studied the Effect of different doses of nitrogen and phosphorus on growth and development. He found that though N and P had tremendous effect on the germination, they did not show significant effect on the growth (height) of the plant.

Monocropping system without any inputs had the shortest plants (3.8 cm), (Figure 6.2). This is because the system did not add any nutrients into the soil rather nutrients were removed through plant uptake resulting in nutrient mining. These results were similar to those conducted by Lal (2008) who found that continuous mono-cropping minus application of fertilizers result in mining of plant nutrients and depletion soil organic matter and thus resulting in stunted growth.

6.5.3 Disease incidence in kale crops

In season one; there was no significant difference between intercropping and monocropping systems with application of both FYM and Rock P, though they had the lowest disease incidence (3.3%), (Figure 6.3). Significant difference was observed with the controls where monocropping control had higher levels (19%) as compared to intercropping control (14%).

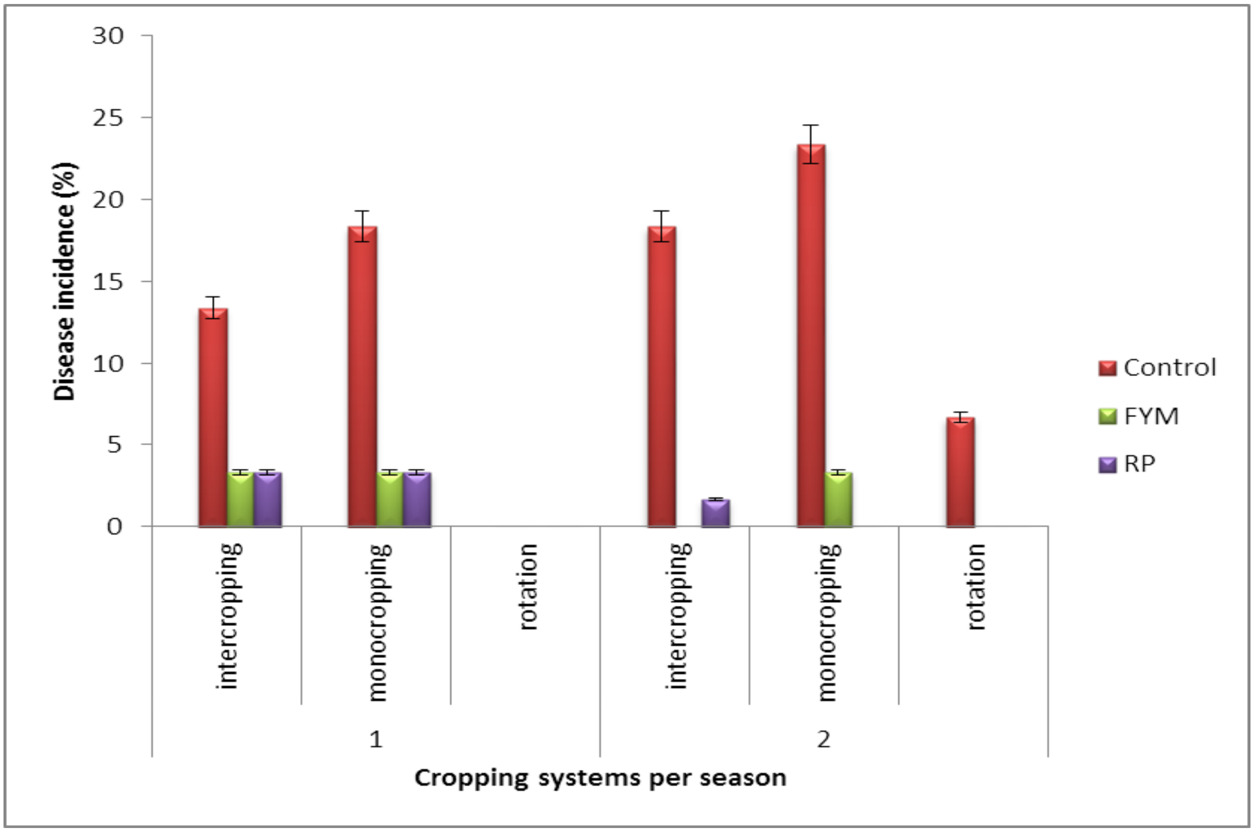

Figure 6.3:Effect of organic inputs and cropping systems on disease incidence of kale at kabete season one and two.

Significant differences among the cropping systems and organic inpuys was observed in saeson two. In season two intercropping with application of FYM and rotation with application of both FYM and Rock P had the least disease incidence (0%), (Figure 6.3). Monocropping system without any inputs had the highest disease incidence (23.3%). The higher levels in the controls may be because the kale crops were weak and not productive due to lack of any added organic inputs and thus susceptibility to disease attack was higher in these kale crops as compared to the kale crops in the FYM and RP plots which had more vigor. According to Marschner H. (1999), plants with optimal nutritional status have the highest resistance to diseases and that susceptibility increases as nutritional status deviates from this optimum. Engelhard (1993) also stated that Phosphorous application seems to favor plant protection against diseases, either by correcting a deficiency in soil Phosphorous, and thereby inducing better growth of the plant, or by speeding up the maturation process, disfavoring some pathogens like Downey mildew that affects the young tissues.

6.5.4 Pest presence and signs in kale crops

In both seasons, significant difference was observed both among the cropping systems and among the organic inputs. Pest presence was highest in monocropping system with application of FYM followed by monocropping system with application of Rock P (Figure 6.4).

