EVALUATION OF SPATIAL VARIABILITY OF SELECTED SOIL CHEMICAL PROPERTIES, THEIR INFLUENCE ON COFFEE YIELDS AND MANAGEMENT PRACTICES AT KABETE FIELD STATION FARM

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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 thesis is dedicated to my beloved wife, Risper and children:
Bethany, Solomon, Jabez and Dan
for their encouragement, prayers and material support
I cherish their sacrifice in allowing me pursue this study.

"You stop to lead when you stop learning"

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LIST OF ACRONYMS AND ABBREVIATIONS

CAVS	College of Agriculture and Veterinary sciences
CBK	Coffee Board of Kenya
CRF	Coffee Research Foundation
FAQ	Fair Average Quality
GAP	Good Agricultural Practices
GBE	Green Bean Equivalent
GPS	Geographical Positioning System
ICO	International Coffee Organization
KFS	Kabete Field Station
KNBS	Kenya National Bureau of Statistics
M.A.S.L	Meters above Sea Level
NPK	Nitrogen- Phosphorus- Potassium
SPSS	Statistical Package for Social Sciences
U o N	University of Nairobi
USDA	United States Department of Agriculture
FAO	Food Agricultural Organization

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ABSTRACT

Coffee production in Kenyan farms (smallholder and plantations) has been on the decline over the last two and half decades in output and quality and this may have been due to declining soil productivity arising from none or minimal soil amelioration. The same trend is reflected at Kabete Field Station coffee farm. Soil varies with land uses from location to location and determination of the extent of spatial variation of soil properties within the farm is key in the evaluation of management practices to be put in place. The spatial variation in soil chemical properties at Kabete Field Station coffee farm which has been under coffee for the last 83 years had not been investigated. To assess and profile soil fertility status of Kabete Field Station Coffee Farm for site-specific input use for improvement of coffee production, a within field spatial variability of soil chemical parameters and coffee yield was evaluated in four of the eight coffee fields in the farm. The fields were divided into 50 m X 60 m rectangular plots in which 122 geo-referenced grid-point soil samples were collected from two depths (0-15cm and 15-30cm) where coffee plant feeder roots extract most nutrients. This study was carried out with the objectives to (i) documenting past and current coffee management practices in use at the farm (ii) to investigate, and profile spatial variability of selected soil chemical properties that influence yield and quality of coffee and (iii) to relate these soil characteristics to coffee yields at the farm. The study examined seven consecutive years of farm operations (2005-2012) through records kept on coffee management practices for evidence-based documentation of various coffee production activities at each stage and compared it with best practice recommended by Coffee Research Foundation (CRF). Grid point sampling scheme was adopted for better characterization and detection of patterns in variability of soil properties within the coffee fields. Grid point soil sampling scheme was carried out for intensive soil and crop information as a baseline for precision coffee farming in the farm. The Geo-referenced soil samples were analyzed for variation in total nitrogen,

available phosphorus, exchangeable potassium at primary macro level and calcium and magnesium at secondary macro levels. Observations from the records studied showed that although the farm is ecologically ideal for coffee production, there was significant divergence in observance of good agricultural best practice resulting in low coffee yield of 0.27 ton ha^{-1} compared to 1.43 ton ha^{-1} obtained by neighbouring coffee farm, Kamundu estate within the same agro-ecological zone. The performance of the farm on the whole stood at 34 % of the achievable optimum potential in the minimum above 1.3 ton ha^{-1}. The soil analysis results showed that soil pH was within the required range (4.4 – 5.4) but on the upper sufficiency levels. Available phosphorus (P) was critically low (1 – 10 ppm) compared to adequate level for coffee plant (20 – 100ppm). This may have affected the uptake of the other mineral nutrients by the coffee as the root mass could be severely compromised. Since P is low, response to phosphate fertilizer application may be expected.GIS spatial analysis to examine within field yield influencing factors showed that organic carbon, total nitrogen and exchangeable calcium influenced yield positively. Multivariate analysis showed that the selected soil chemical properties contributed significantly to the yield as yield-determining factors explaining as much as 91.7 % in F1, 37.1 % in F2a, 32% in F7 and 67.5 % in F20 of the spatially structured or non-random variation of the coffee yield. The spatial variation showed in the distribution of yield determining factors provides opportunity for site-specific application of inputs according to the available quantities in the soil through guided application to save costs and increase nutrient efficiency.

CHAPTER ONE: INTRODUCTION

1.1. Background

Agriculture is the mainstay of Kenya's economy. The performance of the agricultural sector in Kenya directly affects its overall economic growth. The sector contributed 23.9% towards the country's GDP growth in 2012 (KNBS, 2014). Coffee industry is one of the sub-sectors contributing to this growth in agriculture through foreign exchange earnings, family farm incomes, employment creation and food security. The value of coffee as a percentage of all merchandise in Kenya in 2012 was 4.5 % while its percentage contribution to GDP was 0.77% and Per capita consumption (kg) 0.07 (ICO, 2012). However, coffee production in Kenya has declined over the last two and half decades, from an all time high of 129,637 metric tonnes in 1987/88 to as low as 36,322 metric tonnes in 2010/2011(CBK annual report, 2013).This decline significantly affects Kenya's economy and position as the world's producer of highly sought after quality coffee.

Coffee farming in Kenya is regarded as a redeemable key export earner, being the fifth foreign exchange earner after tea, remittances from Kenyans from the Diaspora, tourism and horticulture (KNBS 2014). The sector is composed of two categories of growers: the plantation sub-sector, with 2 ha and above in area planted with coffee and the co-operative sub-sector, comprising farms with coffee trees below 2 ha, who congregate to pool their produce and process together at common processing facility (factory). The latter group is constituted as co-operative societies with one or more primary factories to process cherry (CBK Annual report, 2013). The large scale growers are grouped as plantations.

In spite of the central role it has played in the country's development, coffee production has steadily declined over the last two decades (CBK Annual report,2013). This may partly be due to declining productivity per unit area or per tree (KNBS 2014. However, the increasing demands for quality coffee, which Kenya produces and is used in blending other coffees, is likely to yield benefits for farmers who opt for good agricultural practice to match this demand.

The economic value of Arabica coffee (Coffea arabica L.) is determined both by the yield potential and the bean quality (Agwanda, et al.2003).Yields of 5 tonnes ha-1 and higher have been obtained in some close- spaced and un shaded Arabica coffee farms in Kenya (S¨ondahl et al.2005).Major Arabica coffee cultivars grown in Kenya are S.Ls(28,34 &K7),Ruiru11 and Batian. Intensely managed plantations at conventional spacing(2mx2m) may yield an average of 2 tonnes ha-1 annually(Van der vossen,2009).Data from field trials at Coffee Research Foundation, in Kenya show that Ruiru 11hybrid cultivar planted at a density 3300 trees/ha produces between 2.5 to 3.0 tonnes ha-1 (Van der vossen,2009).Depending on weather and agronomic conditions, coffee yields fluctuate from year to year and from location to location(Gichimu *et al.,*2010).Kenyan coffee are classified under Colombian milds and it thus faces stiff competition from similar coffees of other origins such as Ethiopia.

Therefore production and productivity at the farm must move from 'customary farming' to 'coffee business' model that operates within the stipulated business principles. The principle aim is towards yield increases before considering expansion of planted areas. Arabica coffee being the key cash crop in Kenya's economy requires adoption of sustainable production methods. Cost reductions, economic yield sustainability and quality improvement are now the major priorities in coffee production systems. Sustained agricultural production in most Sub-Saharan countries is under threat due to declining soil fertility and loss of topsoil through erosion (Hellin, 2003; Sanchez, 2002) and the established emergence of climate change, now a reality globally than ever before.

To achieve sustained production, it is important to indirectly evaluate the coffee production potential of an area/region by analyzing the spatial variability of soil properties within that given area/region. This is useful in order to optimize profitability, sustainability and protection of the environment. The spatial temporal variability of important soil properties and associated plant biomass production are also useful in developing effective sampling schemes for future site management (Mulla et al., 1992). The extent of soil spatial variability depends on the variations of soil forming factors and the management practices applied for growth of a particular crop (McGraw, 1994).

The most important link between farming practices and sustainable agriculture is the health or quality of the agricultural soils. Soil health is the foundation of productive farming practices as fertile soil provides essential nutrients to plants. Quality and healthy soil is able to " sustain productivity, maintain environmental quality and promote plant and animal health" (Doran 1994). According to the (USDA) Natural Resource Conservation Service, "Soil quality is how well soil does what we want it to do." Protection of soil quality under intensive land use and fast economic development is a major challenge for sustainable resource use in the developing world (Doran et al., 1996b).

Kabete Field Station Farm is situated in a premium urban land, in which climatic and soil characteristics provide ideal conditions for sustainable coffee production. It is within the coffee Agro-Ecological Zone(AEZ), UM2 and the soils are friable, well drained, very deep (> 180 cm) as described by (Gachene, et al.1989) clay giving rise to favourable conditions for coffee root development and penetration. However, in the last seven consecutive coffee seasons, the yield pattern of the farm has shown biannual trends where coffee yields are good in one season and drop the following season. Soil characteristics vary from point to point within a field and have an impact on the use, fate and transport of chemical inputs as well as on crop yields (Jaynes, et al.1995).

Diagnostic methods of assessing soil fertility levels, pest status, disease scoring are important components of farm management. Records are indicators of performance of previous production and guide future decisions on which enterprise choice can be made. They provide data for use in making alterations to the existing farm enterprise combinations; as well as providing planning and improved profitability (improve farm performance).

Thus complete pest and disease control, fertilizer and canopy management package implementation are key indicators of optimal farm management practices. The level of yield achieved therefore directly affects the profit margin realized. Thus the estate should strive to improve its yield by following the recommended coffee management practices even in time of low coffee price. Arabica coffee cultivar is often used for specialty gourmet market and enjoys better prices. There must be a good production of Kenyan coffee to ensure continuous and sustained supply of these coffees to create a strong demand. Good plant husbandry is essential for the preservation of this potential. High yield and better quality coffee are the best assurance the estate/farm can have towards making profits out of coffee business.

Further, the study compared management practices and coffee productivity at the farm to management practices in use at Kamundu coffee estate (AI.0005) within the same Agro-Ecological zone and Kabete Field Station. This is because farm productivity is directly related to environmental management and soil health and quality.

The determination of the extent of spatial variation of soil properties within a farm is key in the evaluation of management practices to be put in place. In this study, grid soil sampling was adopted for purposes of intensive characterization of the spatial variability of the selected soil chemical properties and yields in the coffee fields. This is because the study seeks to introduce precision agriculture at KFS farm, a technology that allows management to apply the right amount of nutrients to specific zone of need and reduce wastage, and safe costs unlike the current situation where inputs are applied in a blanket manner to all fields irrespective their nutrient variable needs.

1.2. Statement of the problem

Coffee production at Kabete Field Station coffee farm is characterized by a biennial bearing pattern in which there is good crop in one season followed by a lower crop the next season. Biennial cycle is not related to weather as it is related to the way farms are managed. At the current average yield of 0.35 t ha^{-1} the financial returns from the farm to the institution would be too low to permit the close attention which is necessary to sustainably produce coffee of good quality and quantity.

From production records maintained at the Kabete Field Station farm over the last 15 years, a declining trend shows; from a high of 41 metric tonnes (MT) 1998 to 13 metric tonnes produced in 2011(appendix 3). Considering the current coffee acreage of 47 ha, the farm has a potential to produce over 120 MT from the current 13 MT. recorded in 2012/2013 crop year at the farm. The low income obtained from the Kabete field Station coffee farm impacts negatively on annually requested coffee funding from the University finances since it is presumed not profitable. This trend too, contributes to low production nationally and could lead to loss of potential markets in the medium term for Kenya, as regional competitive markets such as Rwanda and Ethiopia are aggressively raising their productivity levels.

At this rate, coffee is becoming an endangered crop, along with Kenya's export earnings that substantially relies on the performance of the sub-sector. It is therefore, imperative that production and productivity at the farm level must move from 'customary farming' to 'coffee business' that operates within business principles.

Presentation of the coffee stand in the fields suggested low husbandry practices and soil related nutrient deficiencies. Most of the coffee trees did not carry crop on them portending continuous loss of income for the University farm. This may lead to poor soil health and quality degradation, hence decline in soil fertility resulting in net nutrient depletion, which may contribute to coffee yield decline at Kabete field station farm.

1.3. Justification of the study

Coffee production at the Kabete Field Station farm has been declining for the last 15 years and the main causes for the low production at the farm have not been fully established. The university has invested in 47ha of prime land under coffee plantation and revenue from the farm is way below its stipulated minimum threshold. Yet there is great potential for increased and sustainable coffee production at the Kabete field station farm. The farm, too, is likely to be underperforming compared to similar farms within the same AEZ in the area. As farms get smaller and smaller and as population pressure increases, it calls for intensive cropping within the available land. There is need therefore to increase yields per unit area to maximize profit. So intensification of production and productivity are paramount. Technological advances in agriculture such as Precision Farming could be used in coffee production to increase productivity within the available land area. This study will carry out intensive grid point geo-referenced soil sampling for identification of within field nutrient variability and generate application maps for variable rate input use. Coffee estate farms can exploit niche markets, interested in coffee from an identified unique highland farms with special characteristics. Coffee yields could therefore vary over landscapes within a field.

1.4. Objectives of the study

1.4.1 Overall objective

To evaluate the spatial variability of selected soil chemical properties, management practices influence on coffee yield at Kabete Field Station in comparison with well managed neighbouring Kamundu estate, for site –specific application of agro-inputs within the farm.

1.4.2 Specific objectives

(i). To document and evaluate the past and the current coffee management practices at Kabete Field Station coffee fields in comparison with neighbouring Kamundu Coffee estate for benchmarking with best practice

(ii). To investigate and profile spatial variation of selected soil chemical properties in the coffee fields of Kabete for site specific guided application of farm inputs in the farm.

(iii). To relate soil quality parameters to coffee yield within the various coffee fields for determination of factors limiting coffee yield in the farm.

1.5. Hypothesis

(i). The coffee management practices at the Kabete Field Station coffee fields are not in line with Coffee Research Foundation standard recommendations

(ii). The spatial variability of soil quality within the coffee fields is not influenced by management and soil depth

(iii). The coffee yields are not influenced by differences on soil quality across the coffee fields

CHAPTER TWO: LITERATURE REVIEW

2.1. Importance of the coffee industry in Kenya

The importance of coffee in the world economy cannot be overstated. It is one of the most valuable primary products in world trade, in many years second in value only to oil as a source of foreign exchange to developing countries.

Coffee production has been a fundamental economic pillar for over 50 developing countries, for which it is the main foreign currency earner (Agwanda et al., 1997). French Missionaries introduced coffee to Kenya around 1900A.D. (Mwangi, 1983) and since then, it has been playing an important role in the country's economy (Condliffe et al., 2008). It provides a major source of foreign exchange for Kenya, as well as supporting the livelihoods of millions of rural families and accounts for 11% in Kenya's total export earnings. It is further estimated that out of the 70% of Kenya's workforce engaged in agriculture, 30% are employed by the coffee industry (Omondi et al., 2001). The performance of coffee in Kenya has, however, been on the decline as is evident from the drop in coffee exports, coffee quality and yields (Condliffe et al., 2008). Over 90% of the total Kenya coffee acreage is under arabica coffee (*Coffea arabica* L.) which is a high-quality yet mild coffee. It is grown on rich volcanic soils, found mainly in the highlands between an altitude of 1500 and 2100 m.a.s.l. The soils found suitable for coffee growing are located in UM1 to UM4 zones (Jaetzold, et al., 1983).

Today, a total of 110,000 hectares of arable land in Kenya is planted with coffee. It is estimated that over 1.35 Million small and large-scale farmers are involved in coffee farming. In addition, the coffee industry, due to its forward and backward linkages, directly and indirectly benefits about 5 million people in the country.

Coffee in Kenya is mainly grown on nitisols, commonly referred to as Kikuyu red loams (Sambroek, et al., 1980). Fertilizers are needed for the vegetative growth of the tree and production of high quality coffee. The mostly grown coffee cultivars are the French Mission and K7 for the low altitude areas of Kenya, SL 28 for the medium to low altitude and SL 34 for the high altitude areas with good rainfall (Mwangi,1983). The hybrid cultivars Ruiru 11 and Batian released by Coffee Research Foundation, Kenya are suited for the medium to high altitude areas.

2.2. Spatial variability of soil properties

Spatial variability occurs when a quantity that is measured at different spatial locations exhibits values that differ across the locations. Spatial variation can be looked at as the way that something changes or varies over an area on the earth's surface, in the atmosphere, or the sea. Soil properties, after suffering successive changes caused by agricultural activities and, consequently, by erosion, behave quite differently across the landscape (Izidorio et al., 2005; Souza et al., 2005; Souza et al., 2006). Soils subjected to the same management system in places with small terrain variation manifest different spatial variability in intrinsic properties. This variability is a function of the position of soils in the landscape (Barbieri et al., 2008) or in slopes, even when the terrain has little expression (Sanchez et al., 2005; Souza et al., 2006). Several studies have documented that soil properties vary across farm fields, causing spatial variability in crop yields (Rockstro¨m et al., 1999; Gaston et al., 2001).

Precision farming or site-specific management is aimed at managing soil spatial variability by applying inputs in accordance with the site-specific requirements of a specific soil and crop (Fraisse et al., 1999). Such management practices require quantification of soil spatial variability across the field. One of the recent approaches to quantify soil spatial variability for site specific management is to divide fields into productivity level management zones (Khosla et al., 2002; Fleming et al., 2000). Healthy and productive soils are the foundations for food production on earth .Soil fertility is the status of a soil with respect to its ability to supply elements essential for plant growth without toxic concentration of any elements. A sufficient and balanced supply of liable and available elements is needed to guarantee suitable plant nutrition.

Soil productivity is defined as “the capacity of a soil to produce a certain yield of agronomic crops or other plants with optimum management”. The soil productivity is dependent on soil fertility as well as management practices and the factors affecting plant growth. Productive soils are always fertile but soils can be unproductive because of limiting growth factors like drought and unsuitable management practices Soil fertility status is determined by chemical, physical and biological factors. The range of acidity (soil pH) influences soil nutrient availability. Thus soil quality is the sum total of the capacity of a soil to function, within its ecosystem and land-use boundaries, with the ability to sustain biological activity, maintain environmental quality, and promote plant, animal, and human health (Doran and Parkin,1994; Doran et al., 1996a). It reflects the biological, chemical, and physical properties and processes and their interactions within each soil resource (Karlen et al., 2001). It also relates to the dynamic nature of soil as influenced by human use and management (Mausbach and Seybold, 1998). Carter et al. (1997) stressed that the concept of soil quality is relative to a specific soil function or use.

The physical, chemical and biological properties of soils are highly variable over time and space (Robertson and Gross, 1994; Ryel et al.1996). This variability may be attributed to the variations in soil parent material that is inherent in nature. Spatial variability of soil properties is somewhat inherent in nature because of variations in soil parent materials and microclimate. (Zhao et al.2007). Farming activities across fields should then be related to this for efficient application of farm inputs, thus necessitating the estimation and mapping of spatial variability of soil properties. The maps so generated shall be helpful to farmers and soil management experts to design land management practices. This knowledge of soil spatial variability and the relationship among soil properties is important for evaluating agricultural land use. The objective of this study was to identify and profile the spatial variability of soil fertility status in the Kabete Field Station coffee farms in order to provide useful information to the management of the University farm to allocate resources more prudently based on the soil fertility variation within the fields.

2.3. Precision farming

There is need therefore to develop cropping systems that can improve agricultural efficiency while meeting environmental goals. One such system has been recognized as precision farming (Bakhsh, 1999). Precision agriculture is an agricultural technology to optimize yield, mitigate risk and maximize profit. Precision farming is defined as the art and science of utilizing advanced technologies for enhancing crop production while minimizing potential environmental pollution (Khosla, 2001) and recognizes the inherent spatial variability that is associated with most fields under crop production (Thrikawala et al., 1999). Once the in-field variability (both, spatial and temporal) is recognized, located, quantified, and recorded, it can then be managed by applying farm inputs in specific amounts and at specific locations (Khosla, 2001). Shanward et al.2004) added that precision farming involves the application of technologies and principles to manage spatial and temporal variability associated with all aspects of agricultural production for improving production and environmental quality. If this technology is adopted by coffee farmers in Kenya, optimum coffee production of high quality may be realised at low cost.

Noting that fields are not homogenous and that variation in soil quality, crop performance and to some extent even weed management, the emerging technologies in farming enable us to map and interpret these variations to the advantage of a farm manager. Armed with these, the manager can farm more efficiently through the use of specific inputs with specific quantities, hence reducing costs and leaching, leading to environmental conservation. These technologies need not be expensive to ordinary Kenyan farmer as knowledge of variation in the field performance will enable him or her to apply inputs differentially, guided by the input application maps. Soil chemical characteristics — including the amount of phosphorus, potassium, calcium, and magnesium — often vary significantly from one area of a field to another. The practice of variable rate takes this variability into account to reduce inputs of water, seed, fertilizers, and fuel as well as to increase yields by dividing fields into sectors and prescribing rates for each one. Thus farmers can best practice their farming by putting fertilizer where it needs to go based on soil properties indicators analyzed. Various services analyze farm data and generate prescription maps. Fertilizer dealers, crop consultants and agronomists take the data, analyze it, and help the farmers make decisions. Farmers are conservative adopters of technology; however, where there is measured benefit, they are quick to adapt. Within the last five years, the location technologies of precision agriculture, in particular geographical positioning system (GPS) based tractor equipment and location-based applications on mobile devices have rapidly become standard modern farming practice. Traceability in the coffee industry is an emerging requirement by consumers who would like to know how the product was produced. Collecting information to trace a crop back to the field, with details on when and with what products the crop was treated, is within reach for all farm products, pending solutions to the interoperability challenges. The whole supply chain has an interest in this level of detail, from the seed and genetics companies that would like to correctly assess seed performance, all the way to the processors that need to ensure product quality and protect human health.

Different crops have different levels of traceability that are driven both by the market and by regulations. The traceability may depend on different characteristics of value, such as with coffee that is shade-grown or fair trade or depending on how it was processed, such as the coffee roast. Fresh produce has a great deal of traceability, as there is little processing, great perishability. Quality is key to marketability, and local-grown is increasing in importance.

Furthermore, growing interest in automated data acquisition and information processing is going to form another milestone towards improved farm management and an overall trace ability in agricultural food production. Precision farming represents a high-tech approach to managing soils and crops and ensuring the most efficient use of resources. There are variations in fields in terms of soil conditions, crop performance and weed development. Geographical Information System (GIS) technologies allow us to map and interpret these variations, as well as to carry outcrop management at a much higher resolution. Adoption of precision farming means more efficient farm management, fewer inputs, reduced leaching and, therefore, less damage to the environment.

2.4. Precision fertilization

Soil characteristics vary from point to point within a field and have impact on the use, fate and transport of chemical inputs as well as on crop yields (Jaynes, et al.1995). Variability and uncertainty are dominant features of field crop production. There are differences between nutrients in the type of variation encountered in field situations. For P and K, the variation is mainly spatial and location-related, but for N there is an additional large temporal (time-related) variation. These are difficult to account for with traditional fertilizer application methods. Soil fertility variations can occur with some portions of the field requiring no fertilizer use while other portions may have excess or deficiency. This calls for intensive soil sampling to assess the nutrient variation to support the need for varying rate of fertilizer application (Penny, et al.1996).

The recent collapse of the coffee price caused by the strong competition of highly mechanized agriculture in countries like Brazil as well as by low-cost production like in Vietnam plunged coffee sector into a deep crisis. Lack of access to knowledge on geo-ecological characteristics of farmland, brings about an undifferentiated use of agricultural inputs. This prevent farmers from profitable and sustainable production because available recommendations are only for an entire region and therefore very general. Judicious management of all the inputs is essential for the sustainability of agricultural production system. The focus on enhancing productivity during green revolution coupled with total disregard of proper management of inputs and without considering the ecological impacts, has resulted into environmental degradation. Now the only alternative left to enhance productivity in a sustainable manner from the limited resources at disposal, without any adverse consequences, is by maximizing the resource input use efficiency.