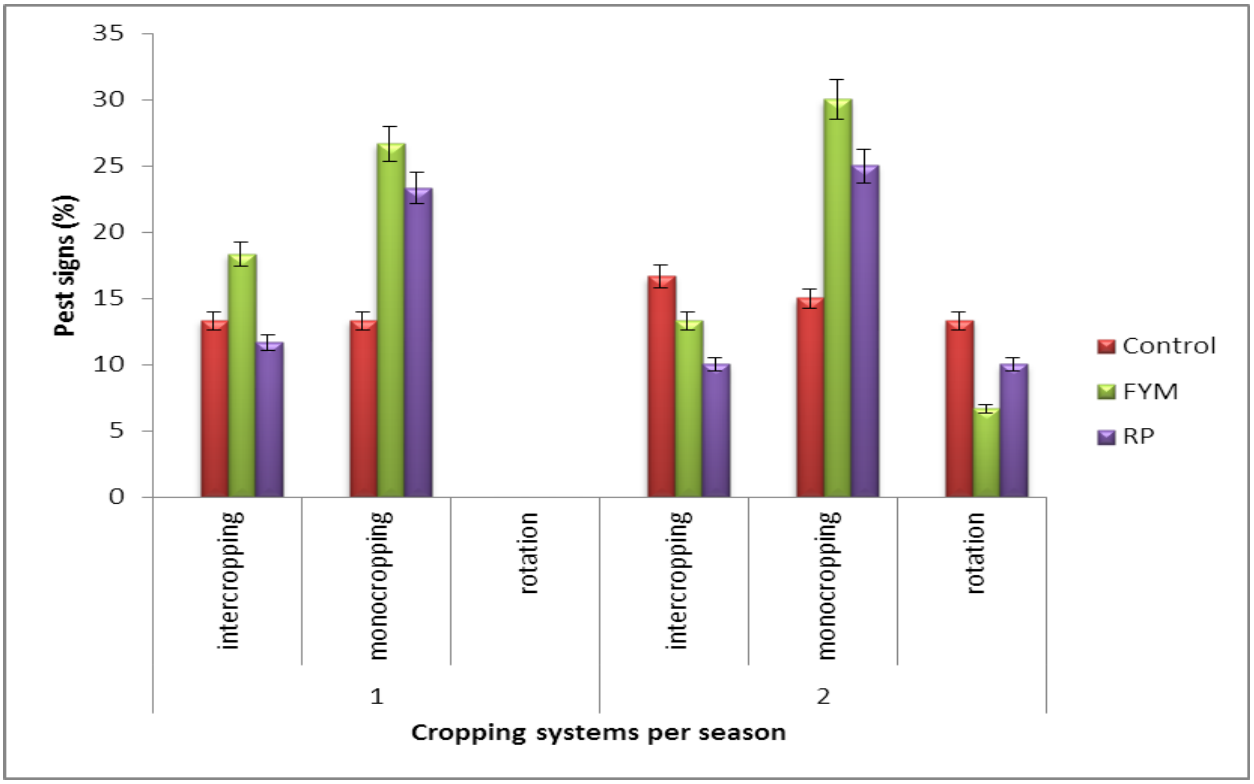

Figure 6.4:Effect of organic inputs and cropping systems on pest presence and signs of kale at kabete season one and two.

Since the N present in FYM increases the N content of the soil and hence increased N in leaf tissue, van Emden (1966) observed aphid and mite response to N fertilization and found that increases in fecundity and developmental rates of the pests were highly correlated to increased levels of soluble N in leaf tissue. In season one the intercropping system with application of Rock P had the lowest pest presence (11.6%), (Figure 6.4).

This may be because the legumes in the intercrops acted as barriers, since the legumes and kale are not affected by similar pests. This decreased the spread of the pests in the intercropping plots opposed to the mono crops where there was no barrier thus the wide spread of pest in these plots (Hama 1992).

In season two, rotation system with application of FYM had the lowest pest presence (6.5%), (Figure 6.4). this may be due to the breakign of the pest cyle when kale was planted in season two after chickpea in the first season. Since the two crops are of different families, the pests that attacked chickpea could not attack kale. Hama (1992) also found that crop rotation was necessary to stop the continuous generations of diamondback moth which accumulated from continuous planting of the same crop.

6.5.5 Yield of kale crop at 12 weeks

In season one the yield was highest in the intercropping system with application of RP (171 bags/ha) followed by intercropping system with application of FYM (130 bags/ha), (Figure 6.5).