2.5. Global Positioning System (GPS)

Precision agriculture is a new and developing discipline in coffee farming that incorporates advanced technologies to enhance the efficiency of farm inputs in a profitable and environmentally friendly manner. The technology has been used successfully with great results in citrus farming in South Africa. Yield monitoring and variable rate application are the most widely used precision technologies. Versatile guidance systems utilizing the global positioning system (GPS) and management zone approaches are also being developed to further increase productivity by reducing error, cost, and time. These technologies provide tools to quantify and manage variability existing in fields across an array of cropping systems.

Receivers-GPS satellites broadcast signals that allow GPS receivers to compute the location. Information is provided in real time meaning that continuous positioning information is provided while in motion. GPS receivers, either carried to the field or mounted on implement such as tractors allow users to return to the specific location to sample or treat those areas.

Precision farming basically depends on measurement and understanding of variability, the main components of precision farming system must address the variability. Precision farming technology enabled, information based and decision focused, the components include, (the enabling technologies) Remote Sensing (RS), Geographical Information System(GIS), Global Positioning System (GPS), Soil Testing, Yield Monitors and Variable Rate Technology.

2.6. Coffee yield variability

Yield variability can come as a result of many factors which are either internal or external to a farm. The external factors include weather, soils, market conditions as well as institutional factors and are outside the control of a farm manager, yet they have direct influence on the farm's decisions and can condition the farm internal factors consequently influencing the adopted farming practices. Internal factors are at the domain of the farm manager. The level of input use and management skills are some of the internal factors that play a major role in determining the achievable yield in a farm. Coffee farmers in Kenya are price takers as far as input and coffee prices are concerned. So they should aim at maximizing (optimizing) the coffee output, thereby reducing the cost per unit of coffee produced.

Using GPS technology, precision farming aims to detect variations in crop yields across fields and to use variable application rates and micro-management techniques in an effort to achieve more efficient use of inputs. The precise locations of yield variability in a field are identified by the GPS. Signals from earth-orbiting satellites are used to locate exact positions on the face of the earth, in real time. Monitoring and mapping of yield variations across the field can provide information about variability of the soil. However the challenge is to associate variations in plant responses with soil characteristics, and other factors like weed populations that may account for these variations. Management levels and coffee productivity within coffee estates in Kenya contributes to disparities in coffee yield. This may be brought about by differing management practices such as level of input use, whether irrigated/non irrigated, and ultimately coffee quality. The main areas of focus to improve productivity include coffee nutrition, disease and pest control, good canopy management and use of modern technology for enhancing production and quality while reducing production costs.

2.7. Soil sampling for precision agriculture

Unbalanced fertilization alone with an undetected soil nutrient variability within fields can seriously affect crop yields, quality, economic returns and environmental quality in the farm. Therefore the first critical step in precision agriculture is assessment of variability of factors that affect yields across fields. Soil sampling is an important step in site-specific crop management as soil variability is often directly correlated to variations in yield. Traditional soil sampling consists of collecting and compositing random samples from across a field resulting in a uniform application of fertilizer and lime. This broad application often leads to an over, or under, application of plant nutrients. Precision soil sampling provides information to identify localized regions of nutrient deficiencies and excesses within fields (Crozier and Heiniger, 1998). This type of soil sampling is accomplished by geo-referencing soil samples from the area which the sample was taken using a Global Positioning System (GPS). This allows growers to manage field variability by optimizing nutrient and lime inputs on a site-specific basis. Precision soil sampling is accomplished through either zone or grid sampling methods. Soil chemical analysis is among the diagnostic indicators for estimating nutritional status of the soil and help to spot soil conditions that require use of fertilizers and soil amendments.

2.7.1 Grid-point soil sampling scheme

Grid Point sampling is regarded a better method for detecting patterns of soil variability because all soil samples are collected near geo-referenced grid points (Crozier and Heiniger, 1998). Soil augering is done at a fixed radius of the grid point, which is geo-referenced using GPS. In grid-point sampling, an interpolation method like spline, kriging or some other estimation approach can be used to develop a more continuous surface of soil test results (Wollenhaupt et al., 1994; Chang et al., 1999). Grid-point sampling also has been recommended for variable rate fertilization (Wollenhaupt et al., 1994). Grid-point does not satisfy random requirements as the first selected point can be considered random, but subsequent points are chosen based on preset distances. Grid-point sampling provides excellent soil nutrient information for land managers if the points are close enough to assure spatial dependence. However, developing a universal recommendation for grid distance is difficult because different fields may have different sampling requirements. For example, Wollenhaupt et al. (1994) had one recommendation for fields in the non-responsive categories (91-m grid) and a different recommendation for fields in the responsive range (61-m grid). Other problems with grid-point sampling are that important information may be missed when grid distances are too large, and many farmers perceive that grid-point sampling is not profitable, because of the close sample point spacing required for the calculations to be reliable (Crozier and Heiniger, 1998).

Grid point sampling uses the point information to estimate the soil test level at locations where samples were not taken. To make meaningful estimates, the point samples have to be taken on a grid sufficiently small enough so that data collected would still relate to one another spatially (Lauzon et al., 2005) i.e. correlation coefficient should not be less than 0.3. The most widely used commercial method to date, to characterize soil variability has been based on grid sampling, with grid sizes often based on the acceptability of the cost rather than the usefulness of the information being generated (Lauzon et al., 2005). Experience in the Midwestern United States and from North Carolina suggests that points should be spaced 100 to 200 feet i.e. 33 m to 66 m apart (Crozier and Heiniger, 1998). The North Carolina Department of Agriculture recommends that samples from cultivated fields be collected to the depth of the plough layer, generally 15 or 20 centimetres. For established no-till fields, soil samples should be collected to a depth of 10 cm (Crozier and Heiniger, 1998). In Kenya for soil fertility analysis purposes, soil samples are taken at a depth of 0-30 cm (Kenya Soil Survey Staff, 1987).

2.8. Spatial variability in soil reaction (pH)

The soil pH value is one of the most important chemical properties of soil because it affects the availability and form of nutrients in the soil (Grier et al., 1989) and tree growth. Coffee is reported to do well within soil pH range of 4.4 – 5.4 (Bould, C., 1974), ($CaCl_2$ method).The productivity of a soil depends on its chemical, physical and biological conditions. Among the chemical conditions is the soil reaction. Soil reaction (pH) is a measure of soil acidity or alkalinity. Crops differ in their tolerance of acid conditions. The harmful effects of high acidity or alkalinity are due to their consequences (secondary effects) rather that H+ or OH- ions. It is an important factor in considering the productivity of soils. Soil reaction affects availability of nutrients and at pH levels which are either extremely high or extremely low, deficiencies or toxicities can become serious. At low pH values, beneficial soil micro-organisms are adversely affected. The pH of a soil can decrease through loss of nutrients occasioned by leaching, removal by crops or through application of acidifying fertilizers but protection of the soil by crops decreases losses due to leaching. pH has historically been measured in either water or $CaCl_2$. pH_{water} is considered to be closer to the pH that plant roots are exposed to in the soil rhizosphere, but is subject to large seasonal variation due to seasonal soil moisture and ionic strength changes. By contrast, measurements of $pH_{Calcium}$ are less affected by seasonal variation and are therefore a more robust measurement for diagnostic purposes. The influence of the soil reaction (pH) determines the form and type of N-fertilizers to be used in coffee soils under Kenyan conditions. Soils with weak acidity (high pH) will require acid-forming N-fertilizers to reduce the pH. Conversely, soils with strong acidity (low pH) will be treated with a non acid/neutralizing N-fertilizer.

2.9. Spatial variability of total nitrogen (N)

At the vegetative stage of a coffee tree, N is needed for growth and development. It influences flowering and bearing capacity of the plant. Adequate supply of N to coffee is therefore necessary as this will encourage vigorous growth of leaves and new bearing wood, thus assuring increased yields and better quality as it prevents overbearing due to faulty leaf to crop ratio, provided pruning has been carried out properly and the tree does not suffer from water stress. Plants assimilate mainly ammonium (NH_4^+) and nitrate (NO_3^-) forms of nitrogen which are also the sources of available nitrogen in the soil. Indeed it has been shown (Pereira and Jones, 1954) that the main coffee soils in Kenya are low in nitrogen.

The amount of nitrogen to be applied depends on the natural nitrogen level of the soil, the condition of the trees, the yields expected, whether the coffee farm is grown under shade or is un-shaded. Nitrogen requirements are highest during the rainy seasons when the berries are developing and new branches, leaves, buds are being formed; nitrogen applications should be timed in such a way that enough nitrogen is available at that time as the amount of nutrients available to the tree from a soil at a specific time may be such as not to impair the tree's efficiency and hence reduce its production. Therefore the N demand by the coffee tree crop frequently exceeds the supply of this essential plant nutrient from soil and sustained production of non leguminous crops requires the input of fertilizer N on annual basis. Nitrogen fertilizer application is necessary in the early part of the long rains because following a marked initial flush at the onset of the rains, nitrate values in the soil rapidly fall to a very low (leaching)and steady level at a time when the growth surge is at its maximum. Nitrogen fertilizer is mostly applied by hand to a circular area around the trip line of each individual tree. The application of Nitrogen after 4 weeks from the onset of rain has been shown to modify the shape of the growth curve. The total amount of nitrogen fertilizer to apply each year depends on how much coffee each tree is carrying, trees with heavy crop will require higher rates. Studies by Oruko (1977) showed that N gave the best results if applied during the rains and more so during the long rains (Mitchel, 1970). During the rains, N demand would be high and supply is low. This is explained by the fact that coffee tree has rapid vegetative development during the rainy period and two crops, early and late crops would be developing at the same time (Huxley and Cannell, 1968). At the rain period, nitrate values in the soil rapidly falls below to very low levels due to leaching (Willson, 1985 b). Nitrogen is needed for growth as well as for its influence on flowering and bearing capacity of the plant at this stage (Willson 1985a) through chlorophyll and protein formation.

2.10. Spatial variability of available phosphorus (P)

In coffee production, Phosphorus is needed for high flower spiking (spiking and synchronized flower blooms), large green dark green coloured leaves, robust bearing wood, large beans/high density, high density quality beans above fair average quality (FAQ), high feeder root intensity in the top horizon. Optimal P is therefore an indicator of optimal soil pH, high uptake of mineral nutrients and anticipated higher bearing capacity. It is noted that the supply of available P in tropical soils usually falls short of crops' requirements and it is often the first element that limits growth when soil is first brought into cultural farming activation. It is particularly important to mature coffee trees for sound fruit formation and early maturing of berries (Anon 1987).

The main effects of phosphorous are on root and bearing wood development, growth and other colour of coffee plant and quality as well as composition. These effects arise from stimulation of vital processes (enzymic reactions) within the living cells, giving rise to the incremental production of nucleic acid and chlorophyll necessary for normal production of carbohydrates, and the conversion of starches into sugars. An adequate supply of phosphorous also favours flower initiation, good pollination and fruit formation bringing about early ripening of berries. Plants starved of phosphorous will have stunted root growth and will show a stunted root system.

The soils at Kabete field station farm are classified as a humic Nitisols (Kikuyu red clays-typical coffee soil) (FAO, 1990, WRB, 2006). Nitisols are among the most productive of humid tropics, are deep and permit deep rooting of crops especially tree crops like coffee. However, these soils are known to have a high retention of P and there is need to saturate this with P fertilizer to facilitate attainment of adequate uptake of P (as measured by P contents of leaves) from fertilizers. Patel and Kabaara (1976) in their isotope studies on the efficient use of P fertilizers by coffee concluded that the mechanism which governs the movement and distribution of P32 (as well as normal P) taken up by roots from the soil seems to be very inefficient and suggested that in order to overcome this, heavy doses of phosphorous fertilizers should be applied in the zone and during the period of high activity (during the rainy period) and thereafter this zone should be dressed annually with smaller doses of P. Fruiting load on the coffee trees enhances the uptake of P from applied P thus making it possible for the P requirements of the crop to be met, in addition to the P requirements of other growing tissues.

2.11. Spatial variability of exchangeable potassium (K)

Potassium promotes the assimilation of carbon dioxide and the translocation of photosynthesis in the plant (Wilson 1985b). Potassium also facilitates efficient utilization of soil water through regulation of opening and closing of the stomatal cells which is dependent on the changes in the chemical potential in respect of potash in these cells. Further, adequate potash in the soil (hence plant tissue) enables the plant to repel sap-sucking insects, thus reducing pest induced damage on the coffee crop. This means that high potash plant sap forms a defence mechanism within it. Similarly, adequate supply of potash has a role in the production of a lot of mucilage that enhances primary processing pulp and acts as a positive index of quality. Potash also has a synergic relationship with boron in conferring the plant with efficient water use.

2.12. Effect of slope on soil fertility and yield

Most coffee plants in Kenya are grown in fields of varying topography (slope). Information on this is necessary since soil fertility is very often influenced by the slope of the land on which the coffee is grown. Soil properties, affected by agricultural activities and even erosion, behave quite differently across the landscape (Izidorio et al., 2005; Souza et al., 2005; Souza et al., 2006). Soils subjected to the same management system in places with small terrain variation manifest different spatial variability in intrinsic properties. This variability is a function of the position of soils in the landscape (Barbieri et al., 2008) or in slopes, even when the terrain has little expression (Sanchez et al., 2005; Souza et al., 2006).

CHAPTER THREE: MATERIALS AND METHODS

3.1. Description of the study area

This study was carried out at Kabete Field Station farm, Nairobi County, Kenya. The farm is owned by University of Nairobi and is situated at upper Kabete about 10 km North West of Nairobi. It is 2 km off Nairobi-Nakuru road and lies 1°15l´ S and 36° 44l´ E at an altitude of 1850m above sea level. The coffee farm is part of former Kirima Kimwe estate, acquired from the Government by the University in1967 as documented by Nyandatt et al. 1970. (Figure 3.1(a) & (b)

The farm at present has 47 ha under coffee plantation divided into eight fields: field1 measuring 8.32 ha, field 3 (6.77ha), field four, (5.8ha), field five, (5.26ha)and field seven, (9.34 ha) all S.L 28/34 cultivar, planted in 1938. The other fields, F 20 (2.9 ha) 2A (5.11 ha) and 2B(3.50 ha) have Ruiru 11 cultivar) planted 1989 and 1994, respectively. The four fields F20, F7, F1 and F2a) are representative of the whole coffee estate in terms of soils and climate.

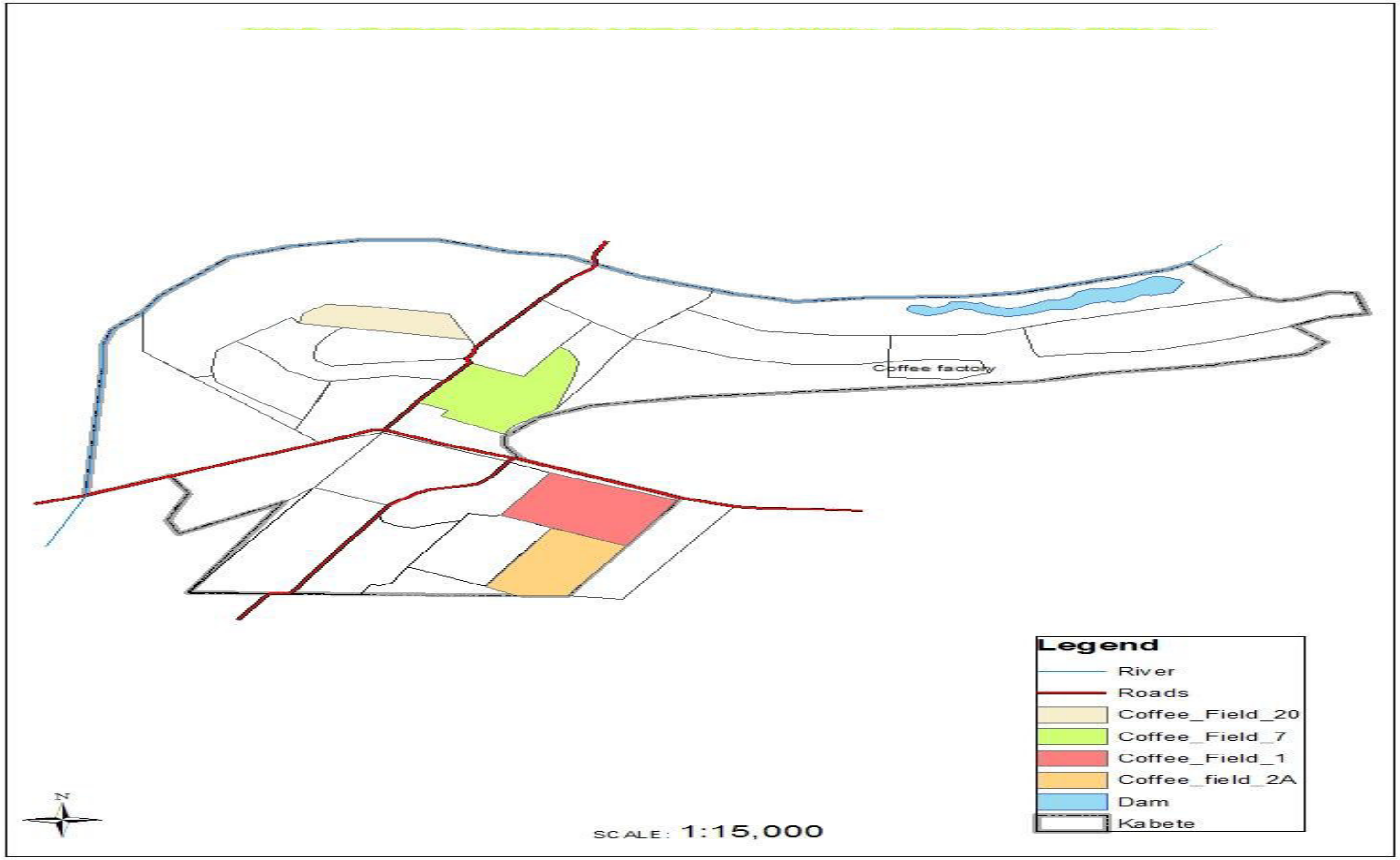

Figure 3.1(a) Sketch map of Kabete Field Station farm: selected fields

Source: Own sketching from the satelite map

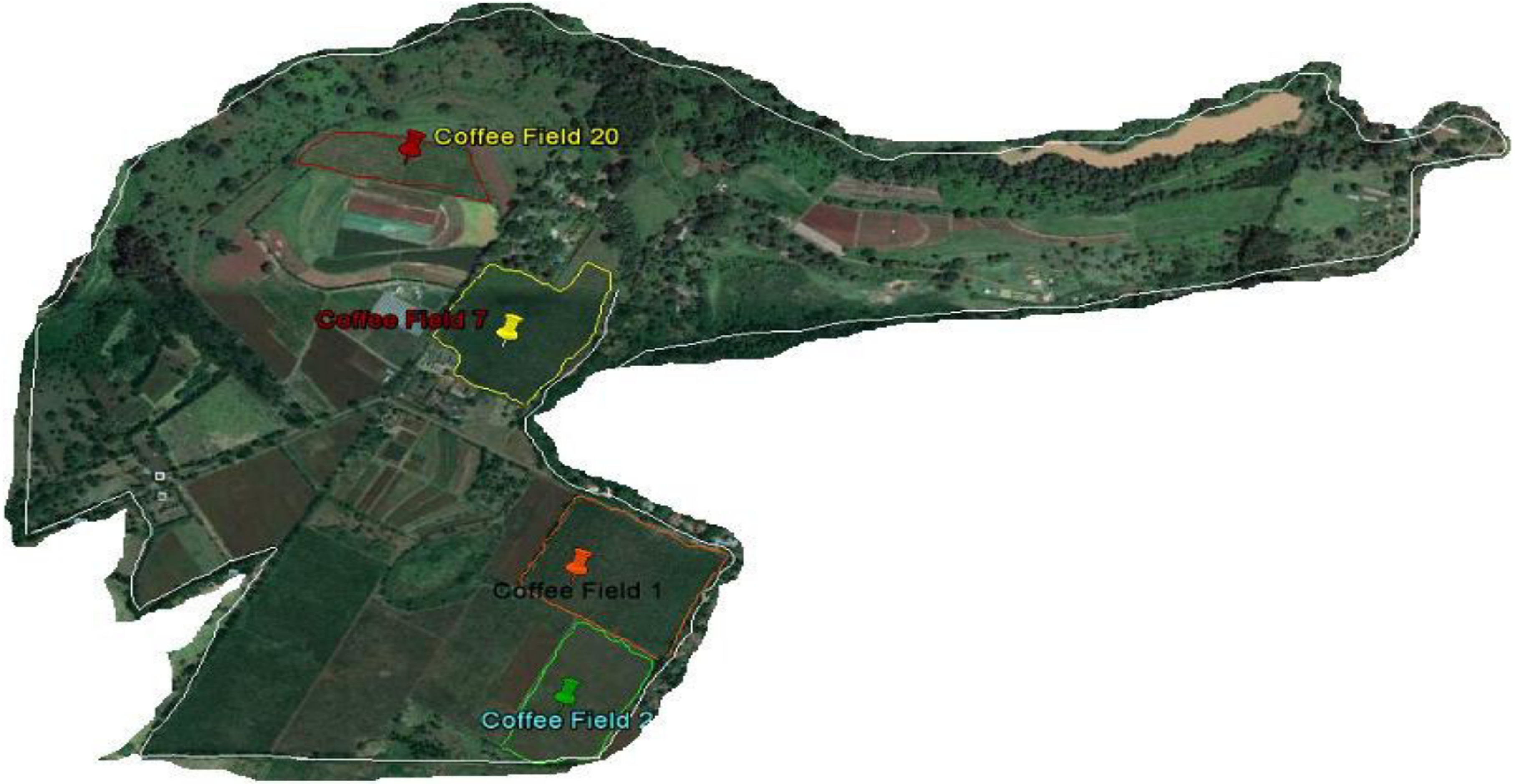

Figure 3.1(b): Satellite map of the study site
Source: Google Earth 17/1/2011

The site experiences a bimodal pattern of rainfall distribution that results in two distinct coffee flowering periods: February/March and September/October each year. This further results in two coffee harvesting periods: September to December and May to July respectively. Long rains start from March to May and the short rains from October to December. (figure3.2).The mean annual rainfall and temperature are 1089.7 mm and 18.6 °C respectively .The dry season stretches from January to March.