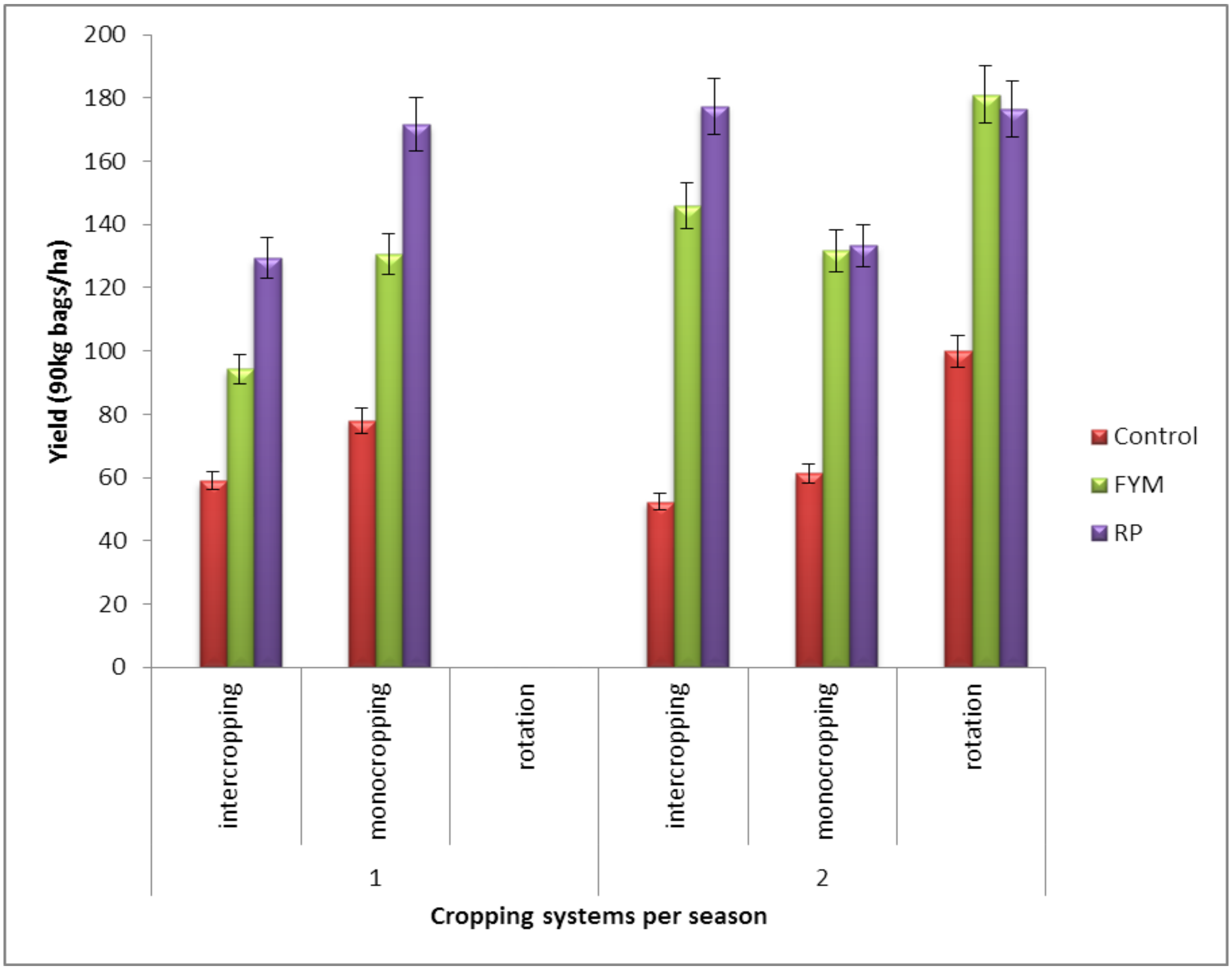

Figure 6.5:Effect of organic inputs and cropping systems on yield of kale at kabete season one and two.

This may be because the inter crop effect through competition increased the number of leaves and leaf density. This was due to the increase in N through N fixation. Also inter cropping may also have had an effect on P solubilisation in the RP plots thus making the nutrients readily available to the crops. This is may be the reason RP intercrops had the highest yields. These results are similar to those of Horst *et al.* (2001); Kamh *et al.* (1999) and Vanlauwe *et al. (*2000) who found that Legumes increase the dissolution and utilization of phosphate rock (PR) P compared with non-legumes mainly due to rhizosphere processes.

In season two rotation system with appication of FYM had the highest yield (181 bags/ha) followed by intercropping system with appliaction of Rock P (177 bags/ha), (Figure 6.5). This is due to the chickpea residue incorporated into the soil from the previous season and also the effects of N fixation from the previous season. These nutrients resulted in vigorous growth of the kale in season two. The use of green manures from legumes in cropping systems offers considerable benefits because of their ability to fix atmospheric nitrogen (N2) that is available after senescence of legume residue to an associated sequentially cropped non-legume (Tian et al., 2000; Nyambati et al., 2006).

6.6 Conclusion

The yield and quality attributes of kale clearly showed that rotation followed by intercropping with application of FYM and Rock P had positive effect. This is evident by results achieved from the controls which showed low yields and quality of kale due to lack of input application. Continuous mono-cropping minus application of fertilizers result in mining of plant nutrients, increases pest and disease severity and reduces yield of the produce. This study hence showed that incorporation of a legume in either intercropping or rotation with application of FYM and RP result in increase in yield.

6.7 Recommendations

- Farmers should be educated on the best combination of cropping systems and organic input application rates that would suit both their crops and environmental locations so as to maximize on the quality and quantity of produce.

- Pest and disease control strategies should be made available for each specific crop so as to reduce losses that occur when crops are affected.

CHAPTER SEVEN

7.1 INFLUENCE OF ORGANIC INPUTS AND KALE BASED CROPPING SYSTEMS ON SOIL N, P and K BALANCES

7.2 Abstract

Nutrient balances for the last two decades in Sub-Saharan Africa reveal, almost unequivocally, alarming nutrient deficiencies. This is due to the limited use of adequate nutrient inputs and poor farming practices especially in kale production since kale is a major crop consumed in Kenya. The study was thus conducted to determine a combination of organic based farming practices that would lead to improved soil fertility and thus positive nutrient balances. The study was conducted for 2 seasons (March- May 2012 and October - December 2012) at the Kabete on site station. The treatments consisted of three cropping systems and two organic inputs with a control. The cropping systems were monocropping, intercropping (kale and chickpea) and rotation (chickpea/kale). Organic inputs used were rock P and Farmyard manure (FYM).Resource flow monitoring for the quantification of nutrient balances was monitored for two seasons at plot level using the farm-NUTMON approach. The Farm Section Units (FSUs) were the replicates/blocks, the primary production units (PPUs) were the plots. For the quantification of nutrient flows for calculation of balances, methods utilized included (i) sampling and analysis of product (grain, yield and inputs) flows for N, P and K, (ii) use of transfer functions and (iii) other approaches using sub-models and assumptions. Results were analyzed using NUTMON software model. Positive full N balances were realized in the crop rotation systems with application of FYM whereas the partial N balances were all negative across cropping systems and organic inputs except for the monocropping system with application of FYM. Positive full and partial P balances were realized in all the cropping systems with the application of Rock P. Negative full P balances were realized in all cropping systems with application of FYM and control. Negative full and partial K balances were realized across cropping systems and organic inputs. Kales grown in rotation with chick pea with application of FYM are a sustainable strategy for enhanced kale production.

Key words: Cropping Systems, Full balances, Kale, Nutrient Monitoring (NUTMON), Organic Inputs, Partial balances.

7.3 Introduction

African poverty is mainly a rural phenomenon attributed to low soil productivity (FAOSTAT, 2002). The low soil productivity is due to the limited use of nutrient inputs among smallholder farmers thus exerting pressure on soil nutrients, leading to nutrient mining which further results in nutrient deficiency (Stoorvogel and Smaling, 1990; De Jager *et al*., 1998). Mining of nutrients from soil is a major problem causing soil degradation and threatening long-term food production in developing countries. A decision support tool known as NUTrient MONitoring-Toolbox (NUTMON-Toolbox) which is easily useable by farmers has been developed to check on the nutrient in and outflows. This will help farmers in keeping tabs on how much goes in and out and hence solve agricultural problems such as nutrient mining hence increase crop yields and at the same time maintain soil fertility (Stoorvogel and Smaling _1990). A nutrient budget is an account of inputs and outputs of nutrients in an agricultural system. NUTrient MONitoring (NUTMON) is a multiscale approach that assess the stocks and flows of N, P and K in a well-defined geographical unit based on the inputs *viz.*, mineral fertilizers, manures, atmospheric deposition and sedimentation and outputs of harvested crop produces, residues, leaching, denitrification and erosion losses (Smaling 1998).

Based on the nutrient monitoring concept, Stoorvogel and Smaling (1990) concluded that agriculture in most of SSA is unsustainable. The estimated nutrient losses due to erosion, leaching and crop harvests are sometimes staggering, at over 60–100 kg of N, P, and K per hectare each year in Western and Eastern Africa (Stoorvogel and Smaling, (1990); De Jager *et al*., (1998)). In many areas of Kenya, low soil fertility tends to decline further, as farmers remove many nutrient outputs in crops, crop residues and through losses by processes such as leaching, and soil erosion. Nutrient mining has thus led to negative nutrient balances (Van den

Bosch *et al*., 1998; Lesschen *et al*., 2003). Recent studies have indicated that, use of well managed nutrient replenishment regimes incorporating use of manure and modest amounts of fertilizer inputs are important to increased and sustained crop yields (Kimani *et al*., 1998) such as kale. Organic based soil fertility management strategies such as use of FYM, mineral bearing rocks, incorporation of crop residues and improved legume fallow (Place et al. 2003), have been shown to improve soil health and fertility by increasing soill organic matter and microbial biomass (Bell 2005, Fisher 2005, Kirby et al., 2006).

The broad objective of this study was to calculate the nutrient balances in thevarious cropping systems with application of FYM, RP and control, and hence find the best organic based practices that lead to positive soil N, P and K balances. Positive nutrient balances mean that the soil fertility is improved and hence increased kale yields.

7.4 Study approach

7.4.1 Study site

The experiment was conducted in upper Kabete field station, Kiambu County. Kabete is situated about 15 km to the West of Nairobi city and lies at Latitude 1^{o} 15′S and Longitude 36^{o} 44′E, and at altitude 1940 m above sea level (Sombroek et al., 1982). The study was conducted for 2 seasons (March- May 2012 to October - December 2012). The two seasons in a year are the short rains occurring from October to December and long rains from March to May.

7.4.2 Treatments and experimental design

The treatments consisted of three cropping systems and two organic inputs with a control. The cropping systems were monocropping, intercropping (kale and chickpea) and rotation (chickpea/kale). Organic inputs used were rock P, a control and Farmyard manure (FYM). This resulted in nine treatments combinations. The treatments were replicated three times.

7.4.3 Soil sampling and analysis

Soil samples for analysis were taken from the plots at 0-30 cm depth. The chemical parameters analysed included Total N, Phosphorous and Potassium. Physical properties analysed included bulk density and texture. Soil analysis was done according to the methods described by Okalebo *et al.*, (2002).

7.4.4 Plant sampling and analysis

Sampling and analysis of crop products for N, P and K was used to quantify flows such as IN 2, OUT 1 and OUT 2 (table 1.1). Kale and chickpea were harvested 12 weeks after planting. Sampling of the kale leaves and chickpea pods was done from the middle rows of each subplot. The harvested produce were then heaped and left for drying. For chickpea, the dried plants were threshed to separate seeds from pods. The chickpea and kale yield was oven dried at 600C to a constant weight. Nutrient extraction in seeds and yield samples was done by wet oxidation procedure (Parkinson and Allen, 1975) based on a Kjeldahl digestion using H2SO4 and H2O2. The N and P were determined colorimetric determination, while K was measured by flame photometry. The yields were then weighed. Product flows were quantified by extrapolating the recorded yield to kgha^{-1}.Amounts of Nitrogen, Potassium and phosphorous in the product flows were calculated using the N, P and K contents of the organic inputs, yield and seed of kale and chickpea respectively.

Table7.1: Product flows of N, P and K

INFLOWS	OUTFLOWS
1. Mineral fertiliser	1. Harvested produce
2. Manure	2. Removal of crop residue
3. Atmospheric deposition	3. Leaching
4. Biological nitrogen fixation	4. Gaseous losses

7.4.5 Calculation of nutrient balances

Resource flow monitoring for the quantification of nutrient balances, was monitored for two seasons at plot level (March to December 2012) using the farm-NUTMON approach (De Jager et al. 2001). The Farm Section Units (FSUs) were the replicates/blocks, the primary production units (PPUs) were the plots. For the quantification of nutrient flows for calculation of balances, methods utilized included (i) sampling and analysis of product flows for N, P and K, (ii) use of transfer functions and (iii) other approaches using sub-models and assumptions (van den Bosch *et al.*, 1998).

Use of transfer functions and assumptions**:** Transfer functions are used in estimating those flows which cannot be obtained by simple measurements namely IN 3, IN 4, OUT 3, OUT 4 and OUT 5 (table 1.1). Transfer functions explain variables which are difficult to obtain as a function of parameters which are easy to obtain (Stoovogel and Smalling, 1990; Smaling et al., 1993).

NUTMON-toolbox then calculated the balances by subtracting the sum of the nutrient outputs from the sum of the nutrient inputs and presents then in Kg ha^{-1}

Partial nutrient balance (N, P, K) = [input 2 –output1]

Full nutrient balances (N, P, K) = {[inputs 2, 3, 4] – [outputs 1, 2, 3, 4]}

7.5 Results and discussion

7.5.1 Nitrogen balances

The partial N balances were positive in the monocropping system with application of FYM but negative across other cropping systems and organic inputs. This is because the FYM contained N and thus the N input into the soil was higher while the N output as a result of the harvested produce was lower in the monocropping system as compared to the intercropping and rotation systems which had the legume component. This resulted in the positive partial N balances. The full N balances were positive in the intercrop and crop rotation systems with application of FYM and Rock P, and FYM respectively (Figure 7.1).