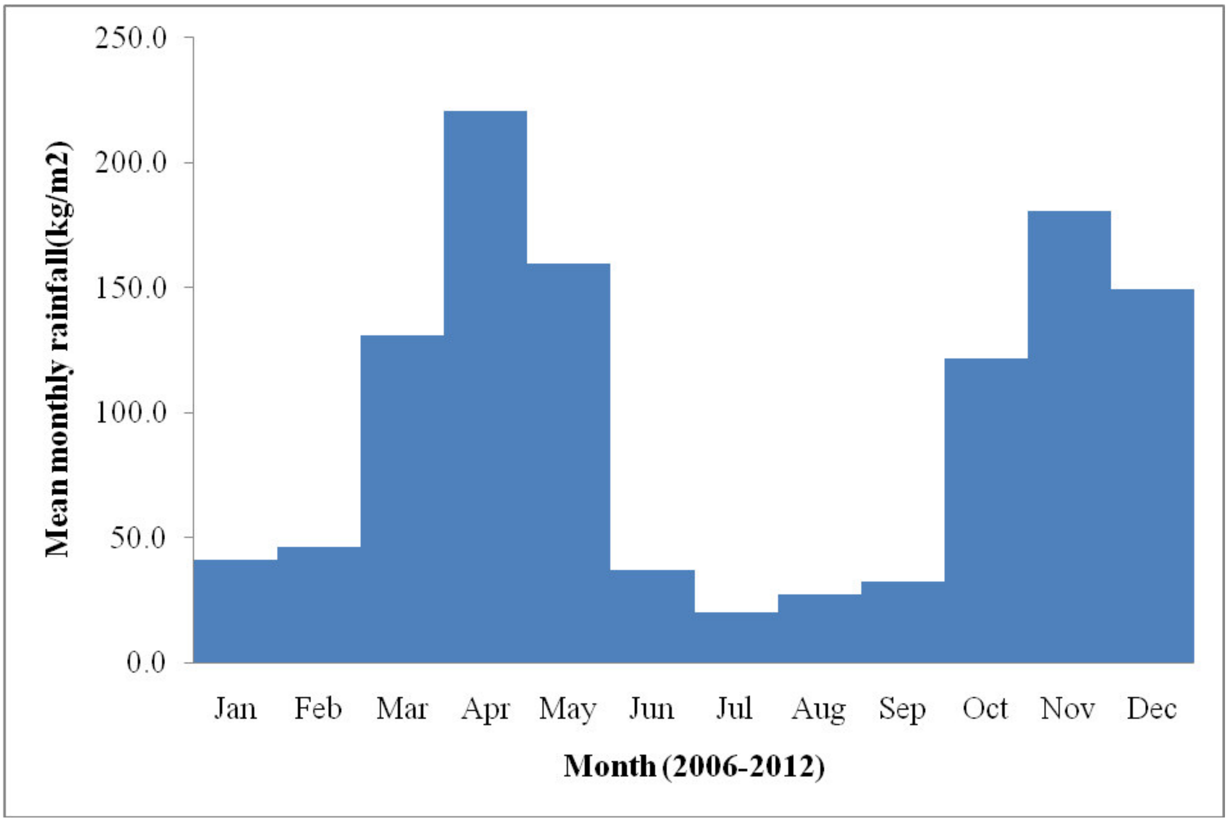

Figure 3.2: Mean monthly rainfall (2006-2012) for Kabete Field Station farm
Source: Kabete Field Station metrological station

3.2. Location of the study

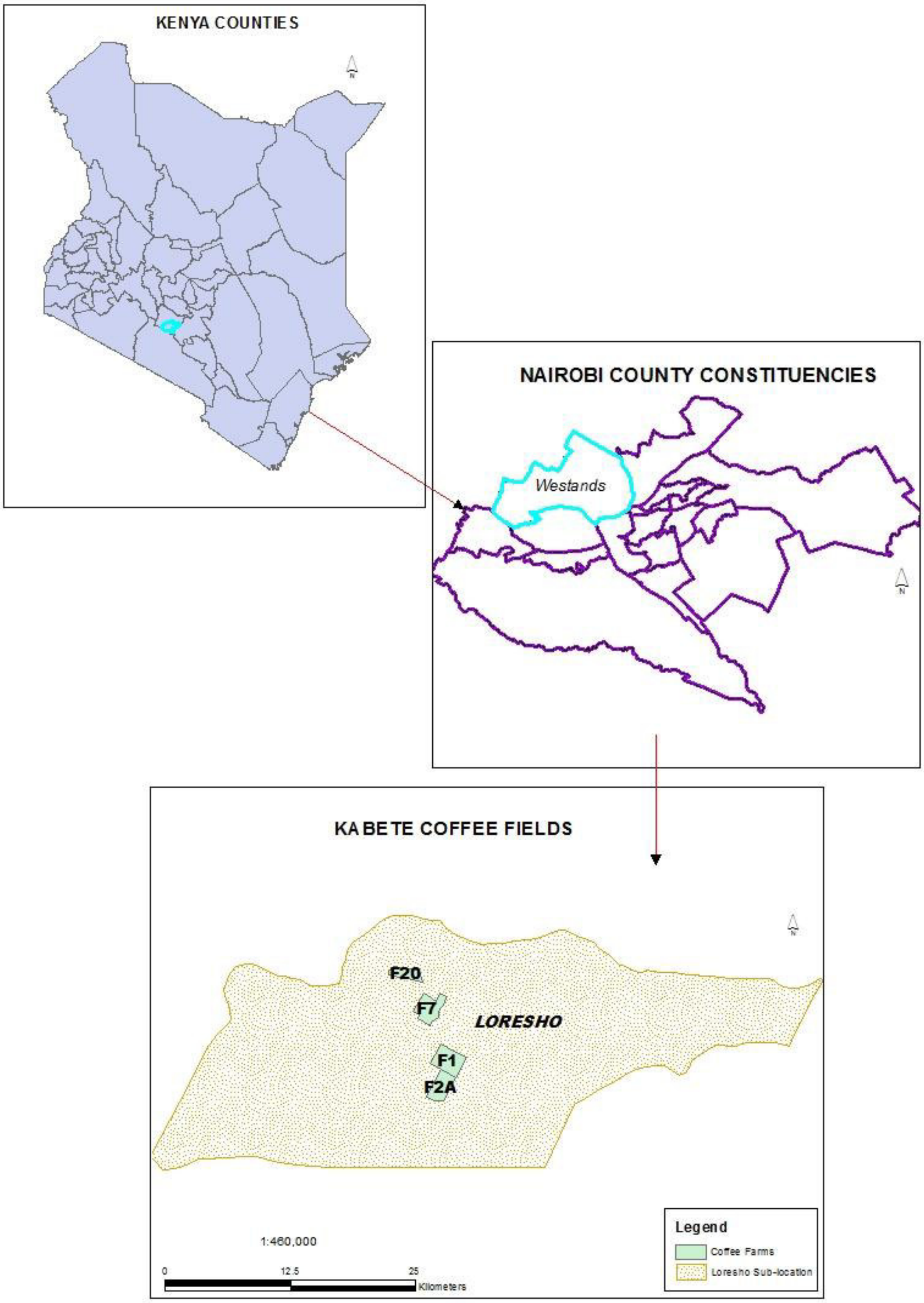

Figure 3.3: Map of the study area

3.3. The soil characteristics

The soils of the study area are classified as a humic Nitisols (WRB, 2006.,UNESCO, 1977) known locally as Kikuyu red clay and are considered representative in terms of climate, of large areas of the Central Kenya highlands (Karuku, et al., 2012). The soils are well-drained, very deep (> 180 cm), dark red to dark reddish brown, friable clay as described by Gachene,et al. 1989.These soils have a high clay content of 60-80 %, high water holding capacity and good porosity (Michori, 1975) and due to the presence of poorly crystallized aluminium (Al) and iron (Fe) oxides/hydroxides these soils have a high adsorption capacity for phosphorus (Michori, 1975., Oruko, 1976, Keterand Ahn 1986). However, Nitisols are among the most productive of humid tropics and are deep and permit deep rooting of crops especially tree crops like coffee. The soils derived from volcanic lavas occur mainly in the East of Rift Valley areas on the slopes of Mt. Kenya and Aberdares and are the predominant type of coffee soils in Kenya. Due to the presence of poorly crystallised iron and aluminium oxides/ hydroxides these soils have a high fixing capacity for phosphorous.

3.4. Existing Coffee management practices

This study sought to examine the state and level of good agricultural practices and coffee productivity at Kabete Field Station farm with regard to the level of existing management practices, input usage, coffee productivity and coffee quality. Benchmarking was made between Kabete Field Station and Kamundu coffee estate, a farm within close proximity and within similar agro-ecological zone (UM2) zone. The level of adoption of various practices and input usage by the two farms provided some indication of the level of uptake of CRF technical recommendations. The objective was to provide up- to -date information on the range of management practices (coffee nutrition, disease & pest control, canopy management) and identify the main factors influencing coffee production and profitability of the coffee estate as seen from the comparison of the two farms.

3.5. Field work

A general survey of Kabete field station farm which formed the study area was undertaken. The farm had 47.01 Ha under coffee, divided into 8 fields. For this study 4 fields were chosen for a detailed study (2 fields with SL28 cultivar and 2 fields with Ruiru 11 cultivar). In each of the selected fields the area was mapped using GPS unit and approximate area calculated. The coordinates defining the boundaries of each of the four fields were recorded, and the boundaries mapped using ArcView 3.2 Gis software. The number and distribution of soil samples collected from each field for analysis is shown in Table 3.2.The samples were determined by the size of each field.

3.6. Information and data collection on coffee management practices at KFS

Data and information to enable analyses of the farm's present and past activities were gathered mostly from secondary sources. The records kept at the University field Station farm, records kept at Coffee Board of Kenya (CBK), Coffee Millers as and data collected from field visits to other farms within the author's knowledge of the sector. Specific areas of focus were farm-level operations (planting, weeding, fertilizing, pruning, spraying, picking/harvesting of red cherry) and coffee factory primary processing: pulping, fermenting, washing and drying to produce parchment coffee, at the farm. Economic analysis of possible production levels/productivity per unit hectare (2.5 acres) was done and bench marked with a neighbouring Kamundu, well managed coffee estate within the same AEZ but differing on management levels.

Similar data and information was collected from Kamundu coffee estate, AI.0005, owned by Sasini Ltd, Kiambu County, Kenya for performance comparisons. These two estates lie within close proximity and are within similar Agro-Ecological Zone (AEZ) UM2 but at different crop management levels. The purpose was to illustrate that management practices play a key role in farm productivity. Farm operation records maintained at the University farm were studied with a view of highlighting any gaps in the production and protection practices at the field station in the last 7 years (2005-2012).These agronomic practices included soil fertility management through fertilization programme/manure/liming/timing and canopy management, disease, insect and pest control and weed management. The level of adoption of various practices and input usage by the two farms provide some indication of the level of uptake of CRF technical recommendations. The objective was to identify main factors influencing coffee production, productivity and profitability of the coffee estate.

Table 3.1: Number of samples collected per field

Field	GPS determined Size(Ha)	Number of samples	Average sample size(ha)
F1	6.66	16	0.41 (1acre)
F20	3.16	12	0.26 (0.65 acre)
F2A	4.95	15	0.33 (0.81 acre)
F7	6.05	18	0.34 (0.83 acre)
Total	20.82	61	0.34 (0.84 acre)

3.7. Soil sampling, preparation and analysis

The four fields in this study were divided into (50 x 60m) approximately 0.34 ha rectangular plots with 61 sampling points. Soil sampling was carried out in four selected coffee fields in February 2013 (based on crop cultivar and age), when it was relatively dry and no fertilization had been done. Two of the fields (F2a & F20) had Ruiru 11 varieties (planted 1989 & 1994) and two had S.L 28 cultivar (Planted 1938). Soil samples were collected from two depths: 0 – 15 cm (top soil) and 15 – 30 cm (sub-soil). This is the zone of maximum root activity in a coffee plant (Plate 3.1). GPS coordinates; altitude, slope and yield were taken from each of the sampled points. The condition of the field was examined for presence of factors that may contribute to yield variability such as weeds. Auger cores from four spots in a (E-W and N-S) direction and within a radius of 3m around the coffee tree drip line were collected from each depth and thoroughly mixed and composite sample taken for analysis.. The GPS referenced soil samples collected at the four fields were then transported to Coffee Research Foundation Laboratory, Ruiru for analysis of the selected soil parameters. The soil samples were air dried, then crushed and ground using a pestle and mortar. They were then sieved using 850 micrometer mesh.

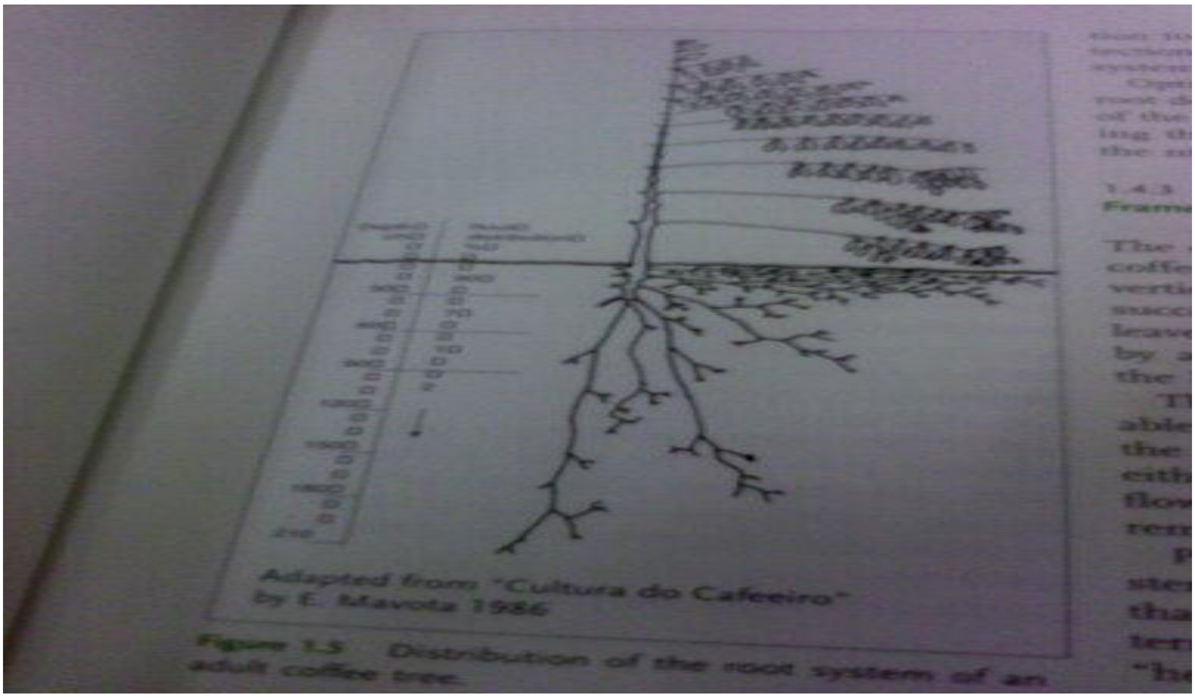

Plate 3.1: Coffee plant root showing area of root concentration (0-45)

3.7.1 Grid –point soil sampling scheme

Systematic unaligned grid sampling method was used (Franzen 2011). In field 20, which measures 3.1 ha, 12 soil samples were picked giving an observation intensity of 3 observations per ha. Field 7 measures 6.05 ha, had 18 soil samples taken, giving an observation intensity of 3 observation per ha. Similarly, Field 2a had 15 soil samples taken, giving an intensity of 3 observations per hectare and 16 soil samples were taken from field 1 from a rectangular block of 6.6 ha giving 2.4 observations per hectare. In total, 122 soil samples were taken for chemical analysis at Coffee Research Foundation from the four fields. At each spot, slope measurements were taken using spirit level. Two recordings were done and slope value determined.

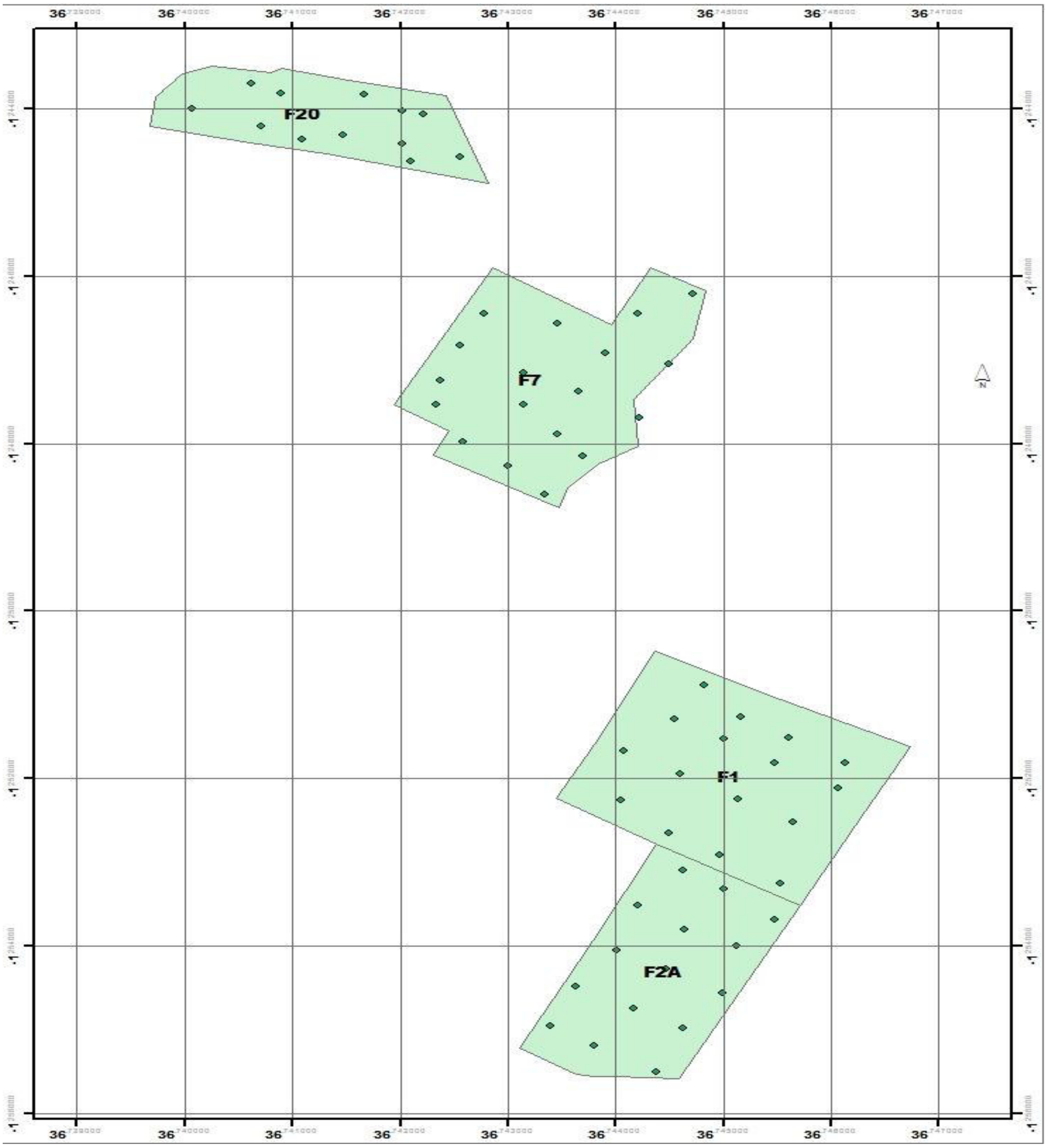

Figure 3.4: Grid sampling points map in the coffee fields

3.8. Yield determination

For yield determination, four plants within a radius of 3m of the spot where the geo-referenced soil samples were taken were tagged, giving rise to 61 yield spots Coffee berries were harvested, weighed and recorded during the entire cropping cycle. The yields obtained became the geo-referenced yield of the spot for purposes of determining yield variability within the fields.

3.9. Laboratory soil analysis

Soil sampling was done at the begriming of February 2013 and analysed for pH, Hp, N, C, P, K, Ca, Mg and Mn. The soil pH was determined using methods described by Anderson and Ingram (1989).The soil nitrogen, potassium, magnesium, calcium and phosphorus were determined by spectrophotometry using the flame and atom absorption method, on Pyre Unicam spectrophotometer as described by Mehlich et al., 1962. Soil nitrogen was determined by Kjeldhal method (Hesse,1971), while carbon was determined by Walkley and Black method (Black, 1965).

From the processed soil samples, five (5) g of dry soil were weighed into 50 ml plastic bottles and 25 ml of the working extracting solution (0.1N HCl and 0.025N H_2SO_4) added and mixed and then shaken in the mechanical shaker for 30 minutes. A Whatman No. 42 filter paper was placed on a glass bottle, and one scoop of the phosphate free charcoal added and filtered. The aliquot was then used for determination of the following elements: exchangeable bases, K, Ca, Mg, and available phosphorus (P).

Calcium and magnesium were determined through the atomic absorption spectrophotometer (AAS) utilizing the absorbance mode at wavelengths of 422.7 and, 285.2 nanometres respectively, while Potassium was determined through the lower energy emission mode at wavelength of 766.5 nanometres. Phosphorus was determined through calorimetric method at a wavelength of 420 nanometre by use of the flow analyzer.

3.9.1 Soil reaction (pH)

The soil reaction (pH) was determined by Calcium chloride method at a ratio of 1:2.5 soil: 0.01M$CaCl_2.2H_2O$ solution (Anderson and Ingram, 1989) by use of glass electrode pH meter model PW9418 Philips Into 100ml plastic beakers, 10 g of air dry soil samples were weighed and 25mls of working 0.01M $CaCl_2.2H_2O$ solution was added. Buffer solutions pH 4.0 and 7.0 were used for calibration. This method involves the use of a salt solution (0.01M $CaCl_2$)

rather than distilled water for the determination of soil pH because it is generally assumed that the salt concentration in the soil is negligible with regard to the amount of salt in the $CaCl_2$ solution (1/100th $MCaCl_2$) used for preparation of the suspension or mixture. The 1:2.5: soil: $CaCl_2$ pH determination method is adopted at Coffee Research Station for routine soil analysis because it was found to be consistent and reliable.

3.9.2 Organic carbon determination

The soil organic carbon was determined using the Walkley-Black method (Black, 1965). In this procedure, 5g of dry soil were ground to a fineness of less than 0.5mm with a pestle and mortar and passed through a 0.5mm sieve. Half (0.5) gram were weighed accurately and transferred to a 500ml wide mouthed conical flask. 10mls of 1.0N Potassium dichromate were added and the flask swirled gently to disperse the soil in the solution. In a fume cupboard, 15ml of conc. H_2SO_4 was added. The flask was swirled gently at first until the soil and the reagents were well mixed then shaken vigorously for about one minute. The mixture was allowed to stand for exactly 30min. 150ml of water was added to the reacting mixture and allowed to cool. To the cooled mixture, 5ml of 85% phosphoric acid was added and finally 10 drops of diphenylamine indicator added. The solution was titrated with 1.0N ferrous ammonium sulphate. Two blank samples were included. The amount of ferrous ammonium sulphate used to reach the end point was recorded

The % carbon was calculated as follows:-

$$\% C = \frac{3 (B-S)}{B \times W}$$

Where B = ml ferrous ammonium sulphate used for the blank

S = ml ferrous ammonium sulphate used for the sample

W = weight of soil in g; 3 = corresponding wt of c in ml 1.0N ferrous ammonium sulphate

3.9.3 Determination of total nitrogen

Total Nitrogen was determined using the Kjeldahl method (Black, 1965; Hesse, 1971). The procedure was as follows: Half gram of fine air dried soil was transferred into a digestion tube calibrated to 50ml.0.5ml selenium mixture (selenium+$CuSO_4$+Na_2SO_4) as catalyst was added and mixed. A few drops of water to moisten the soil and 10ml of H_2SO_4 (95-97%) were added and mixed thoroughly. The digestion tube was heated in a block digester at about 350° C in a fume cupboard until it was pale green and thereafter heated gently for about 30minutes. It was then removed from the block digester and allowed to cool. About 40ml of water was added little at a time with frequent swirling and the mixture allowed cooling. The total nitrogen was then determined through the calorimetric method at the wavelength of 625 nm in a flow analyzer.

3.10. GIS analysis

The boundaries of each field were mapped using Arc View GIS ver.3.2 software. This method was adopted because it is easy to learn and use to create maps using own data. The GPS data (Table 4.13) were typed into excel 2007 software as two columns. One column represented the X-co-ordinates (Easting's) and the other column Y-coordinates (Northing's). The soil properties (pH, Phosphorus, Nitrogen, Carbon, Calcium, Magnesium, slope and yield) were given a new column represented by Z.

3.10.1 Grid-point sampling scheme

Grid-point sampling was chosen particularly because it is useful where there is little prior knowledge of within-field variability. The "Points" theme was integrated in Arc-view GIS as point-shape and converted to shape file and given a new name (Grid-point sampling scheme). From this Grid-point sampling scheme theme, interpretation method called 'Spline' was used to produce continuous surface maps using general procedures given in ESRI (1996) manual. This was applicable only for the quantitative variable data.

3.10.2 Generation of spatial variability maps

Fertility status maps of the study area were produced using the grid-point sampling scheme. Soil fertility parameters considered here were: available phosphorus, total nitrogen, organic carbon, exchangeable calcium, magnesium and soil reaction (pH) in 0.01M $CaCl_2$ solution.

Grid-point sampling scheme: The six spatial variability maps were produced using detailed procedures of interpolation adopted by Kathumo, 2007 as follows:

- Grid-point sampling scheme theme was made active.
- From the surface menu, 'Interpolate grid' was chosen
- On the output grid specification dialog, output grid extent was set to be the same as the study area theme. Cell size was set to 3 metres; number of rows and columns was set to 100 and 212 respectively.
- The methods was set to Spline, Z value field was set to either; Phosphorus, Total Nitrogen, Organic Carbon or soil pH depending on the map being produced and weight set to 0.01. This produced a continuous surface map of either of selected Z value field.
- Using legend editor, legend was rearranged to have dark colours for the high values and light colours for the low values. All the continuous surfaces were saved in a certain directory to be used later on in producing comparison charts.
- From the Analysis menu, 'Reclassify' was chosen to get a Re-class theme.
- In the classification dialog, column of new values, invalid ranges were changed to zeros and valid ranges to integers; 1,2,3,4.
- The Re-class theme was then converted to a shape file.
- Since the interest is the study area within the continuous surface map, then the study area was clipped using Geo-processing wizard in view menu.

- The legend was edited where grid code was selected as classification field and graduated colour chosen.
- All the above steps were followed in the production of the six spatial variability maps based-on the Grid-point sampling scheme.

3.10.3 Generation of relationship charts.

Soil fertility parameters versus yield relationship charts were produced to help in determining the major factors influencing soil fertility within the study area. The soil fertility parameters included available Phosphorus, Total Nitrogen, Organic Carbon, Calcium, Magnesium, slope and soil reaction (pH) in 0.01M $CaCl_2$ solution. Each soil fertility parameter was summarized with each of the eight factors mentioned above using the following steps as adopted by Kathumo, 2007

- One of the four factors was made active (vegetation).
- From the Analysis menu, ‘Summarize zones’ was chosen.
- From the Summarize zones dialog, the saved continuous surfaces of the four soil fertility parameters were chosen one at a time as the theme to summarize with.
- From the Summarize zones dialog, the mean was selected as to the statistic to chart.

3.10.4 Generation of soil management zones

Soil management zone maps were produced based-on Grid-point sampling scheme, the delineated soil management zones gave a range of values and was not possible to know which value to consider when making soil management decisions. The soil management zones were based on; phosphorus, total nitrogen, organic carbon or soil reaction (pH) in 0.01M $Cacl_2$

3.11. Statistical analyses

The soil samples were collected from the Kabete field station coffee farm and soil testing analysis was done at CRF laboratory, Ruiru. The data from the chemical analysis of the soil was then archived in the form of Microsoft Excel file then sorted and transferred to Microsoft excel and formatted to be loaded into SPSS Version 21 for statistical analysis.

Grid-point sampling data was then integrated into SPSS software for analysis of variances using one-way ANOVA. This was analyzed by selecting yield as dependent variable and an independent variable factor (organic carbon, phosphorus, soil pH) at a time giving 8 correlations Tables. Degree of spatial variability was tested using data for the sampling schemes. Spatial analysis was performed by calculating variogram's statistics (general variances). Soil properties (organic carbon, total nitrogen, phosphorus, soil pH, % organic Carbon and slope) were selected as data and X- Y co-ordinates as positions. This gave seven different soil properties general variances. Regression was also performed for all quantitative data in the grid-point soil-sampling scheme.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. The past and the current coffee management practices

4.1.1 Coffee varieties

There are two Coffee cultivars planted in the farm: SL.28 planted in 1938 (35.50 Ha) (76%) of total coffee area and are varieties that are disease susceptible and require costly disease control programmes to avoid a serious decline in coffee production. Ruiru 11(11.61ha), planted 1989-1995 and occupies 24% of total coffee area. This cultivar is resistant to Coffee Berry Disease (CBD) and leaf rust, the two most common diseases of economic importance in coffee in Kenya.

4.1.2 Spacing

The S.L. 28 cultivar is conventionally spaced. 2.74 x 2.74m. (9'x 9') giving 1330 trees per ha while Ruiru 11 had two spacing's: field 2a & 2b are spaced at 2mx2m giving a total population 2500 trees per hectare while Field 20 was spaced at 2mx1.5m with an alley of 2.5m x 1.5m after every 4 rows to facilitate tractor movement, giving plant population of 3,200 trees/ha.

4.1.3 Canopy management

The results showed that canopy management (pruning, change of cycle, handling and de-suckering) which form a critical agronomic activity in every coffee farm that is inclined to doing coffee business for a profit was not done as per CRF recommendations. The flower initiation was less on heavily/dense canopy than on less canopy. The tree vigour (amount of bearing wood in terms of diameter, length and increased root growth) that is built up in one season to give results in the next season was poor. The University farm has adopted capped multi-stem with1-3 bearing heads instead of four. The frequency, timing and quality of canopy management influence positively coffee yield, ease disease and pest control, and economises on quantity of inputs to be used and coverage of the tree during spraying for disease/pest control. Well maintained tree canopy ensures maintenance of crop /leaf ratio and regular cropping level in addition to avoiding die-back (Plate 4.1). Change of cycle is an important aspect of canopy management and is done on average once every five to six years in medium to high altitude areas. Kabete Field Station falls in the high altitude zone. This was not done in the study period. Therefore, management practices which prepare the tree for maximum assimilation at the time when the weather conditions are optimum for growth was not adopted. The capped multiple stem system adopted at this estate and should have 3 to 4 bearing heads instead of the 2 or 3 maintained at the estate. This is to allow for maximum productivity.

Plate 4.1: Poorly managed coffee plant exhibiting nutritional dieback.

The picture depicts lack of pruning to balance the crop/leaf ratio. In this case, the tree has more berries than leaves which are needed to support the berries.

4.1.4 Coffee nutrition

The coffee fertilization programme was mistimed and application rate was far below the CRF recommended rates of 300gms per plant per year for basic plant maintenance, especially C. Arabica which has high demand for mineral nutrients as evidenced by a decline in yield occurring under continuous cultivation of the same soil for a number of years (monoculture) without adequate fertilization(CRF: Coffee Production Recommendations,2011).The Coffee trees readily showed visual deficiency symptoms of practically all essential elements under field conditions (plate 4.2). Under poor soil fertility status, coffee trees respond fairly well to fertilizer applications.

Plate 4.2: Coffee plant showing deficiencies of nitrogen in fields 2b, 3 and 4

The highest yields in coffee may be expected only in soils which are relatively fertile and in which organic matter content is maintained at a high level and intense fertilizer programme is followed. The loss of fertility in soils, particularly tropical soils is mainly due to crop removal, erosion and leaching of plant nutrients and therefore there is need to restore fertility through fertilizer application.

A sufficient and balanced supply of labile and available nutrient elements is needed to guarantee suitable plant nutrition. The soil productivity is dependent on soil fertility as well as management practices and the factors affecting plant growth as seen from the distribution of soil analysis and yield (Table 4.16).

Fertilizer and manure are used in coffee fields to maintain the soil fertility and also as a means of raising coffee yields and thus ensuring profitability of coffee farming. It is of great importance that coffee farmers should use fertilization and manure as recommended and this is one way of ensuring economic production of coffee. Fertilizer use at the farm was far too low and mistimed. The farm applied 230Kgs of CAN (26%N) per hectare instead of the 400Kgs CAN (26%) recommended by Coffee Research Foundation (CRF Handbook: Coffee Production Recommendations, 4th Edition, 2011.p.21) which is needed to produce 1,000 kg of clean coffee (GBE). Further, there was no application of any compound fertilizer. Yet use of fertilizer compounds is an effective and economical way of supplying nutrients. Most coffee estates prefer to combine nitrogenous fertilizer with compound fertilizer.

4.1.5 Foliar fertilizer application

The farm uses more foliar than is required, perhaps to supplement ground fertilizers but foliar should not be considered an alternative to ground fertilizer. Foliar application of nutrients has proved to be useful method of supplementing ground fertilizer during dry periods when availability of soil nutrients declines. There is higher use of foliar fertilizer for non irrigated coffees.

4.1.6 Management of coffee pests and diseases

The farm has 35.5ha under SL 28 cultivar which are very susceptible to diseases. There is no evidence of any protection method being carried out at the estate against disease and pest. This means that the University farm losses substantial coffee berries to disease and pests. Control of main fungal diseases (CBD & leaf rust management) is a major concern to all coffee growers. The containment of these diseases is through use of pesticides. The estate does not employ an effective disease control programme and consequently risk suffering severe yield losses. The cost of fungicides is a major concern to everyone in the coffee industry. On a typical estate fungicide represent somewhere in the region of 40% to 50% of total variable costs (Roe and Whitaker, 1985).

4.1.7 Insect pest control

There were yield losses due to insect pest infestation at the farm. It was established that there were no application of insecticides to control berry borers (*Stephanoderes hampei* Ferr.) and antestia bugs (*Antestiopsis lineaticollis* Stal.). These are insect pests of economic importance in coffee plantations in Kenya. Insect damage lowers the quality of coffee beans in the estate. This is attributed to dense canopy of the coffee trees which provide a conducive environment for the insects to thrive.

4.1.8 Weed control

Substantial resources are allocated for the control of weeds in the estate. This happened because of delayed weed control. Weeds are an avenue for nutrient diversion and compete with coffee for available moisture. Weed competition has adverse effect on coffee yields and on bean size in Kenya (Jones and Wallis, 1963). The emphasis is on timely weed control, through cultural, mechanical and or chemical methods. Chemicals of choice should be foliar acting herbicide, and soil applied herbicides and to obtain the greatest benefit from herbicides, a system of zero or minimum tillage combined with mulching has been advocated (Outram, 1967).

The farm has often been late in controlling weeds (Plate 4.3). They mature and seed before being slashed or by use of rotavator. Beary (1981) found out that using high pressure low volume sprays of one third normal dosage of phennedipham in sugar was better than full dosage at normal pressure and volume. Therefore, low rates and volume of recommended herbicides and water can be used effectively to control annual weeds (Njoroge and Kimemia, 1991). The annual weeds must be controlled with the low rates at early stage of their development for good results to be realised,1-3 leaf stage is best. It is recommended that owing to the high presence of weed in the farm, after slashing and rotavating the first 1 inch of the top soil, the weeds are allowed to germinate and controlled at 3rd leaf stage.

Plate 4.3: KFS coffee farm under mature weeds

Plate 4.3 shows coffee tree under heavy weeds that are overgrown in the University farm. The weeds choke the coffee tree and compete for nutrients resulting in dieback of primary berry bearing branches, consequently the tree takes two more years to recover and generate the bearing branches. This results in loss of produce to the estate. The coffee cultivar in this field is SL.28 and is 83 years old (stump).The coffee trees in this had been applied with 118kgs of CAN per tree in 2011. No NPK compound fertilizer was applied. Yield realization was 1.5kgs of cherry per tree per year.

Plate 4.4: A well managed coffee trees from an adjacent coffee estate.

The coffee trees from the adjacent farm (Plate 4.4) were clean weeded and received optimal supply of CAN fertilizer (300g/tree per year), 250g of NPK compound fertilizer, once in a year and regularly changed cycle (after every 5-6 years of production) in addition to light pruning/handling(canopy management). This resulted in the farm realizing 36 kgs of cherries per tree per year in 2011.The coffee cultivar in the coffee estate is SL.28 and is aged 50 years (stump).

The coffee trees in the two instances received differing input application, resulting in differential productivity. This indicates that tree care (canopy management) and fertilization (NPK and CAN) play a key role in production and productivity of a farm. Therefore higher yields can be obtained from strong, healthy trees which have been given all essential nutrients in the right time, proportions and rates.

4.1.9 Coffee Production

Kabete field Station coffee farm has recorded a drop in coffee production, productivity and quality over a period of 15 years (Table 4.1, and 4.2). At the national level, similar trend is exhibited. The trend though is biannual, where the harvest for 1 year is good but drops in the subsequent year.

Table 4.1: 15 Year trend in coffee production at KFS compared to national level

Year	Production(MT)	National Production(MT)
1997/1998	2.4	55,634
1998/1999	41.5	68,677
1999/2000	25.4	100,850
2000/2001	37.7	50,543
2001/2002	36.7	51,895
2002/2003	25.6	55,443
2003/2004	23.2	48,431
2004/2005	17.7	45,245
2005/2006	10.0	48,835
2006/2007	21.6	54,340
2007/2008	5.6	43,000
2008/2009	35.5	54,000
2009/2010	19.3	40,000
2010/2011	11.0	36,322
2011/2012	16.2	49,960

Source: KFS coffee farm records.

There was a significant difference in coffee yield between 2007 and 2008 with p-value <0.001 and mean difference of 44066.50kgs.This could be attributed to adverse weather conditions which occurred during 2007.The Estate recorded 1089.4mm of rain compared to 944.4mm received in 2008(appendix 5).The same effect is also noticed in 2010/2011 where the farm recorded a reduction of coffee yield from 19.3 MT to 11.0 MT after rainfall record of 1322.3mm. Reduction in coffee yield in both cases was high because there were no disease and insect protective measures applied. In the following year, production shot up more than twice in every field possibly because the coffee plants had accumulated enough nutrients in the soil since there no enough berries to exert demand for nutrients.

The estate productivity in 2011/2012 stood at 0.35MT per ha compared to a potential of over 1 tonne ha-^{1}. There is a disparity with regard to fertilizer application (type and amount), fungicide usage, disease/pest control and time of application (Table 4.6). The differing application and use of these management activities ultimately led to disparities in productivity. These low yields could be attributed to low level of input usage in the farm. The critical production inputs are NPK compound fertilizers like 17:17:17, 20:10:10, and 22:6:12 and straight N fertilizers (CAN/ASN/Urea) are applied such that the whole farm receives 40% of total N requirement for maintenance and an extra 1 unit of N for every 10 kgs of tree production. In addition, regular tree canopy management through: change of cycle, pruning, handling/de-suckering and disease and pest control may improve productivity. Manure application at the onset of every inorganic fertilizer application enhances nutrient uptake and conditions the soil. There exist therefore a great potential for increasing production by adopting coffee research recommended good agricultural practices in the areas of coffee nutrition, weed control, disease control and canopy management the estate could substantially improve its performance and consequently increase the overall level of estate productivity.

At a yield of 344kg /ha of clean coffee in 2011/12, and at average prices of US $ 4.4/kg, the financial return to the University would be too low to permit the close attention which is necessary to produce coffee of competitive quality.

4.1.10 Coffee productivity

Table 4.3: Coffee productivity (GBE) per field (MT/ha)

Field	F2A	F20	F7	F1
Age	**22 Years**		**83 Years**	
Variety	**Ruiru 11(MT/Ha)**		**SL 28 (MT/Ha)**	
2011/2012	**0.409**	**1.231**	**0.113**	**0.288**
2010/2011	**0.004**	**0.471**	**0.284**	**0.538**
2009/2010	**0.477**	**0.601**	**0.292**	**0.166**
2008/2009	**0.927**	**2.971**	**0.998**	**1.027**
2007/2008	**0.109**	**0.778**	**0.085**	**0.310**
2006/2007	**0.352**	**2.113**	**0.551**	**0.497**
2005/2006	**0.758**	**0.673**	**0.237**	**0.139**

It is noted that there exist significant differences between the fields, in production per unit area, for example, the highest significant mean difference of 904.3 kg/ha (p= 0.000) was between field 20 and 7. Whereas field 7 had an average yield of 0.113 MT/Ha in 2011/2012, Field 20 had 1.231MT/Ha. This yield gap shows considerably that there is potential for improvement of coffee productivity in KFS. The significant yield disparities between the two fields were due to varietal differences (p=0.008). The coffee variety in field 7 is SL.28 and field 20 is Ruiru 11. The seven year average yield per tree (kg of cherry/tree) for field 7 (SL.28) was 1.83 kg (0.26kgs GBE) compared to 2.9 kgs (0.41 kgs GBE) per tree. This shows that Ruiru 11variety 11 is a better variety to plant because their yields were higher in the two fields (field 20 and 2a) studied. This probably due to disease resistance associated with Ruiru 11 variety. The yields from the SL. varieties were likely to have been affected by disease as seen from the assessment coffee quality from the farm.

4.1.11 Coffee quality

From the Sensory evaluation (organo-leptic assessment) performed by trained qualified liquorers on the Kabete field station coffee delivered to the mills, it was noted that the quality had declined in the farm over the years. Coffee quality is a combination of production level and is linked to bean size, lack of defects and availability as and when required, physical characteristics/attributes and the price biochemical compounds and organo-leptic quality (Leroy et al., 2006). It should be noted that each consumer market or country may define its own organo-leptic qualities; at the consumer level: coffee quality deals with price, taste and flavour, effects on health and alertness, geographical origin, environmental and sociological aspects. Whereas Kenya had classes 1 and 2 in the 1990s, this class has disappeared in the coffee qualities of the farm. These are the classes that fetch more prices per unit measure (Table 4.4) and are sought after by the market. There is increase in poor grades. As observed earlier, there were no protection measures against disease and pest practiced at the farm. This has resulted in detection in the sensory quality analysis the presence of several diseased beans, insect damaged beans, and antestia bug (*Antestiopsis lineaticollis* Stal.) damaged beans which have greatly affected the cup quality. Most of the estate's coffees were in class 3 minus (-) to class 5 have been recorded and no class 1 or 2 (Table 4.4). The coffee was considered slightly light in body and flavour when cupped. This could be so considering that a large percentage of the premium grades of low quantities and increasing lower grades from AB towards C. The class obtained is reflective of the farm's agronomic practices, processing and prevailing storage conditions. The low quality of the clean beans could be attributed to mixed medium sized beans resulting from poor grading of beans during harvesting and processing. Reason could be as a result of low N application. Poor drying/uneven drying was due to faulty factory processing. There were coated beans indicative of water stress conditions, overbearing and nutrient deficiency. This could have arisen from weed competition for nutrients with the coffee plant. There were several diseased and insect damaged beans reflecting lack of protective fungicidal applications.

Table 4.4: Class performance in the farm

Estate Coffee Class Performance(%) trend						
Year	**Classes**					
	1 -2	**3 - 4**	**5 - 6**	**7 - 10**	**buni**	
2011/12	0	33	27	2	38	100
2010/11	0	53	19	1	27	100
2009/10	0	33	32	3	32	100
2008/09	0	53	32	0	15	100
2007/08	0	70	17	0	13	100
2006/07	0	60	6	0	34	100
2005/06	0	57	27	3	13	100

Source: own computation

Table 4.4 shows a declining trend in coffee quality over seven year period. Coffee is classified into 10 classes, where class 1 is the best while class 10 is the poorest.

Table 4.5: Percentage of coffee grades produced at the farm over 7 years

Percentage(%) coffee Grades Produced by Kabete Field Station Estate from 2005-2012							
	2005/06	**2006/07**	**2007/08**	**2008/09**	**2009/10**	**2010/11**	**2011/12**	**NCE average Price/50kg bag (US $)(2011/2012)**
AA	17.1	3.3	11.2	6.1	4.7	13.0	4.7	329.0
AB	40.1	34.0	43.2	43.0	30.7	38.0	27.5	253.6
C	16.6	20.7	24.2	26.5	24.7	14.4	18.9	198.9
T	1.3	0.9	1.5	0.8	3.0	1.2	2.2	140.8
TT	4.6	2.8	2.2	2.2	1.1	1.2	2.2	205.7
PB	3.4	0.9	3.1	2.1	1.1	3.2	1.9	250.9
E	0.2	0.1	0.1	0.0	0.0	0.1	0.0	342.3
UG1	1.3	1.7	0.7	2.1	1.1	1.1	3.7	162.2
UG2	2.1	1.5	0.6	1.7	2.0	0.6	2.3	127.2
MH	5.3	5.0	12.0	11.9	23.3	16.5	24.4	137.5
ML	7.8	29.0	1.3	3.5	8.2	10.7	13.1	95.2

Source: Computed by the author from KFS records

Table 4.5 shows a declining trend in coffee grades being produced. Coffee grading is a good indicator of coffee quality in an estate. Grading is done based on size of the bean (indicative of nutrients applied) good agricultural practices, processing, climatic conditions, altitude and soils of the farm. This decline in the grades produced at the farm could be attributed to the low input use and husbandry practices within the estate.

4.1.12 Coffee factory

Coffee processing is one of the most critical value addition activities that must be done at the farm before coffee is sent for milling and eventually to the market. This is done at the coffee factory. The equipment here must be in good working condition so as to permit quality processing and maintenance of quality from the farm. The coffee is pulped, fermented and dried to a moisture content of 10.5-11 %. The ripe cherry is selectively picked and processed the same day. It is then fermented for a period ranging from 16-24 hours (if weather is warm), to 36 hours if the weather is cold but not more 72 hours. The actual length of fermentation time or period is determined by the prevailing weather conditions. For hotter days, less time (14 -16 hrs) is taken for fermentation to be complete. The coffee factory at the University of Nairobi coffee farm, Kabete, had been erected during colonial days and is still serviceable.

The pulping unit has a set of 2-3 disc pulper, Aagaard pre-grader with a re-passer. One set is working. The other is standby because cherry output production had declined substantially. The pulping unit required spraying and adjustment of chopping knives for effective pulping. The factory has electricity for pulping coffee. Water is pumped from a river that passes through the factory.

The Fermentation tanks are not covered and require a high roof to protect fermenting coffee from re-wetting and direct light which reduces coffee quality.

The standard dimensions for a fermentation tank is 1mx1.5m. The estate's fermentation tanks conform to these dimensions but are not enough for the target volumes at peak periods.

Wet parchment drying beds/tables; No. 8 (1.5mx10m)

Parchment drying beds: No. 45 (1.5 x 22m) Effective area for drying coffee is equal to1, 245m^2 which is enough for 30,000 kilograms of cherry at a time.

4.1.13 Factory capacity calculation

1 disc of a pulper can process 1,000kg of cherry per hour, which gives 0.5 m^3 parchment volume and this corresponds to 0.6m^3 fermentation/soaking space. This needs 20m^2 drying space when the coffee layer on the Table is 2.5cm (1") and needs only 10m2 drying space when the thickness of the coffee layer is 5cm (2")

4.1.13.1 Pulping

As stated earlier, a well-set disc pulper which has a good even feed to all sections, can, without damage to the beans, process 1,000 kg of cherry per hour. Thus a 3 disc pulper can process 3000kgs of cherry per hour. When processing 5 days per week and 7 hours per day, then the pulper capacity of a 3 disc factory is 5 x 7 x 3000 = 105,000kgs cherry/week. Always make sure that the discs are well sprayed and the pulper well adjusted and maintained. Coffee should always be pulped the same day it is picked.

4.1.13.2 Fermentation

Presuming that 100,000kg of cherry has to be processed in one week and presuming this will be done in 5 days then each day the parchment of $\frac{100,000}{5} = 20,000$ kg cherry.

20,000 kg cherry will enter the fermentation tanks occupying a space of $\frac{20.000 \times 0.6}{1,000} = 12$

So for 3 discs fermentation space required is 3 x 12 = 36m^3.To speed up fermentation re-circulate the water at pulping to add extra sugars and enzymes to the fresh parchment while at the same time, increasing the temperature resulting in a faster and improved fermentation. Recirculation provision is not available in the factory but important for quality and environmental sustainability. The Coffee estate is capable of producing above one (1) tonne of clean coffee, totalling above 50 tonnes. This is equivalent to over 350,000 kgs of cherry, requiring fermentation space of 210m3. The available space at the farm is $27m^3$.

4.1.13.3 Skin drying

The most important stage in processing is the skin or wet parchment drying since here an uncontrolled fermentation can take place when drying is done too slowly resulting in low and eventual cup quality and poor colours at the raw bean stages. Assuming that the wet parchment layer is ½ inch (1.25 cm) thick, then, 40m2 skin dying area is required for 1,000kg. Thus:

$\frac{20,000 \times 40}{1,000} = 800m^2$ skin drying space is required.

When usıng the skin drying Table of 20m x 2m, $\frac{800}{40} = 20$ Tables are required.

4.1.13.4 Parchment drying

This is the most important part of the factory process and should receive the personal attention of factory manager throughout the period. This is to ensure that the correct amount wet parchment coffee is put in the drying tables for better sun drying and quality preservation.

Assuming that the thickness of the coffee layer on the drying tables will be 2.5cm (1") during 'white stage' and will be increased to 5cm (2") during "hard black" and "fully dry" stages, then the average thickness of the coffee layer is $\frac{2.5}{2} \times 5 = 3.7$ cm (1 ½ inch) throughout the drying.