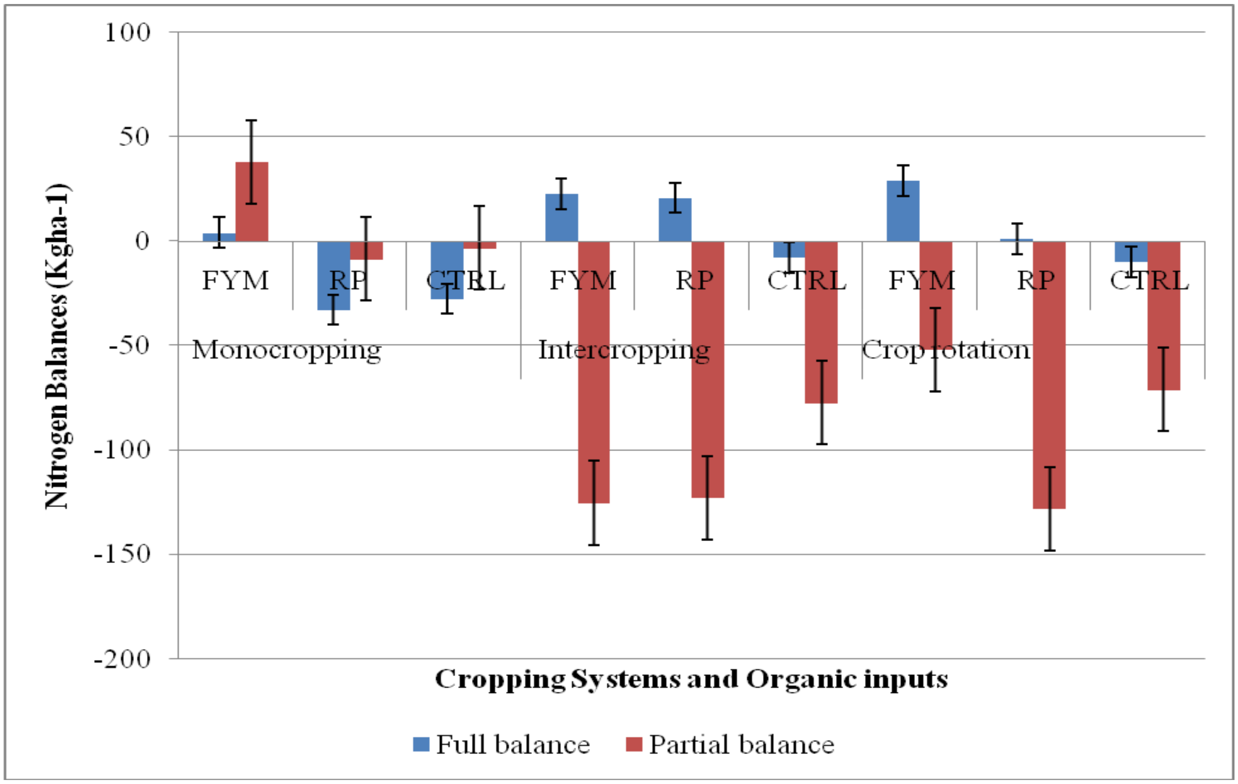

Figure 7.1: Effect of cropping systems and organic inputs on full and partial Nitrogen balances

This is due to the addition of N through BNF from the legumes in the cropping systems and also because leaching in these systems was very minimal. There were pronounced partial negative N balances in the intercropping and crop rotation systems with application of FYM and Rock P, and Rock P, respectively. This is because for the partial N balances, the output of N as a result of harvested produce (kale and legume) was very high because the two crops take up a lot of N for germination and growth as compared to the monocropping system where only the kale was harvested.

These findings are similar to those of (Tian et al., 2000 and Nyambati et al., 2006) who indicated that the use of legume as an intercrop and green manures from legumes in cropping systems offers considerable benefits because of their ability to fix atmospheric nitrogen (N_2) that is available after senescence of legume residue to an associated sequentially cropped non-legume. According to Koepf (1973); Kristensen et al (1995) and Drinkwater et al (1998) organic farming reduces nitrate leaching which is a major environmental concern. literature review also showed that the average leaching of nitrate over a crop rotation was somewhat lower per unit area from organic systems than conventional systems (Kirchmann and Bergström 2001).

7.5.2 Phosphorous balances

The partial and full P balances were positive in all cropping system with the application of Rock P (Figure 7.2).

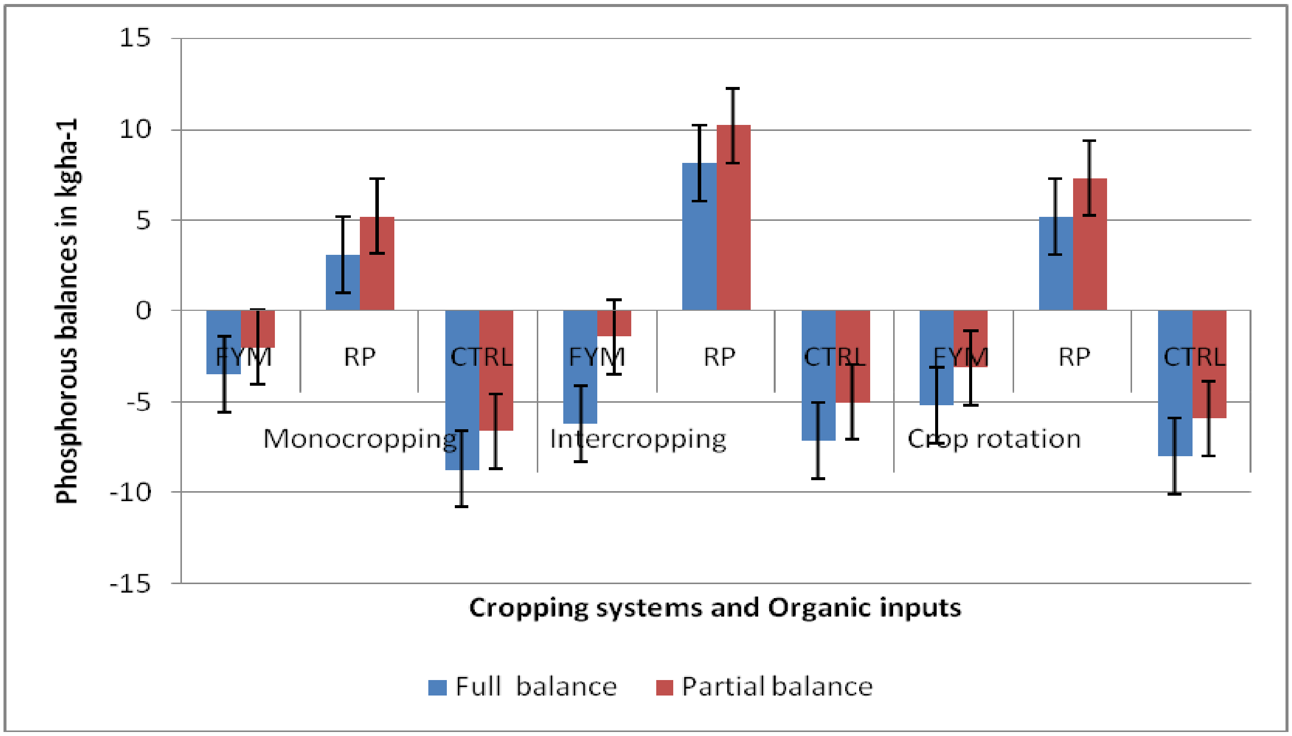

Figure 7.2: Effect of cropping systems and organic inputs on full and partial Phosphorous balances

This is because the Rock P had a higher P content as compared to FYM and thus the input into the soil was higher than the output through harvested produce and erosion losses. For the FYM and controls, more P was removed through harvested produce than was applied to the soil. These findings are similar to those of (Kaffka and Koepf (1989); Spiess et al (1993); Fagerberg et al (1996); Ivarson and Gunnarsson (2001)) who stated that Phosphorus balances of organic systems indicate that more of these nutrients are removed through harvested products than applied to soil. Thus an addition of P in the soil is required to balance the removal through harvested produce. Rock phosphate is also used to maintain a positive P balance on organic farms {Nguyen et al (1995); Derrick and Dumaresq (1999); Ryan et al (2000) and Lockeretz et al (1980)}.

The P balances were however higher in the legume incorporated plots such as the intercrops and rotations. This is because legumes have been shown to increase the dissolution and utilization of phosphate rock (PR) P compared with non-legumes mainly due to rhizosphere processes (solubilisation of RP by roots of legumes) {Horst *et al.* (2001); Kamh *et al.* (1999); Vanlauwe *et al.* (2000)}.

7.5.3 Potassium balances

The partial and full K balances were all negative for the cropping systems with application of FYM, Rock P and controls (Figure 7.3).

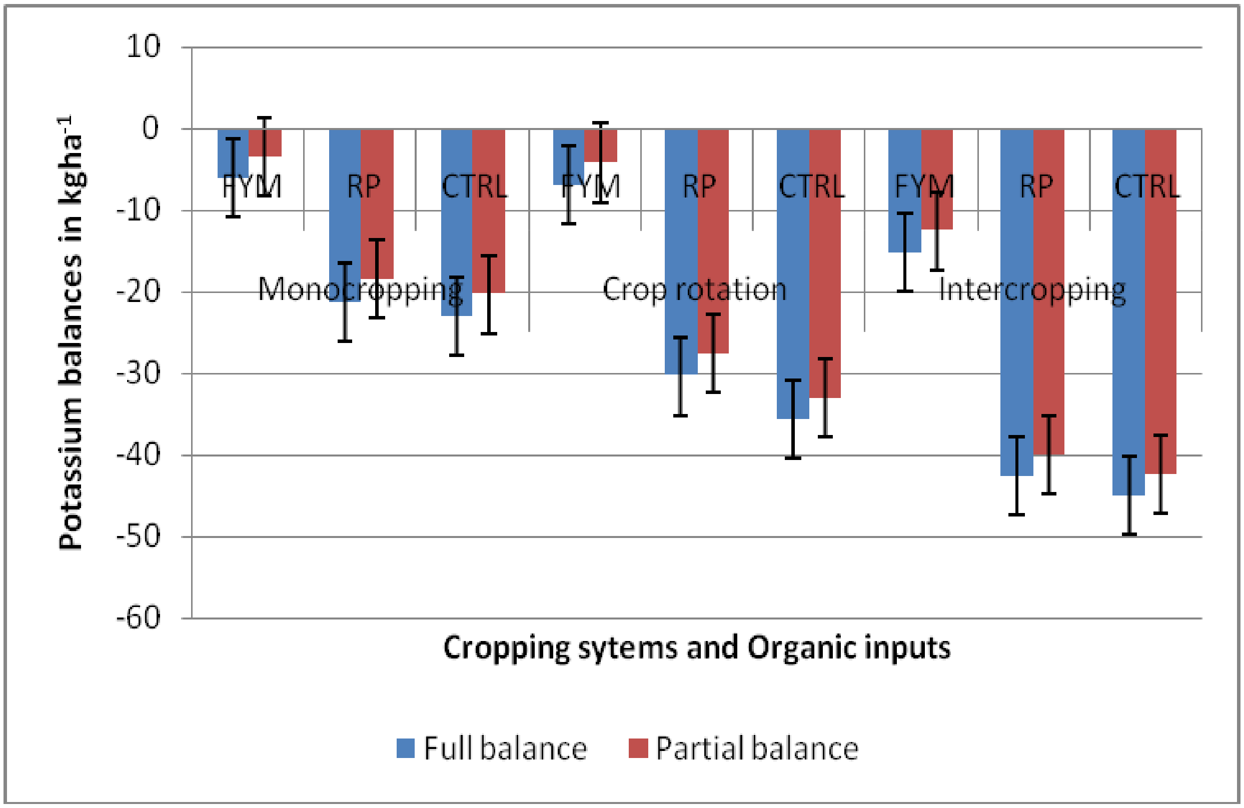

Figure 7.3; Effect of cropping systems and organic inputs on full and partial Potassium balances

This may be asa result of not adding any sufficient sourece of K such as bone meal. At the same time the plants took up the available K in the soils thus depleting the soils. These findings are similar to those of {Kaffka and Koepf (1989); Spiess et al (1993); Fagerberg et al (1996); Ivarson and Gunnarsson (2001)} who stated that Potassium balances of organic systems indicate that more of these nutrients are removed through harvested products than applied to soil.