Assuming the drying time is 14 days (2 weeks) then the drying area has to hold a parchment produced by the two weeks as thus

2 x 100,000 = 200,000kg cherry which will be $\frac{200,000 \times 0.5}{1.000} = 100m^3$ parchment

With an average thickness of 3.7cm the required drying area will then be

$$\frac{100 \times 100}{3.7} = 2700 \text{ m}^2$$

Or when assuming each drying table is 23m (75') long and has as effective width of 1.5m (5'),

then $$\frac{2,700}{23 \times 1.5} = 78 \text{ drying table is required}$$

4.1.14 Results of 7 year assessment of field operations at KFS

The evaluation of past and current coffee management practices at Kabete Field Station Farm, University of Nairobi was done through desk assessment of its field operations in seven year period, starting from coffee year 2005/06 to 2011/2012 period (7 years). The summary of the activities as carried out per each year are shown in Table 4.6

Table 4.6: A 7 year assessment of field operations at KFS coffee farm

Field 1

Period	Activity	Type	Rate	Application	Month	Remarks	Yield(kg) cherry
2005	**No input applied**						8,152
2006	Fertilization	CAN	118	Low rate	Marc;Feb	Timed	29,151
	Manuring	Boma	0.96t/ha	Low rate	March	mistimed	
	Foliar	Farm phoska	5.14 L/ha	1	Nov.; Sept;Dec;Dec	Low but timed	
	Weed management	R/Up	7.94 L/ha	1	February	Timed	
2007	Foliar	foliar spray	0.94L/ha	1	March	Timed,low rate	17,171
	Weed management	R/up	2.8L/ha	1	April	Late application	
2008	Mulching	Grass	adequate cover	1	June	timed light coverage	60,194
2009	Foliar	foliar spray	1.52L/ha	1	July& Sept	Timed;low rate	9,723
	Mulching	Grass	light cover	1	Jan.May;August	Timed,adequate	
2010	Fertilization	CAN	118g/tree	Low rate	May	mistimed	31,519
2011	Fertilization	CAN	118g/tree	Low rate	April	Timed	16,872
	Pruning	main	done	1	January	Timed	

Table 4.6: continued

Field 7

Period	Activity	Type	Rate /Task	Application	Month	Remarks	Yield (Kg)
2005	Fertilization	NPK	11kg/tree	Low rate	Mar/Apr	mistimed	15,613
	Foliar application	foliar spray	1.3L/ha	Low rate	September	mistimed	
2006	Fertilization	CAN	91g/tree	Low rate	March	Timing; low rate	36,278
	Manuring	Boma	0.32t/ha	Low rate	March	mistimed	
	Weed management	R/Up	5.36/ha	7	March	Late application	
2007	Manuring	Boma	1.2t/ha	Low rate	April	mistimed	5,589
	Weed management	R/up	3.3L/Ha	7	May	Late application	
2008	Manuring	Boma	1.8t/ha	Low rate	March	mistimed	65,625
	Weed management	R/Up	0.5L/ha	7	April	Late application	
2009	Manuring	Boma	0.43t/ha	Low rate	June	mistimed	19,223
	Foliar application	foliar spray	0.63L/ha	Low rate	July/Aug/Sept	Timed;low rate	
	Weed management	R/Up	1.9L/ha	7	August	Late application	
2010	No input applied to this field			7			18,731
2011	No input applied to this field						7,436

Field 2a

Period	Activity	Type	Rate /Task	Application	Month	Remarks	Yield(kg) cherry
2005	Manuring	Boma	0.9Kg/tree	Low rate	March	Untimed	27,282
2006	Fertilization	NPK	111g/tree	Low rate	April	Untimed	12,669
	Weed management	R/Up	3.4L/ha	2A	May	Late application	
2007	Weed management	R/up	3.7L/ha	2A	April	Late application	3,936
2008	Manuring	Boma	4t/ha	2A	April[& August	Untimed, low rate	33,361
2009	Fertilization	CAN	96g/tree	Low rate	June	Untimed	17,180
2010	Fertilization	CAN	26 g/tree	Low rate	May	Untimed	156
2011	Fertilization	CAN	111g/tree	Low rate	April	Timed	14,725
	Pruning	main	done	2A	February	Timed	

Field 20

Period	Activity	Type	Rate /Task	Application	Month	Remarks	Yield (kg)
2005	Fertilization	CAN	100g/tree	low rate	Mar/Apr	mistimed	13,747
2006	Fertilization	CAN	100g/tree	low rate	February	Timed	43,167
	Fertilization	Foliar feed	9.2 L/ha	High rate	September	Timed;low rate	
	Weed management	R/Up	9.76 L/ha	High rate	March	Late application	
2007	Manuring	Boma	2.1t/ha	low rate	April	untimed	15,895
	Foliar fertilizer	foliar spray	0.62L/ha	low rate	March	Timed	
2008	Manuring	Boma	4.1t/ha	low rate	May & September	Untimed,low rate	60,677
2009	Foliar fertilizer	foliar spray	1.5L/ha	low rate	September	Timed	12,266
	Weed management	R/Up	4.2L/ha		September	Late application	
2010	**No inputs applied to this field during the year**						9,625
2011	Pruning	main	done		February	Timed	25,155

The results of this assessment of past and current and current management practices of the farm, indicated that timing of input use such as herbicides, fertilizers, manure, and mulch were generally outside the recommended practices. For example NPK was often applied in April/May and none in Oct/Nov. as is expected for Kabete Field station AEZ to promote growth of the bearing wood for main cropping. Rates of inputs were frequently far below the recommended ones. Critical operations like tree training and rejuvenation (including change of cycle and major pruning) were omitted in the coffee production cycle while pest management (disease and insect) control was not carried out, though liquoring report on the coffee beans indicated insect damage. Antestia bug is a major insect pest within the farm which needs to be controlled as it reduces coffee quality by 40% (CRF).weed control was done in selected blocks and was not systematic in regard to seasonal changes. Records of farm operations do not appear in a sequential schedule and were often missing or kept in old torn files. Diagnostic methods of assessing pest status, soil fertility level, disease scoring were lacking at the period sampled in this study. Application of inputs or implementation of most operations was not exhaustive in terms of ground coverage and random. Some blocks were fertilized with CAN for instance but denied manure or NPK. Thus a complete pest control or fertilizer or canopy management package implementation was avoided altogether. As a result the decline or elevation pattern of any soil fertility related attribute could not be traced across field.

4.1.15 Economics of coffee production

Coffee, being a life time crop requires substantial investment. Coffee growers or investors require realistic guidelines on calculating costs and returns to their investments, weather changes may affect production as the coffee is not irrigated. However there have been no major adverse weather effects for the last 30 years. Good knowledge of coffee physiology, agronomy and pest and disease challenges are essential to successful production. The ability of investors to process and market their green bean is essential for farm profitability.

The economics of coffee production and productivity at the farm must move from ‘customary farming’ to a ‘coffee business’ model that operates within business principles. The principle aim is to re-orient the coffee bushes at KFS towards yield increases, not planted areas. In Kenyan coffee estates, production can be classified into three levels depending on the level of investment employed: low, medium and high management. In order to demonstrate how this farm can strategize to improve its profits, an attempt is made to propose a model showing costs of production and profits per tonne at various levels of production and at various prices of clean coffee(Table 4.7). This is to show that coffee farming is profitable if the right management strategies are used.

Table 4.7: Return analysis for coffee estates sector in Kenya, 2012-2013.

	Low Mgt	Medium Mgt	High Mgt	AVERAGE SL	SL CULTIVAR	Ruiru 11
Yield (tonne of clean coffee /ha)	0.27	0.4	0.81	0.42	2	2.5
Production/ tree (kg of cherry)	1.42	2.11	4.26	2.22	10.53	7
Average price/tonne (USD/50 Kg cc)	129.32	169.6	192.92	155.45	212	212
Gross Revenue (Ksh/Hectare)	63,865.41	126,266.62	288,689.27	159,607.10	787,198.40	983,998.00
Gross Revenue (Ksh/tonne)	224,008.10	293,781.12	334,176.02	269,274.27	367,226.40	367,226.40
VARIABLE COSTS						
FERTILIZERS: C A N	4,522.00	16,252.00	27,200.00	12,980.42	13,443.64	11,875.00
N.P.K 17:17:17	9,310.00	18,620.00	23,310.00	15,207.12	9,177.00	13,125.00
MANURE	19,950.00	29,940.00	39,900.00	27,283.53	26,600.00	12,500.00
FUNGICIDES: Copper:Green copper	20,020.00	10,010.00	40,040.00	20,837.82	10,450.00	0
Tank Mixtures: Organic-Green copper	0	5,933.13	11,866.25	4,359.07	5,280.00	0
Organic-Daconil	0	3,370.40	3,370.40	1,788.33	3,370.40	
Organic-Delan	0	0	7,920.00	1,616.47	7,920.00	
INSECTICIDE: Sumithion	5,625.00	5,625.00	5,625.00	5,625.00	2,750.00	2,500.00
HERBICIDE : Gramoxone	2,964.00	2,964.00	5,928.00	3,568.95	1,800.00	1,400.00
LABOUR:						
Hand weeding	9,975.00	6,650.00	9,975.00	8,889.39	2,660.00	2,659.57
Canopy Management:-:Prunning	8,250.00	16,500.00	16,500.00	12,627.45	3,325.00	5,555.56
Handling & Desuckering	7,500.00	7,500.00	22,500.00	10,561.50	5,911.11	10,000.00
Fertilizer Application	1,105.00	1,370.00	1,657.50	1,304.29	670.32	920
Fungicide / Insecticide Application	2,770.00	2,770.00	8,310.00	3,900.71	3,990.00	1,250.00
Herbicide application	665	665	1,330.00	800.73	295.56	295.86
Manure application	3,325.00	3,325.00	3,325.00	3,325.00	1,330.00	2,500.00
Picking :1st crop(main)	9,350.00	23,350.00	35,000.00	19,156.17	21,840.00	22,750.00
Picking :2nd crop	4,750.00	9,325.00	17,500.00	8,846.01	15,680.00	19,600.00
Cost of production/Tonne	413,838.35	409,400.31	348,954.28	387,059.83	68,246.51	42,772.40
Cost of production/ha	110,081.00	164,169.53	281,257.15	162,677.96	136,493.03	106,930.99
Net Revenue per Tonne(ksh)	-189,830.24	-115,619.19	-14,778.26	-117,785.56	298,979.89	324,454.00
Cost per kg of cherry	59.12	58.49	49.85	55.29	9.75	6.11
Gross Margin / Ha	-46,215.59	-37,902.90	7,432.12	-3,070.86	650,705.37	877,067.01
Net Revenue /Ha	-32,350.92	-26,532.03	5,202.48	-2,149.60	455,493.76	613,946.91
Production Per tree in Kgs	1.4	2.1	4.3	2.2	10.5	7
Cost per kg of cherry	59.12	58.49	49.85	55.29	9.75	6.11
Average Price per Kg of Cherry	41.96	41.96	41.96	41.96	41.96	41.96

Source: CRF, economics section 2013 with own modification

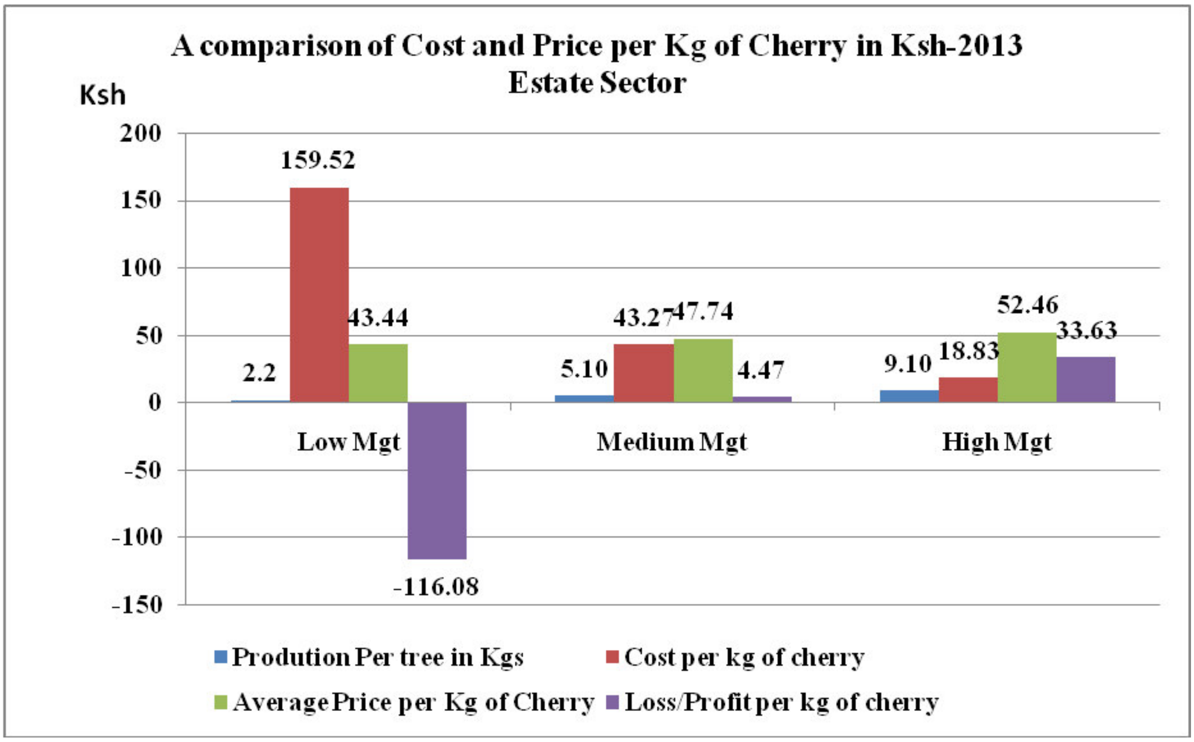

Figure 4.2: Comparison of cost and price per kg of cherry in Ksh. 2013 estate sector

On comparing input usage between Kabete Field Station coffee farm and Kamundu coffee estate (AI.0005) it showed disparities in coffee yield. It is observed that the disparities in yield could be attributed to differing management levels of individual coffee estates and level of usage of farm inputs which is at variance with CRF technical recommendations. This result agrees with what was observed by (Njagi and Kamau 1981) that there exist variance between farmers' practices and CRF technical recommendations.. It is impossible for an estate producing 1.45kgs of cherry per tree (production of the farm during 2011/2012 crop season) and at a cost of Kshs 33 per kilogram and being paid at a price of sh.38 per kg to break even. It is easier for a farmer producing 7.5kg/tree at a cost Kshs. 18 a kilogram of cherry to break even, and make some profit out of the coffee business. Kamundu coffee observed high management levels as their input use was within CRF technical recommendations, though these recommendations are blanket recommendations and not area specific.

Table 4.8: A two year comparison of cost of production in the estates subsector

Cost of Production in the Estates subsector			
Year	**2012**	**2013**	**% Change**
Average Price (US$/50Kg of Clean Coffee)	169.34	166.70	-2
Average Exchange Rate	82.30	86.61	5
Average Sales revenue (Ksh/tonne)	287,886.15	288,759.74	0
Less Deductions:			
Statutory deductions	11,515.45	11,713.44	2
Marketing Charge	4,137.12	5,082.00	23
Milling Charge	5,569.20	5,600.00	1
Net Income	266,664.38	266,364.30	0
Less Expenses:			
Field Expenses	67,792.86	86,771.27	28
Crop Expenses	44,525.85	57,161.28	28
Processing cost (Ksh/tonne)	54,676.95	56,897.00	4
Total cost (Ksh/tonne)	**166,995.66**	**200,829.55**	20
Gross Margin Per tonne	**99,668.72**	**65,534.75**	-34

Table 4.9: Field expenses: estate performance 2011-2012 crop year

Farms	Yield Kgs/Ha(GBE)	Field expenses per tonne of clean coffee (Ksh)	Field expenses per tonne of clean coffee (USD)
Top 25%	1,417	122,589	1,442
Average	1,190	171,175	2,014
Bottom 25 %	1,020	231,745	2,726

Table 4.10: Ideal field expenses achieved by top 25 % farms in Kenya 2011/2012

Field expenses	Field Cost/Tonne KSH	Field Cost/Tonne USD	Field Cost/Ha KSH	Field Cost/Ha USD
First Pruning	4,581	54	6,493	76
Main Pruning	4,764	56	6,752	79
Handling	4,908	58	6,957	82
Weed control	6,953	82	9,855	116
Fertilizer & soil improvement	53,816	633	76,280	898
Irrigation	17,177	202	24,347	286
Pest & disease control	28,210	331	39,985	470

Source: Tropical Farm Management Kenya Newsletter Issue 2-October 2013 p.7

Table 4.10 illustrates that expenses are higher when yield per unit area are low and serves as a guide to possible range of production costs a farm manager can operate in.

Within a well managed estate the cost of producing coffee varies from Ksh.231, 745 (2,726 US$) to Ksh.122, 589 (1,442 US$) per tonne taking a production range of between 1,020kgs to 1,417 kg per ha.

The cost of producing a tonne of coffee varies with the location of the estate and with intensity of production. Increased productivity per unit area of land means that one is producing a tonne of coffee more / cheaply than a farmer with lower productivity level of less than a tonne coffee per hectare of yield achieved.

The cost of coffee production and profitability is dependent on many factors such as the amount of farm input used and market prices of the inputs. Therefore it is imperative to aim at maximizing (optimizing) the coffee output, thereby reducing the cost per unit of coffee produced (Table 4.10). Record keeping is important in coffee business at the farm level for, calculation of production costs and profitability.

Economic fertilizer application in coffee is best applied based on a thorough knowledge of the nutrients status of the soil and the tree requirements of these nutrients. This is achieved through chemical analysis of the soil and coffee leaf tissue.

Supplementation of the natural nitrogen reservoir by application of N fertilizer is usually necessary where high yields are the goal. This is particularly so, as the N levels are often very low in the main coffee soils in Kenya (Pereira and Jones, 1954). Therefore fairly consistent and often economic responses have been obtained from N fertilization (Oruko, 1977). Higher frequency of application tends to increase the effectiveness of N applied at low rates possibly by reducing the amount of leaching losses. It is also apparent that the split applications may reduce the toxicity negation from imbalance effects of high rates of N applications. For instance, at a rate of 400 kg/ha N, four(4) equal applications are planned to increase yields throughout the cropping period and therefore should be practiced where very high rates of applications (which could be antagonistic when applied at once) are involved.

Kabaara (1970) observed that for the rates of N fertilizer to be effective, it must significantly increase the soil`s inorganic level. Jones et.al (1961) had earlier reported that an annual application of about 50kg/ha N represented the lowest rate at which consistent response is found and that this is the highest it is worth distributing in one application.

4.1.16 Coffee management practices: KFS and Kamundu 2011/12 crop year

In order to bench mark, for best practice, comparison of production and management practices from other similar farm in the same Agro Ecological Zone, was chosen for detailed study. Kamundu Coffee estate, AI.005, owned by Sasini Limited was chosen due to its proximity and had almost identical parameters (Table 4.11(a)).

Table 4.11(a): Farm characteristics between KFS and Kamundu coffee estate

Parameter	Kabete Field Station-FA.020	Kamundu Estate AI.005
Altitude (M.a.s.l)	1850 m	1850 m
Position(GPS)	Latitude -1.24873	Latitude : -1.13866
	Longitude 36.74217	Longitude : 36.79264
Soil Type	Humic nitisols	Humic nitisols
Agro-Ecological Zone	UM2	UM2
Annual rainfall- 3 yr average(mm)	1303.3	1452.9
Rainfall regime(single/bimodal)	Bimodal	bimodal
Area under coffee(Ha) SL 28/34	35.50	103.3
Area under coffee(Ha) Ruiru 11	11.51	16.4
Date planted	1938	1953
Spacing SL 28/34	2.74x 2.74M	2.74 x 2.74 m
No. of Trees	78,480	166,722
Flowering regimes(times of the year)	March/April,-Nov/Dec	March/April &Nov./Dec

Source: KFS and Kamundu Estate Farm Records 2012.

It is noted that the two coffee estates were within the same Agro-Ecological zones (UM2), same altitude (1850 m.a.s.l) similar soil type (humic nitisols) but slightly differing mean annual rainfall, 1303.3 and 1452.9mm respectively. Their rainfall regime is bimodal hence coffee flowering periods were similar (March/April and November-December).

Table 4.11(b): Comparison of productivity per unit area between the two farms

Parameter	Kabete Field Station-UON	Kamundu Estate -Sasini
Production- cherry(Kg)	113,681	1,258,723
Cherry per tree (kg/tree)	1.45	7.55
Green Bean Equivalent(GBE)(MT)	16 .6	180
Production-Clean(GBE) kg/ha	274	1,425

Source: KFS and Kamundu Estate Farm Records 2012.

From Table 4.11(b) it is clear that coffee productivity at Kabete Field station is low (1.45 kg/tree) or 274 kg/ha of clean weight (GBE) compared to Kamundu Estate, which produces 7.55 kg of cherry per tree, or 1,425 kgs per hectare per year of clean weight.

Table 4.11(c): Farm input usage compared

Activity	**Kabete Field Station**	**Kamundu estate**	CRF Recommendations
Soil sampling frequency	Not done	Every 2yrs	Every 2 years
Type of Fertilizer used	CAN	CAN	CAN alternate ASN
Application Rate(g/tree)	**100**	**242**	300 split into 3 appl.
Time of application(Month/s)	May	March/April, - Nov/Dec	March-April-May-Jun.
Type of Fertilizer used N.P.K	0	17:17:17;20:10:10	17:17:17,20:10:10, 16:4:12
Rate Applied (g/tree)	0	310	
Foliar applied	None	3L/ha Phamphoska/Urea	3L/ha
Foliar for flower initiation	None	Zinc,Solubor&Mg (2,3,5 kg/ha)	Boron, Zinc and phosphoric acid
Timing	None	May to December	February,March,June,August & November
Lime used (KGS)(Magmax)	Not applied	600kg/ha	As per soil test
Frequency	N/A	once a year	February

Source: Kabete and Kamundu Estate farm records 2012.

It is evident from Table 4.11(c) that application of the required farm inputs was far below that of Kamundu coffee estate. The rates were low (100g/tree) of Calcium Ammonium Nitrate (CAN) compared to 242g/tree of CAN applied by Kamundu Estate. The optimal rates (CRF) are 300g of nitrogen fertilizer. N.P.K compound fertilizer application was lacking in KFS but in Kamundu it was applied. Diagnostic soil sampling activity had not been done at KFS regularly as is done at Kamundu. Lime application was not done at KFS compared to Kamundu. Foliar feed application, especially those foliar needed for flower initiation was lacking at KFS but the case was different at Kamundu where the farm had applied 2kg/ha of

Zinc sulphate, 3kg/ha of solubor and 5kg/ha of Magnesium sulphate. These foliar feeds are applied before flowering and maintenance of flowers once initiated.

Table 4.11(d): Distribution of coffee grades obtained by each estate (2011/2012).

Percentage distribution of coffee grades obtained by each estate		
Grade distribution	Kabete Field Station (FA 0020)	Kamundu Coffee Estate (AI.005)
AA	4.7	10.76
AB	27.5	37.04
C	18.9	17.38
E	0.0	0.90
PB	1.9	3.41
TT	2.2	3.49
T	2.2	1.96
UG1	3.7	5.94
UG2	2.3	3.67

Source: Computed by the author from KFS records for 2011/2012

Table 4.11(d) shows that Kamundu coffee estate had a higher percentage (52.11 %) of the premium grades (AA, AB, PB, E,) than KFS (34.1%).The Table also shows that more of KFS coffee was in the lighter grades category (C,TT,T) (23.3 %) compared to 22.8 % of Kamundu Estate in the same category . The coffee could be light in body possibly because of nutritional deprivation at the critical expansion and filling stages in their growth cycle.

A well managed farm should have most of its coffee in Grades AA, AB and PB in descending order. These grades are considered to be the premium grades in the coffee industry as depicted in prices they fetch (Table 4.9) at Nairobi Coffee Exchange (NCE).Therefore having more of the premium grades means more returns to a farm.

4.2. Spatial variation of selected soil fertility indicators

Precision farming is an information-technology based agricultural management system that identifies, analyzes and manages site spatial and temporal variability within fields for optimum profitability and sustainability. The purpose for this study was to identify this variability within the coffee fields for better management to increase coffee production in the estate. Intensive soil sampling using grid-point sampling scheme and geo-referencing each of the sample points was done. The results of grid point soil chemical fertility parameters at the study site are shown in table 4.16.

4.2.1 Statistical analysis

To relate soil quality parameters with coffee yield in the coffee fields, factors influencing soil fertility were considered to be source of variation in the fields (soil pH, nitrogen, organic matter (carbon) phosphorus, potassium, calcium, magnesium and slope).These factors were assumed to be treatments in the analysis. Grid point sampling data in Table 4.16 was then integrated into SPSS Version 21 software for multivariate analysis of variances using one-way ANOVA. This was analyzed by selecting all factors as independent variables (organic carbon, phosphorus, soil pH) with yield as dependent variable per field at a time giving 4 ANOVA tables. Influence of age and variety on yield and soil depth was also investigated.

Soil chemical parameters were analyzed from the top and sub soil for soil reaction (pH), total N, available phosphorus, exchangeable K, Ca, and Mg. The results of the selected soil chemical properties (mean± SD) are presented in table 4.12. These results indicate significant variability in depth and across fields of chemical parameters studied. Mean Soil pH showed significant differences (p=0.08) across the fields but showed no significant difference in depth . The pH was adequate and was within the upper sufficiency limits optimal for coffee production according to Coffee Research Foundation (CRF, 2013) comparative guidelines on interpretation of soil analysis results for use in Coffee. Field 20 had the highest mean pH (5.26 ± 0.16) and field 7 had the lowest mean pH (5.05 ± 0.21). Available phosphorus (P) showed significant difference across the four fields but not in depth. It was deficient in all the four fields studied. Highest concentration was found in field 2a, at 10 ppm compared to the critical level of 20 - 100 ppm required for optimal coffee production (appendix 1a). Field 20 had the highest mean exchangeable calcium concentration (8.85 ± 2.55cmol $_{(+)}$/kg) of soil, ranging from 4.3-13.5cmol $_{(+)}$/kg. Exchangeable potassium variability was not significantly different in the four fields but was slightly elevated in field 20 and to a small extent in field 2a. Soil organic carbon and total nitrogen were significant ($p \leq 0.05$) across the fields. Exchangeable magnesium was significant at $p \leq 0.05$. All observed indicators on coffee productivity and yield were sampled randomly as explained in the methodology. However for ease of data manipulation, mean of all the soil chemical properties per field analyzed were calculated and adopted as one depth (0-30cm). Actual results from each depth are presented in appendix 11 (a) and (b). It was observed that there was variation in soil pH in F20 ranged from 91.75 to 83.3%. This was optimum and 8.3 to 16.7 % showed extremes. Similarly there was a variation from 100 - 88.2% for F7. Across all the fields, K, Ca, Mg, pH were within adequate ranges for coffee plants. Collectively, there was low Nitrogen (N) and Carbon(C) in all the fields. The most notable difference was in field F7 where N was 94.1% very low, 5.9 low and C was 82.4% low, 17.6% medium.

Table 4.12: Soil chemical properties (mean ± SD) of the studied fields

Chemical Properties	3L28(83 years)		Ruiru 11(22 yrs)		ANOVA	Comments
	Field 1	Field 7	Field 2a	Field 20		
pH ($CaCl_2$ 1:2.5)	5.1±0.18	5.05±0.21	5.10±0.18	5.26±0.16	0.010**	s
K cmol(+)/kg	1.27±0.32	1.64±0.27	1.32±0.22	1.50±0.45	0.069	Ns
Ca cmol(+)/kg	6.32±2.12	5.98±3.42	5.93±2.15	8.85±2.55	0.184	Ns
Mg cmol(+)/Kg	2.79±0.13	2.49±0.49	2.86±0.13	2.87±0.12	0.010**	s
P ppm	1.97±0.94	4.30±1.26	3.75±1.39	2.29±1.12	0.051*	s
%T N	0.24±0.02	0.24±0.02	0.26±0.03	0.24±0.02	0.015*	s
% OC	2.54±0.19	2.39±0.21	2.49±0.33	2.62±0.17	0.020*	s
C:N ratio	11±0.73	9.87±0.99	9.72±1.02	11.08±1.31	0.022*	s
Base ratio (Ca+Mg/K)	6.35±1.86	4.70±1.41	7.15±1.82	8.03±2.50	0.219	Ns
Yield(kg)	3.42±2.60	7.90±4.04	4.63±3.14	5.51±4.76	0.310	Ns
% slope	1.64±1.34	0.41±0.59	6.39±3.13	2.67±1.80	0.406	Ns

Ns = Not significant ($P > 0.05$), *$P \leq 0.05$ and **$P \leq 0.01$. Means with the same letter within a column are not significantly different according to Turkey grouping at P = 0.05 Abbreviations: TN = total nitrogen; OC=Organic carbon C: N = carbon to nitrogen ratio.

In general, there was significant relationship between the chemical properties across the four fields. In particular, Ca cmol (+)/kg and Mg cmol (+)/kg were significant at $p<0.05$. However, % O.C showed significant variation in depth(p=0.03) and across field(p=0.04). F20 had the highest pH (5.26±0.18), K (1.49±0.47); Ca (8.84±2.70), and Mg (2.87±0.18). On the other hand, F2a, pH (5.05±0.22), Mg (2.49±0.51), % C (2.39±0.27) and % slope (0.41±0.58) compared to other fields. F1 and F7 had similar pH range.

Table 4.13: Soil chemical properties as influenced by soil depth at the four fields

Site/soil depth	Avail.P (ppm)	pH	Exchangeable bases(cmolkg-1)			%TN	%O.C	C:N ratio	Ca+Mg	%Slope
			K	Ca	Mg				K	
F1	Ns	Ns	*	*	**	**	**	**	*	NS
0-15cm	2.19	5.06	1.35	5.57	2.75	0.24	2.58	10.75	6.35	1.64
15-30cm	1.75	5.14	1.19	7.07	2.84	0.23	2.49	11.06	8.36	1.64
F2A	*	Ns	*	**	**	**	**	**	*	NS
0-15cm	4.6	5.05	1.78	6.03	2.44	0.25	2.47	10.07	4.70	0.41
15-30cm	4	5.04	1.50	5.91	2.54	0.24	2.30	9.67	5.62	0.41
F7	**	Ns	**	*	**	**	**	**	**	NS
0-15cm	3.83	5.04	1.37	5.71	2.85	0.27	2.57	9.61	6.32	6.2
15-30cm	3.67	5.15	1.28	6.14	2.87	0.25	2.42	9.72	7.15	6.2
F20	*	Ns	*	*	**	**	**	**	**	NS
0-15cm	2.25	5.23	1.54	8.79	2.91	0.24	2.63	11.25	8.03	2.67
15-30cm	2.33	5.28	1.45	8.90	2.83	0.24	2.59	10.95	8.90	2.67

Ns = Not significant ($P > 0.05$), *$P \leq 0.05$ and **$P \leq 0.01$. Means with the same letter within a column are not significantly different according to Turkey grouping at $P = 0.05$. Abbreviations: TN = total nitrogen; OC=Organic carbon C: N = carbon to nitrogen ratio.

The influence of soil depth on the distribution of the chemical soil properties was assessed and was found that field 1 showed significant differences in K, Ca, Mg, TN C:N ratio and base ratio between the top and sub-soil. pH in all the fields ranged between 4.7-5.4 for top soil and is the same for sub-soil (table 4.13) which represent adequate levels on the upper limit of sufficiency. It was observed that, pH was lower in the top soil (0-15cm) than in the sub-soil (15-30cm). On average pH in field 20 was higher than all other fields (5. 23± 0.17). Organic matter though low was observed to be higher in the top soil than in the subsoil across the fields as shown by the distribution of % TN, and OC. Exchangeable potassium, available phosphorus concentration were significantly higher in the surface soil than in the subsoil, suggesting that most were held in the surface soil and that downward movement was slow. This slow downward movement may be attributed to net upward flux of soil water in the soil profile as a result of high evapo-transpiration as observed by Zeng (Zeng et al., 1999.) Potassium is similar to Phosphorus and tends to remain where it is placed when applied at agronomic rates (Anderson et al., 2010).

Coffee variety showed a significant differences (p=0.008) in yield between the fields. Ruiru 11 variety had a mean yield of 6.66 kgs per spot(0.59 kg ha^{-1}) while S.L 28 had a yield of 4.09 kg per spot(4 plants) equivalent to 0.19kg ha^{-1}. Therefore Ruiru 11 coffee variety is a better yield than S.L.28 in Kabete Field Station farm. Slope variation was significant in field 7, affecting coffee yield and soil quality parameters.

Table 4.14: Correlation analysis of soil chemical properties across the four fields

Location	Properties	pH	Kcmol(+)/kg	Cacmol(+)/kg	Mgcmol(+)/kg	Avil.P (ppm)	%TN	%C	C:N ratio	Ca+Mg/Kg
Field 1 SL 28 cultivar	pH	-								
	K	0.98*								
	Ca	0.96*	0.91							
	Mg	0.10**	0.98*	0.97*						
	P	0.88	0.95	0.74	0.874					
	%TN	0.99**	0.98*	0.95	1.00**	0.89				
	%C	0.99**	1.00**	0.951*	1.00**	0.89	0.10**			
	C:N ratio	0.99**	1.00**	0.97*	1.00**	0.86	0.998**	1.00**		
	Base ratio	0.97*	0.93	1.00**	0.98*	0.76	0.99*	0.96*	0.97**	-
Field 2A Ruiru 11	pH	1								
	K	0.99*								
	Ca	0.99**	1.00**							
	Mg	0.99**	0.98*	1.00**						
	P(ppm)	0.98*	1.00**	0.99*	0.98*					
	%TN	1.00**	0.99**	1.00**	1.00**	0.99*				
	%C	0.99**	1.00**	1.00**	1.00**	0.99**	1.00**			
	C:N	0.99**	0.99**	1.00**	1.00**	0.99*	1.00**	1.00**		
	Base ratio	0.98*	0.93	0.97*	0.98*	0.91*	0.97*	0.96*	0.97*	-
Field 7 SL 28 cultivar	pH	-								
	K	1.00**								
	Ca	0.99**	0.98*							
	Mg	1.00**	1.00**	0.99**						
	Avail.P	1.00**	1.00**	0.99**	1.00**					
	%TN	1.00**	1.00**	0.98*	1.00**	1.000**				
	%C	1.00**	0.99**	0.99**	1.00**	0.999**	1.00**			
	C:N ratio	1.000*	1.00**	0.99**	1.00**	0.998**	1.00**	1.00**		
	Base ratio	0.99*	0.99*	1.00**	0.99**	0.986**	1.00*	0.99**	0.99**	-

Field 20 Ruiru 11	pH	-								
	K	0.98*								
	Ca	0.98*	1.00**							
	Mg	1.00**	1.00**	0.99*						
	Avail.P	0.98*	0.99**	1.00**	0.98*					
	%TN	1.00**	0.99**	0.99**	1.00**	0.99**				
	%C	1.00**	1.00**	0.99**	1.00**	0.99**	1.00**			
	C:N ratio	0.99**	1.00**	1.00**	1.00**	0.99**	1.00**	1.00**		
	Base ratio	0.99*	1.00**	0.97*	0.99**	0.99*	1.00**	0.99**	0.98*	-

*Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Results of correlations between the selected soil chemical properties were found to be different among the four coffee fields (Table 4.14). This could be attributed to the differing soil management practices applied to each coffee field. Table 4.2.6 shows that the four fields did not receive similar fertilizer and manure treatments in the past 7 tears, thus affecting soil fertility status and conditions. The results show that Ca and K was significantly related to pH in field 1 ($p<0.05$). In addition, there were direct relationship between exchangeable potassium, available phosphorus, exchangeable calcium and soil pH in all fields.

Table 4.15(a): Change of soil chemical properties in field 1 over time (1970 vs 2012

Depth(cm)	%C	pH(KCL1:5)	Exchangeable Bases (m.e %)				Base ratio	Year
			Ca	Mg	K	Na		
0-16	3.62	5.60	12.80	3.05	2.85	0.40	5.56	1970
0-15	2.58	5.06 ($CaCl_{2(1:2.5)}$)	5.57	2.75	1.35	0.21	6.35	2013
16-56	-	5.40	10.80	2.25	2.30	0.30	5.67	1970
15-30	2.49	5.14	7.07	2.84	1.19	0.22	8.36	2013

Source: Nyandatt et al. 1970; Author, 2013

Table 4.15(b): Change of soil chemical properties in field 7 over time (1970 Vs 2012

Depth(cm)	%C	pH(KCL1:5)	Exchangeable Bases (m.e %)				Base ratio	Year
			Ca	Mg	K	Na		
0-20	4.44	4.90	11.20	2.85	4.05	0.35	3.47	1970
0-15	2.57	5.04($CaCl_2$1:2.5)	5.71	2.85	1.37	0.13	6.32	2013
20-66	-	4.40	4.40	Trace	1.00	0.20	4.40	1970
15-30	2.42	5.15	6.14	2.87	1.28	0.11	7.16	2013

Source: Source: Nyandatt et al. 1970; Author, 2013

1970 & 2012 analysis of soil chemical changes at Kirima Kimwe Estate (now KFS coffee farm, UoN)

Table 4.15(a), (b) compares selected soil chemical properties that had been determined in 1970 by Nyandatt et al at two of the fields covered by this study to see if any change in soil fertility properties have changed over time due human activity, given that the farm has been under coffee cultivation since then. The results showed that there had been a drop in soil fertility indicators concentrations at the farm over that period of time. In field 1, organic matter has declined by over 28.7 % in the top soil while it drops by 42.1 % in field 7 within a period of 43 years. The earth mineral cations have also featured similar decline in the same period may be due to leaching. Similarly, calcium declined .5 %, potassium by 57% but magnesium did not show much drop (10%). The fields have been under coffee cultivation for 83 years. Therefore this change in soil fertility factors could be attributed to nutrient mining without adequate compensation through fertilization.

4.2.2 Carbon to nitrogen ratio properties

When plant residues are added to the soil system, the determining factors as to whether the fresh weeds and pruning biomass will be mineralized or immobilized is the C: N ratio. Some studies have reported a C: N ratio of 25:1 to be the critical point between immobilization and mineralization (Myrold, 1998). Havlin et al.2005 indicated a range of C: N ratios from 20:1 to 30:1 resulted in no net immobilization or mineralization but C: N ratios above the critical ratios will result in net immobilization while C: N ratio smaller than the critical value will result in mineralization of soil N. The measured C: N ratio in this study ranged from 10:1 to 11:1. This ratio favours auto degradation of the generated green biomass. Net mineralization of decomposing plant residues is achieved in a C: N ratio of ≤25:1 while 25-30:1 is the equilibrium range. Above 30:1 the biomass will not decompose unless ‘loaned’ nitrogen to bring down the C: N ratio to below 25:1. The recorded current tabulated C: N ratio in the study fields ranged from 10-11. This indicates a high net mineralization capacity. This shows that application of fresh green manures in substantial quantities would release nitrogen to the coffee roots rapidly. The fresh green manures could be homogeneously blended with non woody livestock manure wastes of poultry, pig and goat manure. From the point of quenching the soil with green manure with livestock manure wastes phosphorus addition would significantly impact on the productivity of the study fields.

4.2.3 Base ratios

The ratio of (Calcium+ Magnesium) divalent cations to the mono-valent Potassium cations defines the base ratios. The optimum base ratios for coffee range between 4 and 10.The base ratios generated from the topsoil of the study fields ranged from 3.3 to 14.7 indicating a sub optimal minima and maxima levels which will require amendment to fall within the optimal range standard. Optimal base ratios define the best balance of the mineral nutrients that creates maximum synergy during uptake as a result of attaining the optimal soil molecular environment defined by pH 4.4 – 5.4 measured in 0.01M $CaCl_2$ solution. The same base ratio range optimizes uptake of all plant nutrients from macro to micro levels and facilitates better utilization of the anionic nutrients, $NH4^+$, $NO3^-$, $HPO42^-$, H2PO4 and SO_4^{2-}.

Table 4.16: Grid point results of soil chemical properties of KFS coffee farm

Grid point	**Y**	**X**	**Sample**	**pH ($CaCl_2$ 1:2.5)**	**K** cmol(+)/Kg	**Ca** cmol(+)/Kg	Mg cmol(+)/Kg	P ppm	% N	**% C**	**C:N ratio**	**Base ratio (Ca+Mg/K)**	% slope	Yield(kg)/spot
38	-1.25088	36.74482	1011	4.95	1.13	5.12	2.84	3	0.25	2.63	11	5.84	1	8.23
39	-1.25126	36.74516	1013	4.95	0.86	4.81	2.72	1	0.22	2.62	12	7.35	1	1.97
40	-1.25151	36.74561	1015	5	1.18	5.53	2.77	1	0.22	2.33	11	5.64	0.9	1.45
41	-1.25181	36.74613	1017	5.35	1.26	6.55	2.92	1	0.18	2.15	12	7.44	0.8	0.91
42	-1.25129	36.74455	1019	4.7	0.73	1.5	2.44	2	0.22	2.26	10	4.3	1	1.21
43	-1.25153	36.74501	1021	5.2	1.07	8.03	2.77	1.5	0.25	2.74	11	9.24	3.1	3.14
44	-1.25181	36.74548	1023	5.2	1.42	8.25	2.82	1	0.22	2.43	11	5.86	2.5	0.3
45	-1.25212	36.74607	1025	5.2	1.56	9.23	2.88	2	0.23	2.63	11	9.81	2	2.76
46	-1.25252	36.74564	1027	5.25	1.47	8.99	2.9	2	0.22	2.54	12	5.52	1.9	2.62
47	-1.25225	36.74513	1029	5.05	1.23	5.14	2.77	1.5	0.22	2.5	12	4.75	2	3.1
48	-1.25194	36.7446	1031	4.9	0.93	4.53	2.69	1	0.24	2.66	11	6.93	4	6.88
49	-1.25167	36.74407	1033	5.1	1.16	6.9	2.9	3.5	0.27	2.76	10	9.4	0	8.96
50	-1.25226	36.74405	1035	4.95	1.47	4.79	2.75	3	0.27	2.8	11	4.29	0	5.34
51	-1.25265	36.74449	1037	5.15	1.22	5.45	2.69	1.5	0.25	2.5	10	5.69	4.4	3.04
52	-1.25292	36.74496	1039	5.35	1.74	9.35	2.94	3	0.25	2.64	11	5.7	0	3.3
53	-1.25326	36.74553	1041	5.3	1.92	6.94	2.91	3.5	0.25	2.37	10	3.86	1.6	1.58
54	-1.2531	36.74463	1067	5.35	2.17	14.1	3.02	8	0.29	2.66	**9**	7.14	0	9.45
55	-1.25332	36.74501	1069	5.1	1.67	6.8	2.52	5	0.23	2.42	11	5.01	0	0.89
56	-1.25369	36.74548	1071	5.3	1.55	11.4	2.88	5	0.28	2.62	9	8.2	0.7	14.08
57	-1.254	36.74512	1073	4.85	1.41	2.84	2.54	5	0.23	2.54	11	3.79	-1.2	12.65
58	-1.2538	36.74464	1075	5.3	1.76	7.68	1.66	3.5	0.24	2.48	11	4.69	1.9	7.03
59	-1.25352	36.7442	1077	5.2	2.02	8.21	1.67	3.5	0.25	2.5	10	4.54	0	10.42
60	-1.25406	36.74401	1079	5.3	2.04	7.85	1.65	4	0.26	2.34	9	4	0	9.62
61	-1.25428	36.74447	1081	4.75	1.42	2.95	2.07	4.5	0.22	2.17	10	3.25	0	4.3
62	-1.25457	36.74499	1083	4.95	1.47	3.17	2.8	2.5	0.21	2.15	10	3.6	0	8
63	-1.25498	36.74463	1085	4.9	1.54	2.77	2.67	5	0.24	2.08	9	3.48	0	2.78
64	-1.25475	36.74417	1087	4.95	1.77	4.92	2.89	4	0.26	2.27	9	4.98	0	3.89
65	-1.25449	36.74363	1089	5.1	1.34	6.07	2.77	3.5	0.25	2.27	9	5.88	0	5.65
66	-1.25496	36.74339	1091	4.85	1.7	3.52	2.92	3.5	0.23	2.83	12	3.47	1	5.25
67	-1.25519	36.7438	1093	4.75	1.35	2.74	2.52	4	0.23	2.17	10	4.07	0.8	11.41
68	-1.25551	36.74438	1095	5.05	41.4	4.62	2.77	3.5	0.25	2.37	9	4.36	0.5	13.09
69	-1.24644	36.74278	1097	5.3	1.24	6.76	2.83	4	0.26	2.52	10	10.48	3	7.2

Table 4.16 continued

Grid point	**Y**	**X**	**Sample**	**pH ($CaCl_2$ 1:2.5)**	**K** cmol(+)/Kg	**Ca** cmol(+)/Kg	Mg cmol(+)/Kg	P ppm	% N	**% C**	**C:N ratio**	**Base ratio (Ca+Mg/K)**	% slope	Yield(kg)
70	-1.24682	36.74256	1099	5.3	1.43	7.98	2.99	4	0.26	2.6	10	7.65	4	4.7
71	-1.24724	36.74237	1101	5.3	1.4	10.06	2.94	5	0.3	2.93	10	9.59	4	10.58
72	-1.24753	36.74233	1103	5.2	1.72	6.78	2.93	5.5	0.31	2.93	9	5.36	2	5.84
73	-1.24798	36.74258	1105	5.2	1.58	5.28	2.86	4	0.26	2.54	10	5.42	4	12.51
74	-1.24753	36.74315	1107	4.95	1.33	4.18	2.82	5	0.26	2.42	9	6.26	4	7.7
75	-1.24715	36.74315	1109	5.0	1.36	6.27	2.73	3.5	0.27	2.38	9	8.13	3	3.71
76	-1.24656	36.74346	1111	5.3	1.63	8.65	2.94	4	0.27	2.48	9	7.58	4	1.86
77	-1.24644	36.74421	1113	5.0	1.31	4.44	2.82	5	0.26	2.38	9	6.16	10	0.79
78	-1.24691	36.74391	1115	4.85	1.08	2.7	2.67	4	0.23	2.71	12	5.02	8	3.41
79	-1.24738	36.74366	1117	5.1	1.25	6.25	2.97	4	0.26	3.16	12	7.48	4	1.99
80	-1.24788	36.74346	1119	5.05	1.39	5.84	2.93	5	0.28	2.65	9	6.02	6	4.42
81	-1.24827	36.743	1121	5.35	1.17	8.26	2.94	3.5	0.27	2.29	9	10.27	9	2.37
82	-1.2486	36.74334	1123	5.25	1.43	8.04	2.97	4	0.24	2.12	9	7.83	10	1.72
83	-1.24815	36.7437	1125	5.0	1.01	5.32	2.92	4	0.23	2.01	9	8.72	10	3.84
84	-1.24769	36.74422	1127	4.8	0.81	2.48	2.48	1	0.2	1.79	9	7.14	10	3.85
85	-1.24705	36.74449	1129	4.9	1.22	3.68	2.88	1	0.23	2.38	11	5.13	9	2.28
86	-1.24621	36.74472	1131	4.9	1.47	3.74	2.9	1	0.26	2.61	10	4.51	11	4.49
87	-1.24457	36.74255	1043	5.3	1.73	9.45	3.05	2.5	0.23	2.34	10	6.33	2.5	5.04
88	-1.24462	36.7421	1045	5.45	1.74	11.5	2.92	2.5	0.25	2.48	10	8.12	1.5	12.51
89	-1.24402	36.74202	1047	5.15	1.13	5.25	2.75	2.5	0.23	2.46	11	7.53	1.5	14.66
90	-1.24436	36.74109	1049	5.3	1.52	8.71	2.91	4.5	0.25	2.38	10	7.76	3	0.55
91	-1.2437	36.74061	1051	5.35	0.73	10.05	2.74	1	0.25	2.85	11	14.68	6	1.26
92	-1.24399	36.74006	1053	5.45	1.82	10.9	2.98	1	0.26	2.69	10	7.99	3	0.58
93	-1.24381	36.74089	1055	5.25	1.64	12.55	2.94	1.5	0.27	2.91	11	9.79	6	3.25
94	-1.24431	36.74147	1057	5.0	2.37	10.9	3.03	2	0.22	2.7	12	5.59	0	6.01
95	-1.24406	36.74222	1059	5.1	0.99	6.58	2.85	1.5	0.2	2.6	13	9.64	2	5.91
96	-1.2442	36.74071	1061	5.45	1.64	6.63	2.88	1.5	0.2	2.69	14	5.66	2.5	0.19
97	-1.24383	36.74166	1063	5.05	1.05	4.69	2.78	4	0.24	2.66	11	6.37	1	9.22
98	-1.24441	36.74202	1065	5.25	1.6	8.95	2.66	3	0.26	2.62	10	6.87	3	6.94

4.2.4 Generation of spatial variability maps of the selected chemical properties

The rocks of the farm comprise the Kabete Trachyte of the Middle Trachyte Division of Tertiary age (Saggerson, E.P. 1970). These rocks overlie the Kirichwa Valley Tuffs and the Nairobi trachyte and are in turn overlain elsewhere by the Karura and Limuru trachytes. The soils are well-drained, very deep (> 180 cm), dark red to dark reddish brown, friable clay (Gachene, 1989). These soils are stable and therefore may not have a major influence on spatial variability of soil parameters being considered. Major factors contributing to soil fertility are the kinds and quantities of the organic and inorganic constituents. These constituents impart widely differing physical and chemical properties of the soil which have an important bearing on fixation, retention and the availability of nutrients.