However, the monocropping system had higher K balances as compared to intercropping and crop rotation. This may be because the legume in the crop rotations and in the intercropping systems took up more K in the harvested produce since legumes require more K for growth and development as compared to the kale monocrop. Also among the organic inputs, FYM had higher K balances as compared to the Rock P and controls. This may be because the FYM had significant K component and hence its application provided a higher K into the soil as compared to application of Rock P and the controls which had no K. The partial K balances in the three cropping systems with application of the organic inputs were slightly higher than the full K balances. The difference between the partial and full K balances was due to leaching. Since K lost through leaching was slight/minimal. This implies that most of the K was lost through harvested produce. These findings are at par with those of Smaling et al. (1993) who found that for the total balance for K, leaching only constitutes a minor loss. Therefore, leaching of K will be passed over lightly.

7.6 Conclusion and recommendations

Soil fertility depletion relates to low and untimely or inefficient application of manure and fertilizer, farm management practices that lead to high losses through leaching and erosion, and to the lack of integration of livestock. Application of organic inputs reduces such losses as leaching of nutrients and erosion losses. Incorporation of legumes as intercrops or as rotational crops assists in BNF and thus improving soil nutrient status. A combination of FYM and Rock P (in soils that are slightly acidic) with incorporation of legumes as intercrops or as green manure will help in improving and sustaining the full and partial soil N and P nutrient balances. This will in turn increase yield and quality of the produce and hence economic sustainability.

Additionally, to improve on the full and partial K balances, addition of organic based inputs that supply the soil with sufficient amounts of K such as bone meal should be incorporated.

Kale grown in rotation with legumes e.g. chickpea with the application of FYM and RP is the best sustainable strategy for soil productivity and hence increased yields.

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APPENDIX

Appendix 1: QUESTIONNAIRE

Part I: Socio demographics use in annex

No	Questions	Coding categories	Skip to
1.	Gender	Female: …………………………..1 Male: ……………………………..2	
2.	What is your level of education?	Less than primary: …………..1 Primary: …………………………..2 Secondary: ……………………..3 College: …………………………..4 University: ……………………..5	
3.	For how long have you been a farmer?	.__________________.	
4.	Do you have any other work besides crop cultivation and livestock keeping?	Yes: ………………………………..1 No: ………………………………...2	 10
5.	Do you do the work all the year round or on a seasonal basis?	All year round: ………………..1 Seasonal: ………………………..2	
6.	What is your major source of income?	…………………………………….…	
7.	What are your other sources of income?	Crops: …………………………….1 Livestock and livestock products: ………………………..2 Home industries: ……………..3 Salary/ wages: …………………4 Other: …………………………….5	
8.	What is your average income from the crop enterprises per	.________________. KSh /yr	

	month		

Part II: Farm characteristics

1.	What is the total size of land you have for farming?	.________________. acres/ha	
2.	Which crops do you grow	……………………………………….. ……………………………………….. ……………………………………….. ………………………………………..	
3.	When was your farm certified as organic?		
4.	Were you certified as an individual organic producer or as a group?	Individual: ………………………..1 Group: ……………………………..2 Name of the group: …………………………………………..	
5.	Why did you decide to certify your farm? **Record in detail** ……… ……… ……… ………		
6.	How were you certified? **Record in detail** **………** **………**		

	…………………………………………………………………………………………… ……………………………………………………………………………………………		
7.	What changed in you farm after you were certified? **Record in detail** …………………………………………………………………………………………… …………………………………………………………………………………………… …………………………………………………………………………………………… …………………………………………………………………………………………… ……………………………………………………………………………………………		
8.	Which crop varieties do you grow for the (organic) market	List here ……………………………………. ……………………………………. ……………………………………	
9.	Which organic amendments do you use on your crops and their rates?	1. 2. 3.	
10	What organic pesticides and herbicides do you use and their rates?		
11	What yields do you obtain of form vegetables		
12	What challenges/constraints do you face in vegetable production?		
13	How do you cope with the challenges you face to better your production?		

Appendix 2 (disease incidence)

No. of plants	Range (%)	Description
0	0 – 10	No crop was infected by disease. Maximum performance of crop quality and yield.
1	11 -20	Negligible crops were infected by disease. Quality and yield performance was good.
2	21 -30	Very few crops were infected by disease.
3	31 – 40	Few crops were infected but the effect on the quality and yield weighed in.
4	41 – 50	Moderate crop infection
5	51 -60	Half of the crops were infected by disease causing 50% loss in quality and yield
6	61 -70	More than half the crops were infected causing very significant loss in quality and yield.
7	71 -80	Severe crop infection.
8	81- 90	Very severe.
9	91 -100	Epidemic. All the crops were infected by disease hence causing 100% crop failure.

Appendix 3 (pest prevalence)

No. of plants	Range (%)	Description
0	0 – 10	No crop was infected by pests. Maximum performance of crop quality and yield.
1	11 -20	Negligible crops were infected by pests. Quality and yield performance was good.
2	21 -30	Very few crops were infected by pests.
3	31 – 40	Few crops were infected but the effect on the quality and yield weighed in.
4	41 – 50	Moderate crop infection
5	51 -60	Half of the crops were infected by pests causing 50% loss in quality and yield
6	61 -70	More than half the crops were infected causing very significant loss in quality and yield.
7	71 -80	Severe crop pest infection.
8	81- 90	Very severe pest infection.
9	91 -100	Epidemic. All the crops were infected by pests hence causing 100% crop failure.

Appendix 4 Analysis of variance

Variate: germ_cnt

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	4.926	2.463	0.63	
REP.season stratum					
season	1	13664.463	13664.463	3497.07	<.001
Residual	2	7.815	3.907	1.79	
REP.season.MAIN_P stratum					
MAIN_P	2	24196.926	12098.463	5536.58	<.001
season.MAIN_P	2	26856.037	13428.019	6145.03	<.001
Residual	8	17.481	2.185	0.35	
REP.season.MAIN_P.SUB_P stratum					
SUB_P	2	424.481	212.241	33.56	<.001
season.SUB_P	2	67.815	33.907	5.36	0.012
MAIN_P.SUB_P	4	140.741	35.185	5.56	0.003
season.MAIN_P.SUB_P	4	11.852	2.963	0.47	0.758
Residual	24	151.778	6.324		
Total	53	65544.315			

Variate: disease_incidence

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	28.70	14.35	4.43	
REP.season stratum					
season	1	11.57	11.57	3.57	0.199
Residual	2	6.48	3.24	0.21	
REP.season.MAIN_P stratum					
MAIN_P	2	545.37	272.69	17.32	0.001
season.MAIN_P	2	12.04	6.02	0.38	0.694
Residual	8	125.93	15.74	0.80	
REP.season.MAIN_P.SUB_P stratum					
SUB_P	2	1673.15	836.57	42.52	<.001
season.SUB_P	2	145.37	72.69	3.69	0.040
MAIN_P.SUB_P	4	482.41	120.60	6.13	0.002

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season.MAIN_P.SUB_P             4       10.19        2.55      0.13   0.970
Residual                       24      472.22       19.68

Total                          53     3513.43


Variate: leaf_size_cm

Source of variation          d.f.        s.s.        m.s.      v.r.   F pr.