4.2.4.1 Soil reaction (pH)

The spatial distribution of soil pH in the coffee fields is shown in figure 4.3(a-d). The soil pH in the study area showed variability range of 4.7 to 5.5 across the four fields (figure 4.3). Coffee is reported to do well within pH range of 4.4-5.4 (Kimeu et al.1975) using $CaCl_2$ 1:2.5 method. The reason for assessing the soil pH variability in the farm was because it is known that soil pH affects availability of nutrients in the soil (Grier et al., 1989). Though these results indicate that the soil pH was mostly within the adequate range in all the fields, it could have arisen due to low usage of N-containing fertilizer and compound (NPK) fertilizers which could enhance high uptake of Calcium and Magnesium. There was little addition of H^+ ions since no ammonium ion (NH_4^+) were added into the soil in form of Calcium Ammonium Nitrate (CAN), hence none acidification of the soil in all fields. It is also likely that the uptake of Calcium (Ca), Magnesium (Mg) and Potassium (K) from the soil exchange sites was limited since no production occurred to create demand for large uptake of Ca, Mg and K. Similarly there might have been no significant net withdrawal of main nutrient Ca^{2+}, Mg^{2+}

and K^+ as there was no incentive to produce. When the plant root has to pick Ca^{++} from the soil it has to trade with 2 ions of hydrogen ($2H^+$). Thus every time an earth metallic ion (Ca^{++} Mg^{++}) is absorbed by the roots, the root acidifies from the traded ions. Hence the plantation was wasting to smaller trees leading to low nutrient extraction. Most of the pH in field1 (figure 4.3 (a)) ranged between 5.2-5.3 in the southern part of the field and drops to 4.6 towards the northern (depressed) side. This raises the possibility of water logging conditions, hence reduced conditions, lowering the pH. In all the fields, pH varied just slightly but within the optimal range for coffee production. Field 2a is largely flat and pH variation is small except towards the western side where it has gentle slope.

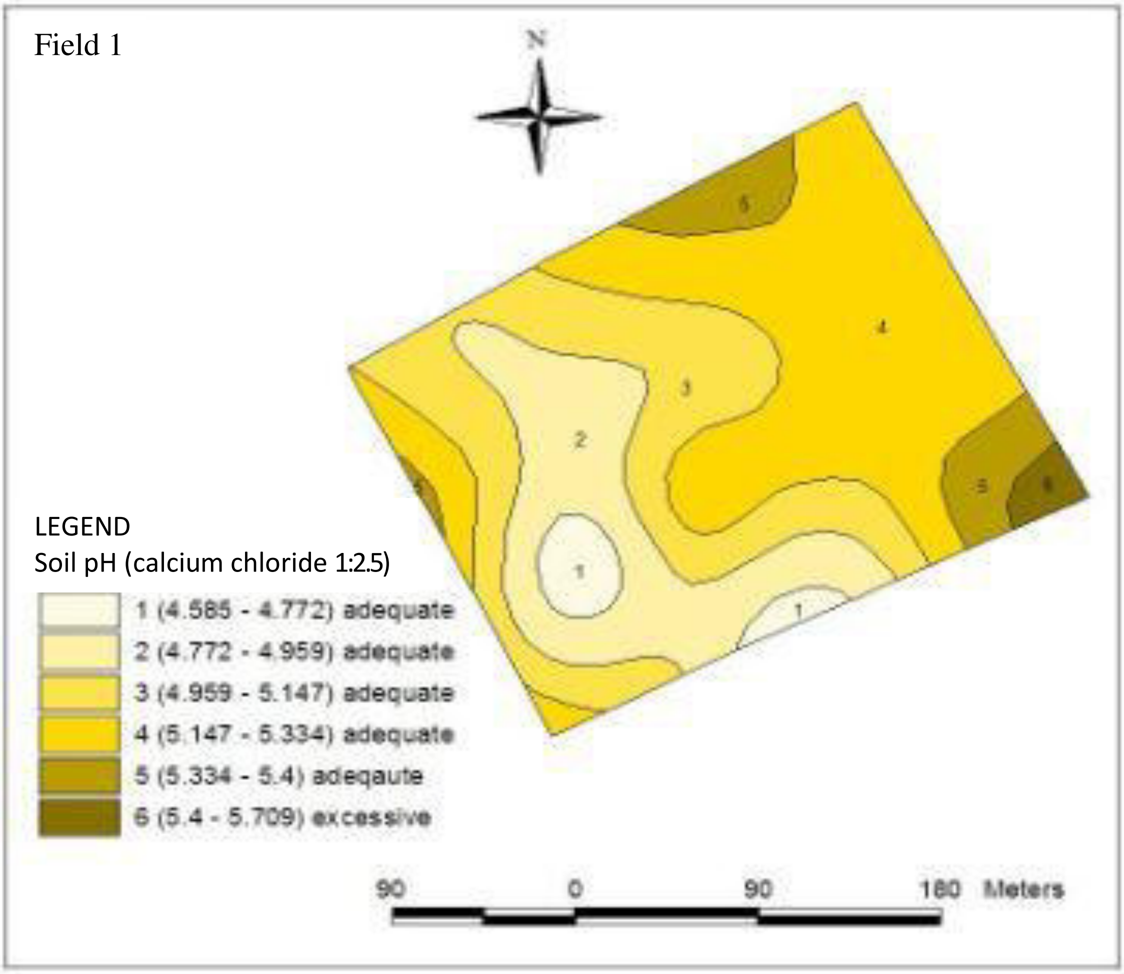

Figure 4.3(a): Spatial distribution of soil pH infield 1

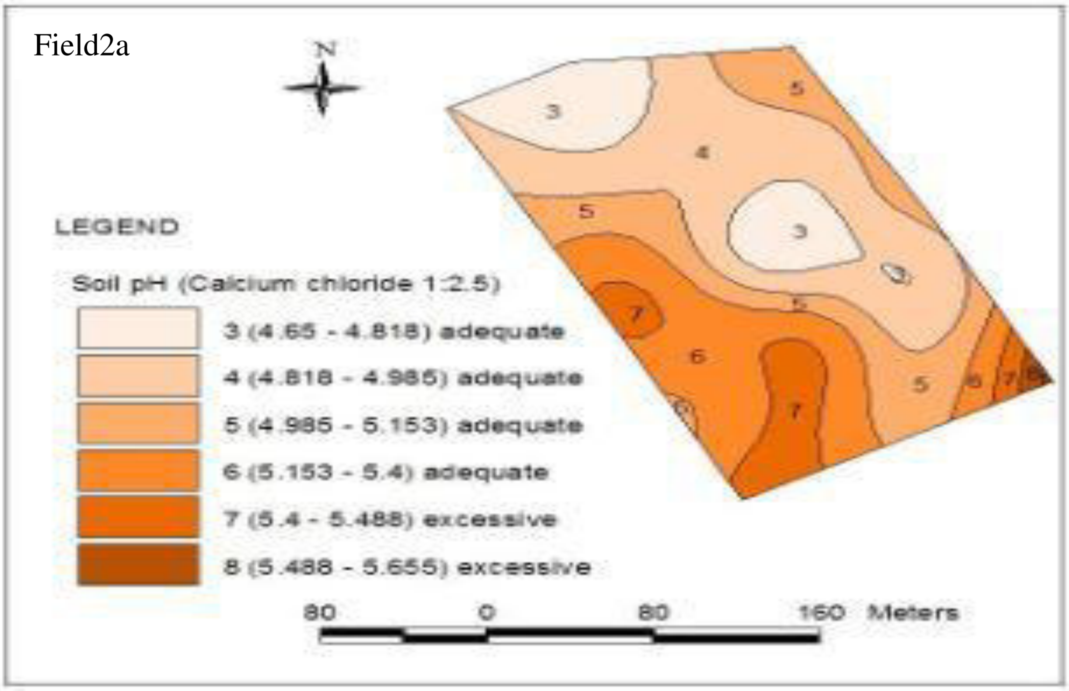

Figure 4.3(b): Spatial distribution of soil pH infield 2a

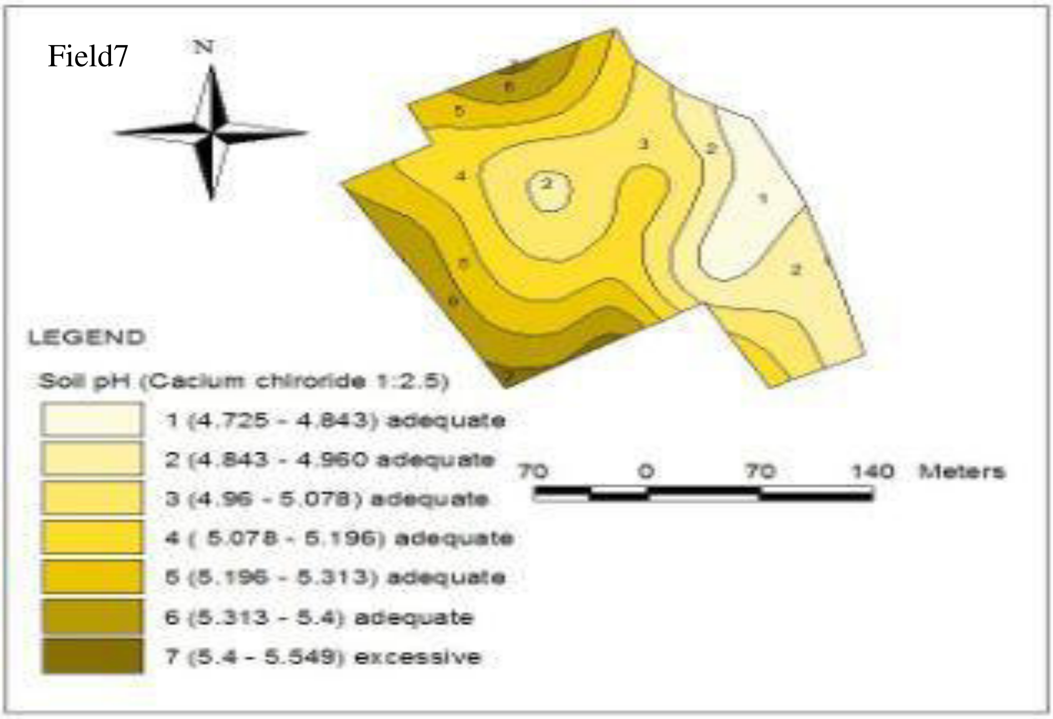

Figure 4.3(c): Spatial distribution of soil pH infield 7

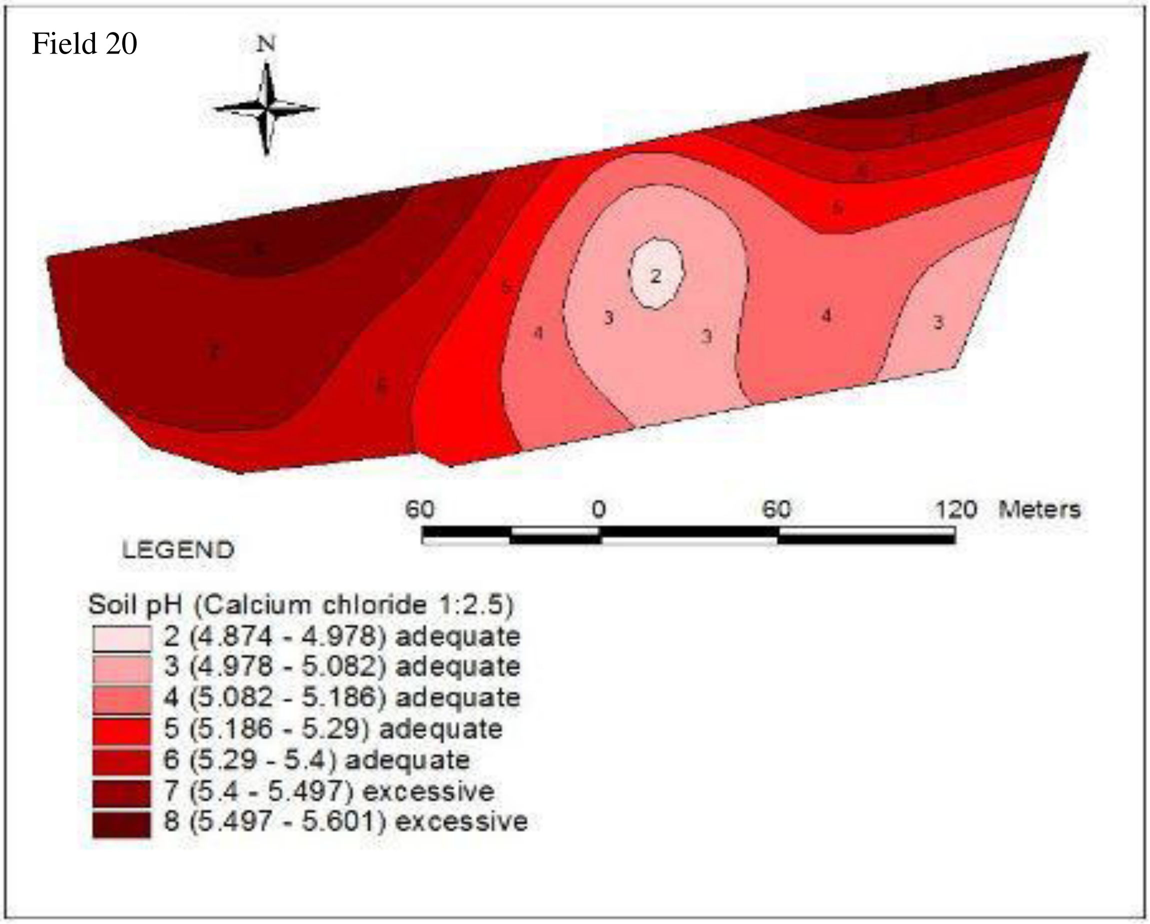

Figure 4.3(d): Spatial distribution of soil pH in field 20

4.2.4.2 Total Nitrogen

The spatial distribution of total nitrogen in the four coffee fields is shown in figure 4.4(a-d). The percentage total nitrogen was generally low to very low in all the fields (0.127 - 0.3) (figure 4.4 (a-d), compared to the soil critical level for coffee (0.3 -0.6 %) (Appendix 1 b).It is noted that in non-legume crop production system, N is the most limiting plant growth factor after water (Havlin et al.2005).This is because the majority of N present in the soil is not available to the plant. This is in conformity with the recorded low organic carbon. The decline on total N may be attributed to the effect of land use and in-field management differences. This could be related to the lower organic matter input and higher mineralization rates under cultivated conditions (Greenland and Nye, 1959; Powloson, 1980). However this parameter is not a good indicator of the nitrogen available to the plant at the period of critical need as it is highly labile and prone to leaching to deeper soil depths beyond reach of roots. The best indicator of nitrogen requirements by coffee is the crop estimates at onset of fruit expansion (post fruit set) or just after formation of pinheads. Importance of nitrogen (N) to coffee is felt during vegetative growth development of the tree. This assessment took place when coffee trees were in fruit and this may explain why the nitrogen was low.

It is has been observed that coffee trees adequately supplied with N show rapid growth, ramification of the fruit bearing branches and abundant formation of dark green leaves (Malavolta, et. al, 1962). Similarly application of Nitrogen fertilizer at the rate of 400 kg ha^{-1} to coffee increased stomatal aperture of leaves implying that N plays a role in water use by coffee(Wormer, 1965). Nitrogen has also been reported to increase the number of flowers, per node, fruiting nodes per branch and the number of fruits per tree resulting in increased yield (Montoya et al, 1961; Cannel, 1973) and the successful setting rate (Cannel, 1973). Nitrogen is easily lost from soil through various mechanisms such as ammonia volatilization; leaching and de-nitrification processes. When N application is not synchronized with coffee plant demand N losses from the soil-plant could be high. Most of the replacements done at the farm were through biomass decomposition from weeds and coffee pruning's, yet this release is still subjected to leaching. Significant differences ($p<0.05$) were observed of total N content for F1, F7 and F20. All the fields in Kabete study area were deficient in N. The non renewal (uncompensated) of mined nitrogen on the farm may have reduced soil carbon and soil N considerably. The carbon deposits to the soil through biomass accumulation and degradation have been on the decline due to the wasting tree through malnutrition. The lighter areas of figure 4.4 (a-d) indicate low level of N while the darker areas represent higher concentrations.

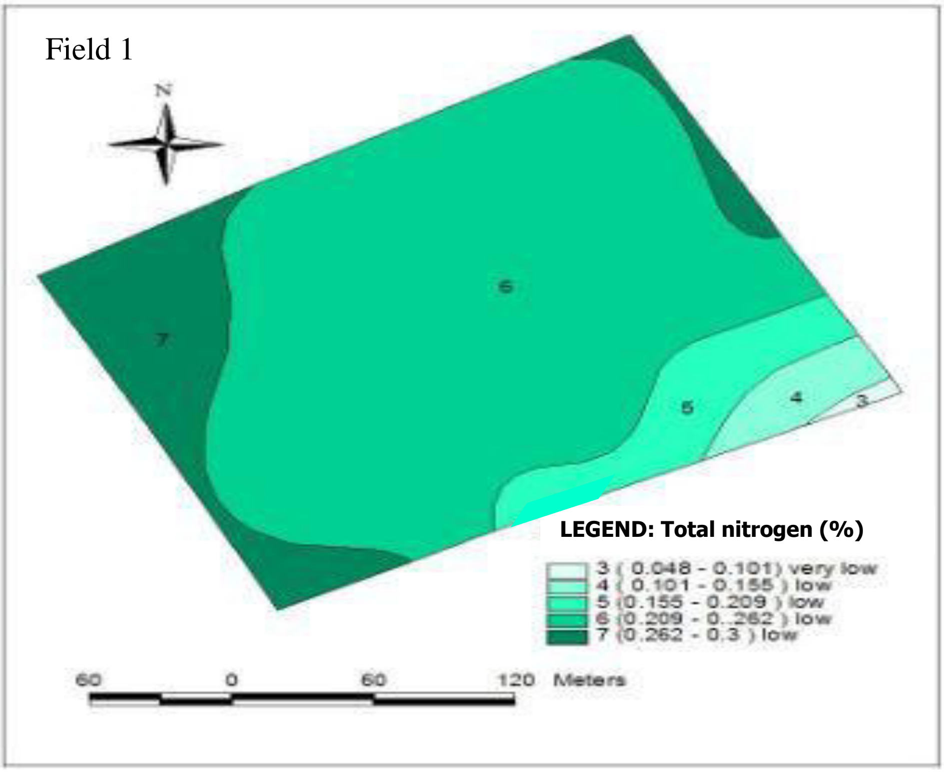

Figure 4.4(a): Spatial distribution of total nitrogen in field 1

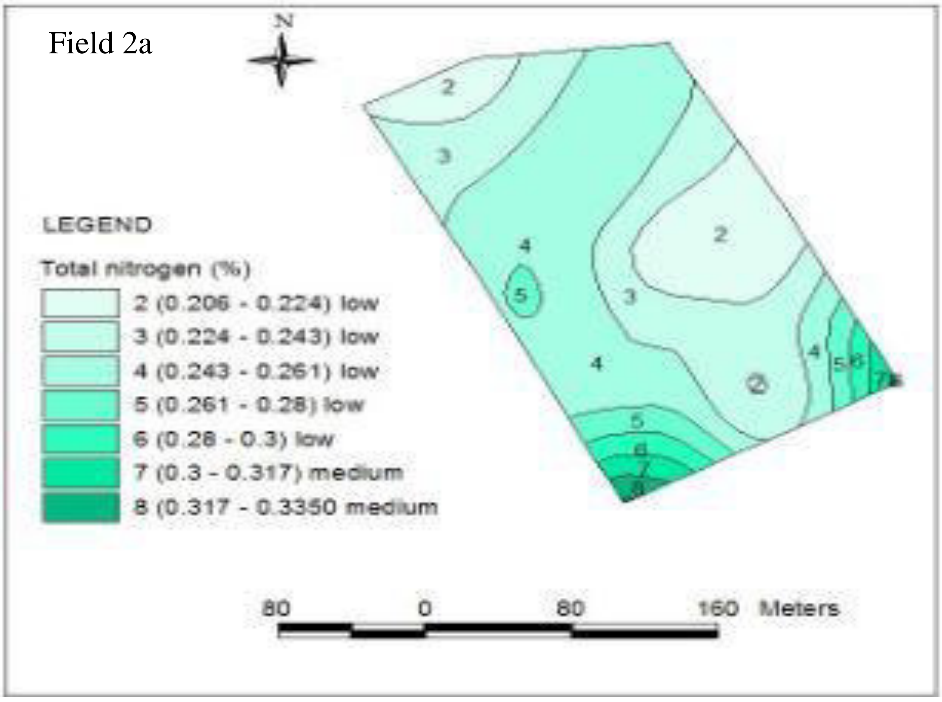

Figure 4.4(b) : Spatial distribution of total nitrogen in field 2a

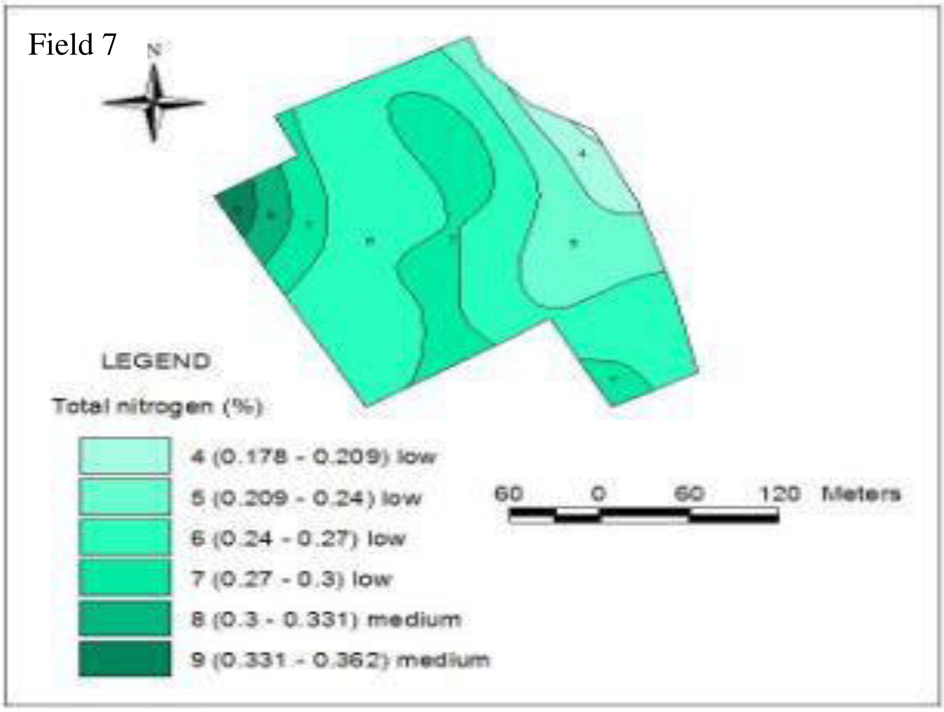

Figure 4.4(c): Spatial distribution of total nitrogen in field 7

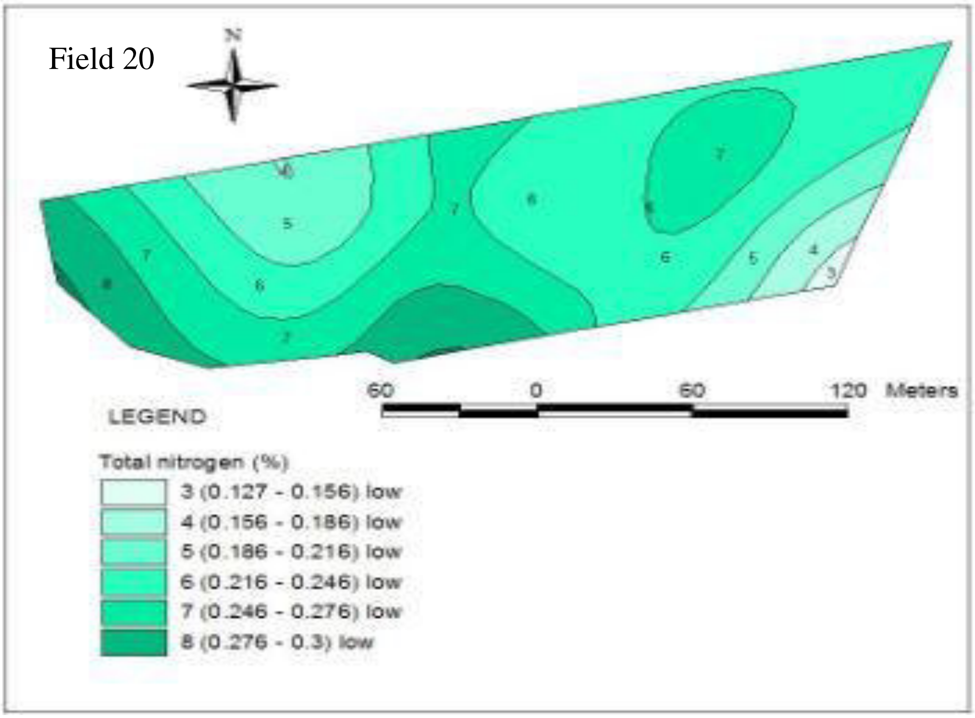

Figure 4.4(d) : Spatial distribution of total nitrogen in field 20

4.2.4.3 Available phosphorus (P)

The spatial distribution of available Phosphorus in the coffee fields is shown in figure 4.5 (a-d). The nutrient contour map shows areas of differing variability, with the lighter areas of field being low. The four fields have shown differing variability in available phosphorus but overall remain acutely deficient since it is below the threshold level of 20ppm in the soil. This critical deficiency is expected to grossly suppress yield of the coffee through the negative impact of P deficiency in bearing wood. Phosphorus is important in developing the bearing capacity of the bearing wood (primary and secondary branches). As such deficiency therefore negatively affects branch girth, length and bearing floral and vegetal nodes. Equally, the deficiency limits root development and hence the uptake capacity as well as the water uptake efficiency during drought periods.