REP stratum                     2      0.1878      0.0939      0.91

REP.season stratum
season                          1    239.8230    239.8230   2316.72  <.001
Residual                        2      0.2070      0.1035      0.93

REP.season.MAIN_P stratum
MAIN_P                          2    363.6400    181.8200   1626.89  <.001
season.MAIN_P                   2    507.8948    253.9474   2272.27  <.001
Residual                        8      0.8941      0.1118      0.72

REP.season.MAIN_P.SUB_P stratum
SUB_P                           2    423.1811    211.5906   1365.92  <.001
season.SUB_P                    2     24.9226     12.4613     80.44  <.001
MAIN_P.SUB_P                    4     46.1456     11.5364     74.47  <.001
season.MAIN_P.SUB_P             4     20.2796      5.0699     32.73  <.001
Residual                       24      3.7178      0.1549

Total                          53   1630.8933



Variate: pest_signs

Source of variation          d.f.        s.s.        m.s.      v.r.   F pr.

REP stratum                     2      45.370      22.685      1.58

REP.season stratum
season                          1     185.185     185.185     12.90   0.070
Residual                        2      28.704      14.352      0.36

REP.season.MAIN_P stratum
MAIN_P                          2    2670.370    1335.185     33.34  <.001
season.MAIN_P                   2     292.593     146.296      3.65   0.075
Residual                        8     320.370      40.046      4.33

REP.season.MAIN_P.SUB_P stratum
SUB_P                           2     139.815      69.907      7.55   0.003
season.SUB_P                    2      45.370      22.685      2.45   0.108
MAIN_P.SUB_P                    4     615.741     153.935     16.63  <.001
season.MAIN_P.SUB_P             4      43.519      10.880      1.18   0.347
Residual                       24     222.222       9.259
```

```
Total                                53       4609.259
```

```
Variate: plant_height

Source of variation                d.f.           s.s.           m.s.        v.r.    F pr.

REP stratum                           2         1.7744         0.8872        8.57

REP.season stratum
season                                1       399.0785       399.0785     3855.14    <.001
Residual                              2         0.2070         0.1035        0.12

REP.season.MAIN_P stratum
MAIN_P                                2       505.8811       252.9406      281.10    <.001
season.MAIN_P                         2       946.7937       473.3969      526.10    <.001
Residual                              8         7.1985         0.8998        0.99

REP.season.MAIN_P.SUB_P stratum
SUB_P                                 2      1216.3478       608.1739      671.81    <.001
season.SUB_P                          2        20.5604        10.2802       11.36    <.001
MAIN_P.SUB_P                          4       313.4978        78.3744       86.58    <.001
season.MAIN_P.SUB_P                   4        32.0141         8.0035        8.84    <.001
Residual                             24        21.7267         0.9053

Total                                53      3465.0800
```

```
Variate: yield_

Source of variation                d.f.           s.s.           m.s.        v.r.    F pr.

REP stratum                           2         174.48          87.24        2.31

REP.season stratum
season                                1       41112.96       41112.96     1087.75    <.001
Residual                              2          75.59          37.80        0.77

REP.season.MAIN_P stratum
MAIN_P                                2       17434.04        8717.02      176.53    <.001
season.MAIN_P                         2       69398.93       34699.46      702.71    <.001
Residual                              8         395.04          49.38        1.75

REP.season.MAIN_P.SUB_P stratum
SUB_P                                 2       52232.70       26116.35      927.82    <.001
season.SUB_P                          2        6486.04        3243.02      115.21    <.001
MAIN_P.SUB_P                          4        5791.63        1447.91       51.44    <.001
```

```
season.MAIN_P.SUB_P          4      4109.41      1027.35     36.50   <.001
Residual                    24       675.56        28.15

Total                       53    197886.37
```

```
***** Analysis of variance *****

Variate: OC_%

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

REP stratum                2   0.003198   0.001599    0.26

REP.*Units* stratum
MP                         2   0.272299   0.136149   22.39  <.001
SP                         2   0.212073   0.106036   17.44  <.001
MP.SP                      4   0.101622   0.025406    4.18  0.017
Residual                  16   0.097299   0.006081

Total                     26   0.686491


***** Analysis of variance *****

Variate: N_%

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

REP stratum                2  0.0015534  0.0007767    1.51

REP.*Units* stratum
MP                         2  0.0383636  0.0191818   37.39  <.001
SP                         2  0.0212201  0.0106100   20.68  <.001
MP.SP                      4  0.0020333  0.0005083    0.99  0.441
Residual                  16  0.0082086  0.0005130

Total                     26  0.0713790




***** Analysis of variance *****
```

```
Variate: P_mg_L

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

REP stratum                2  5.560E-02  2.780E-02    4.93

REP.*Units* stratum
MP                         2  1.982E+02  9.909E+01 17567.53 <.001
SP                         2  1.691E+03  8.457E+02 1.499E+05<.001
MP.SP                      4  1.682E+02  4.204E+01 7453.23  <.001
Residual                  16  9.025E-02  5.641E-03

Total                     26  2.058E+03


***** Analysis of variance *****

Variate: K_mg_kg

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

REP stratum                2  0.0087529  0.0043764   16.05

REP.*Units* stratum
MP                         2  0.1086887  0.0543443  199.29  <.001
SP                         2  0.6495167  0.3247583 1190.92  <.001
MP.SP                      4  0.0626173  0.0156543   57.41  <.001
Residual                  16  0.0043631  0.0002727

Total                     26  0.8339387
```