The average P content ranged between 1-10 ppm in the soil (Figure 4.5). Higher values in the colour scale indicate more concentration of the component of fertility, in this case, phosphorus. Although there were slight variations in soil P content in the different fields of the study area and differences were significant ($p<0.05$) among all the fields, the study revealed that F1 had far less content of available P (2.188 ± 0.356) and (1.75 ± 0.281) at top and sub soil respectively compared to other fields. It is also interesting to note that there was significant difference between all the fields. The recorded low P, like nitrogen in the fields studied despite obvious differences in spatial P distribution explains the low productivity encountered in all the coffee fields sampled. The mean available P was 3.10 ppm (ranging from 1-10 ppm in all four fields. The light potion (0-4) in field 1(figure 4.5) shows the highest P deficient areas. Overall, the soils in Kabete Fields Station coffee farm are critically deficient in phosphorus. This agrees with the findings of Pereira and Jones, 1954; Keter, 1974 and Michori, 1975) that main coffee soils in Kenya are low in nitrogen and available phosphorous. Site-specific application of P will benefit the farm and ensure the right quantity is applied

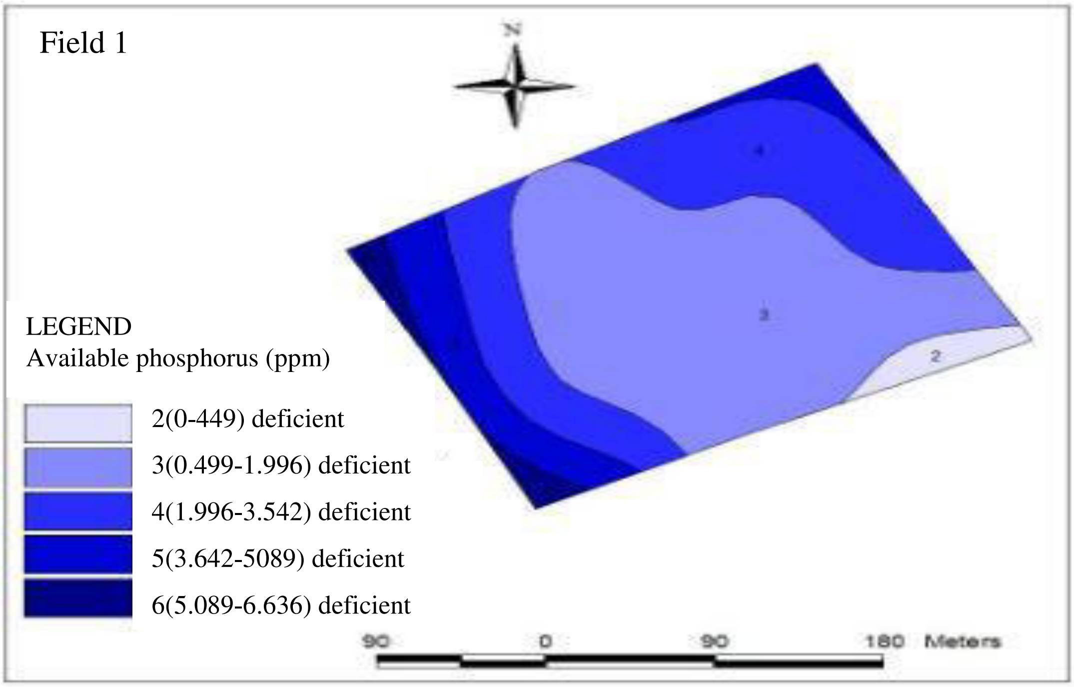

Figure 4.5(a): Spatial distribution of available phosphorus in field 1

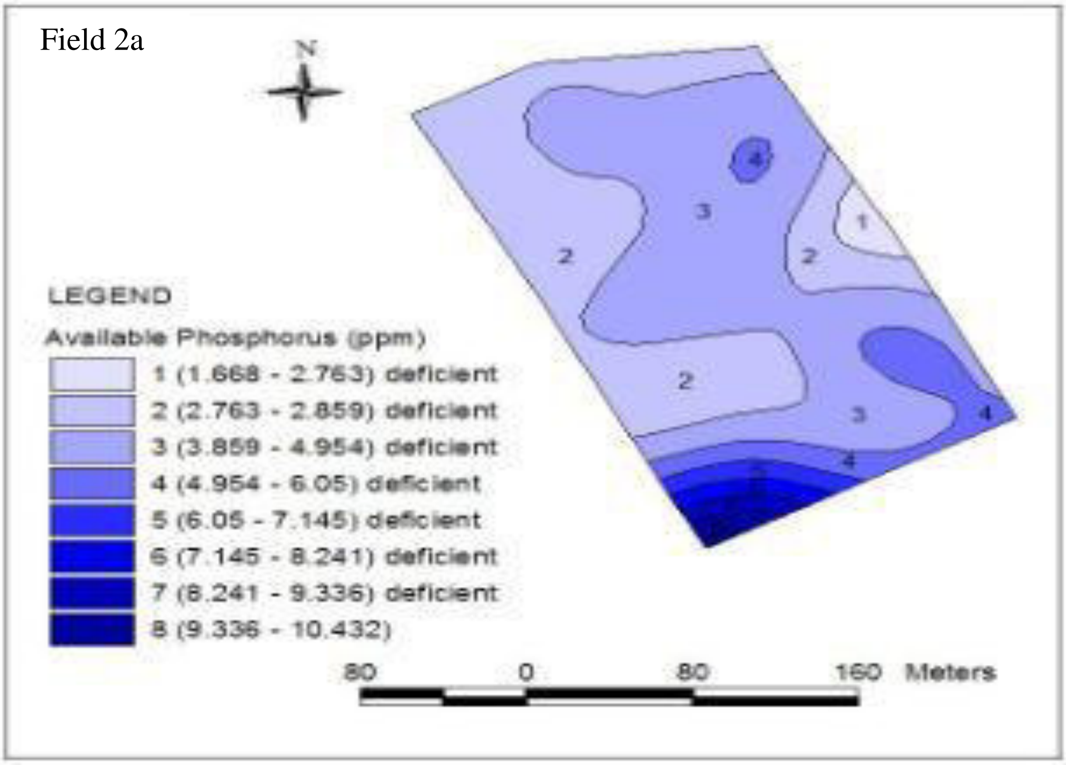

Figure 4.5(b) : Spatial distribution of available phosphorus in field 2a

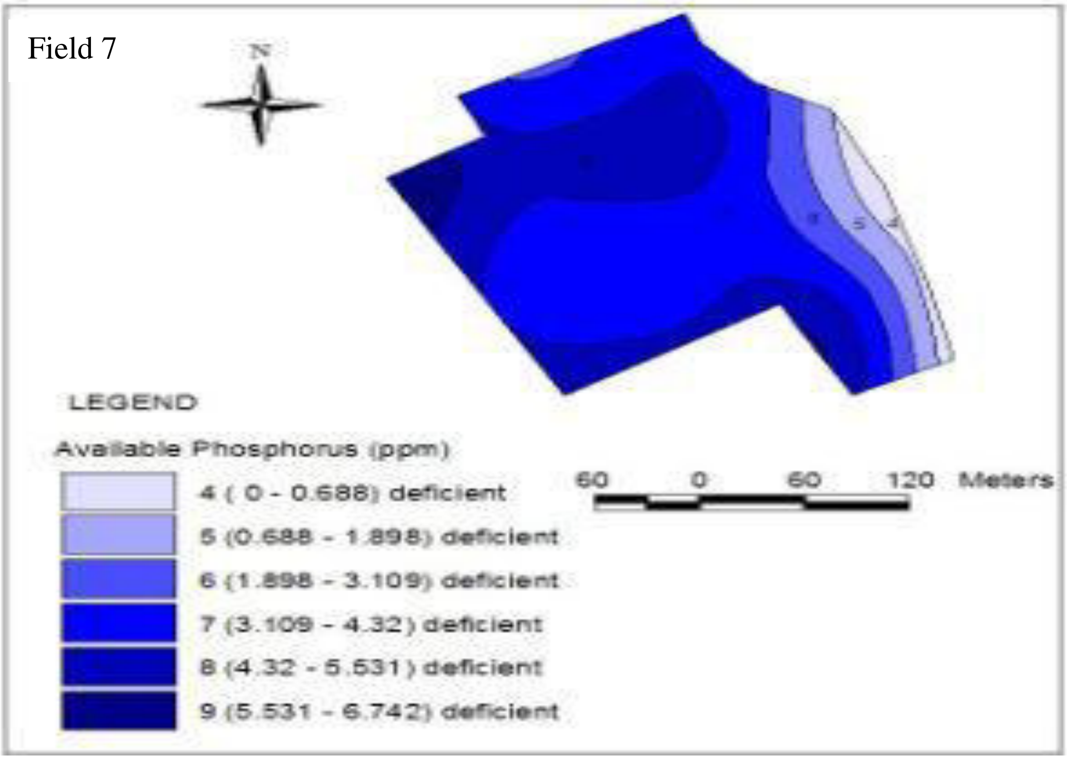

Figure 4.5(c): Spatial distribution of available phosphorus in field 7

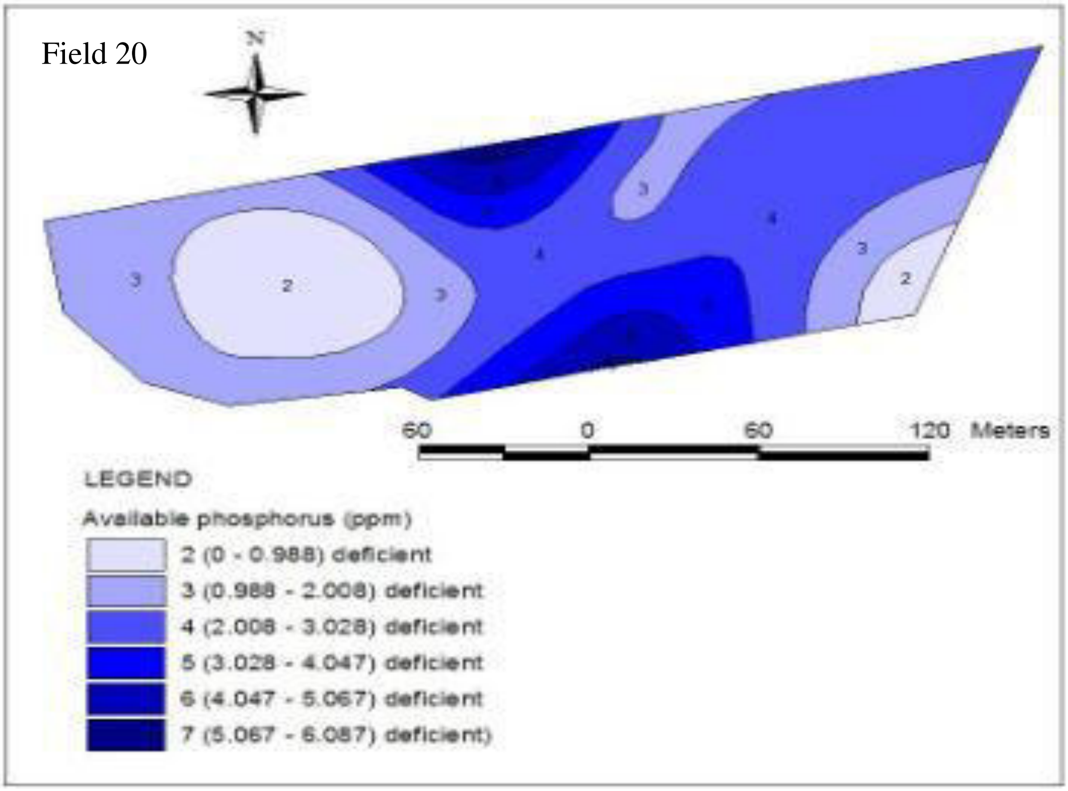

Figure 4.5(d): Spatial distribution of available phosphorus in field 20

4.2.4.4 Exchangeable potassium (K)

The spatial distribution of exchangeable potassium in the coffee fields is shown in figure 4.6(a-d).The supply of exchangeable Potassium (K) in all fields was found to be adequate to excess (F1.F2a and F20). Potassium as a major nutrient is important in enhancing photosynthetic activities in the leaf by clearing and transporting carbohydrates to storage tissues. At the same time potassium controls the evapo-transpiration by regulating the closing and opening of the stomata. Also potassium is a significant player in managing water use efficiency by the plant. Potassium promotes the bearing wood and synchronizes the maturation of floral nodes into flowers. However, the acute deficiency of phosphorus will undoubtedly compromise absorption of potassium, calcium and other mineral nutrients from the soil. The observed excessive supply of potassium, in fields 1,2a and 20 is likely to be due to this compromising effect arising from deficient phosphorus particularly in the soil. Potassium in coffee field soils was observed to be adequate despite the observation (Jessy, 2011) that K requirement and absorption is highest at the berry development stage with its peak during ripening stage. Overall, in the Kabete Field Station coffee farm, K in soil was between 0.82 and 2.5 cmol (+) kg^{-1} at top soil and sub soils in study fields. In fact K status was found to be adequate to excessive across the fields (fig 4.6a-d). Significant differences were observed in F2A and F7 while only a slight variation was found ranging from 0.8 to 2.51 at top soil and 0.62 to 2.22 cmol (+) kg^{-1} at sub soil. Low P and excess K supply could lead to depletion of soil productivity resulting to low production capacity of the farm. Potassium showed significant difference with soil depth suggesting possibilities of risks associated with soil degradation.

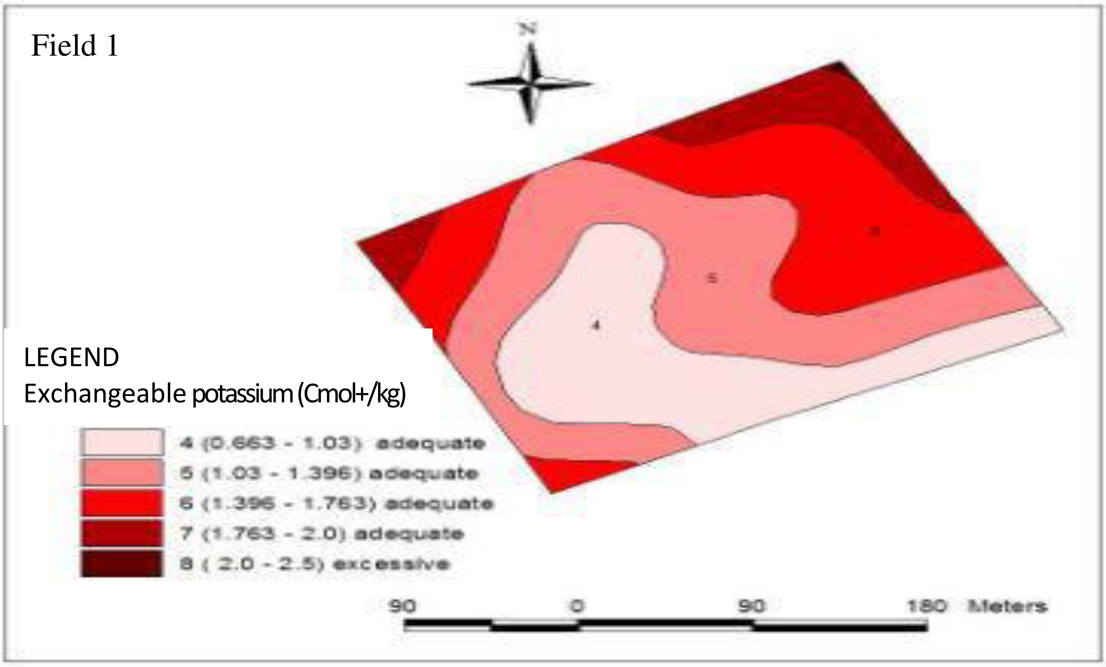

Figure 4.6(a): Spatial distribution of exchangeable potassium field 1

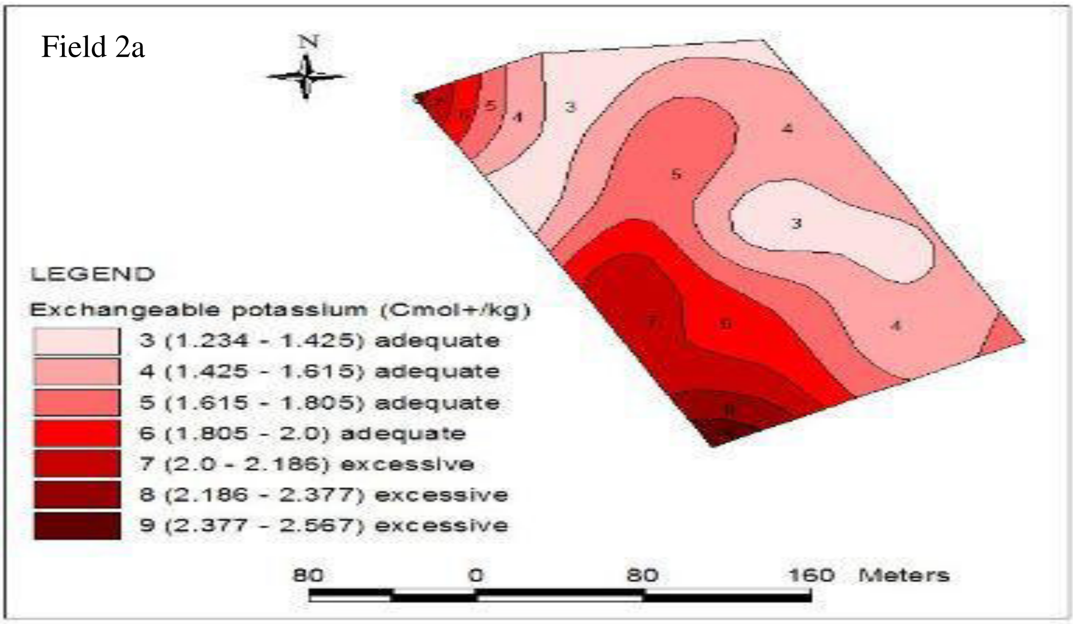

Figure 4.6(b): Spatial distribution of exchangeable potassium in field 2a

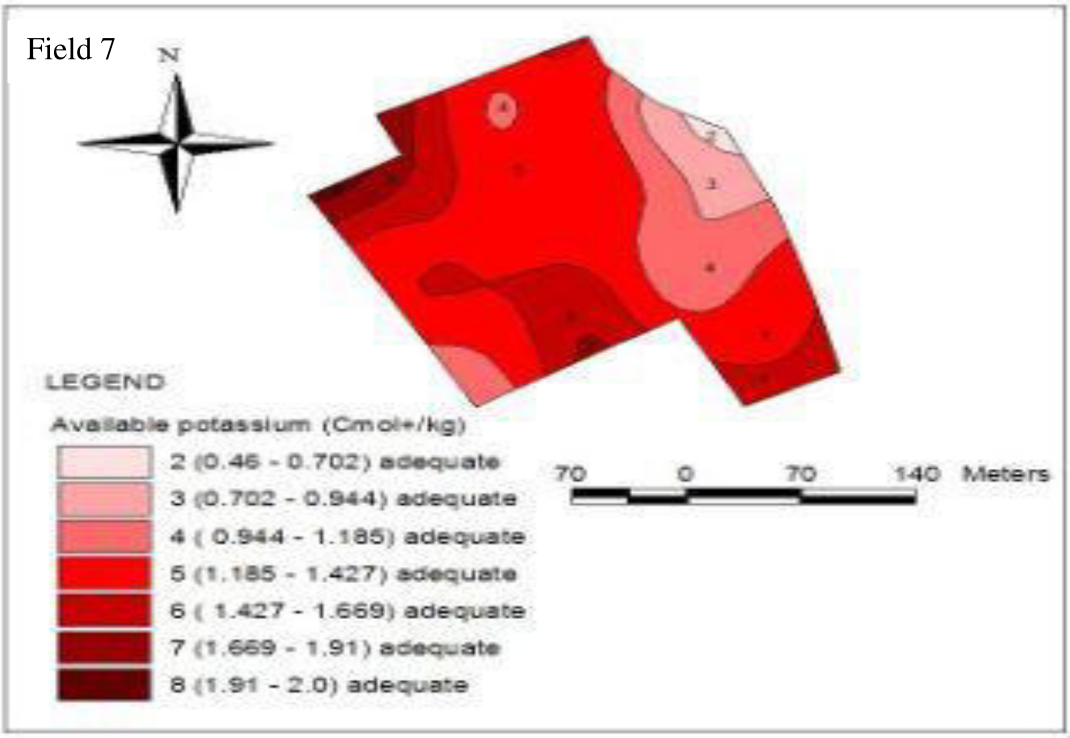

Figure 4.6(c): Spatial distribution of exchangeable potassium in field 7

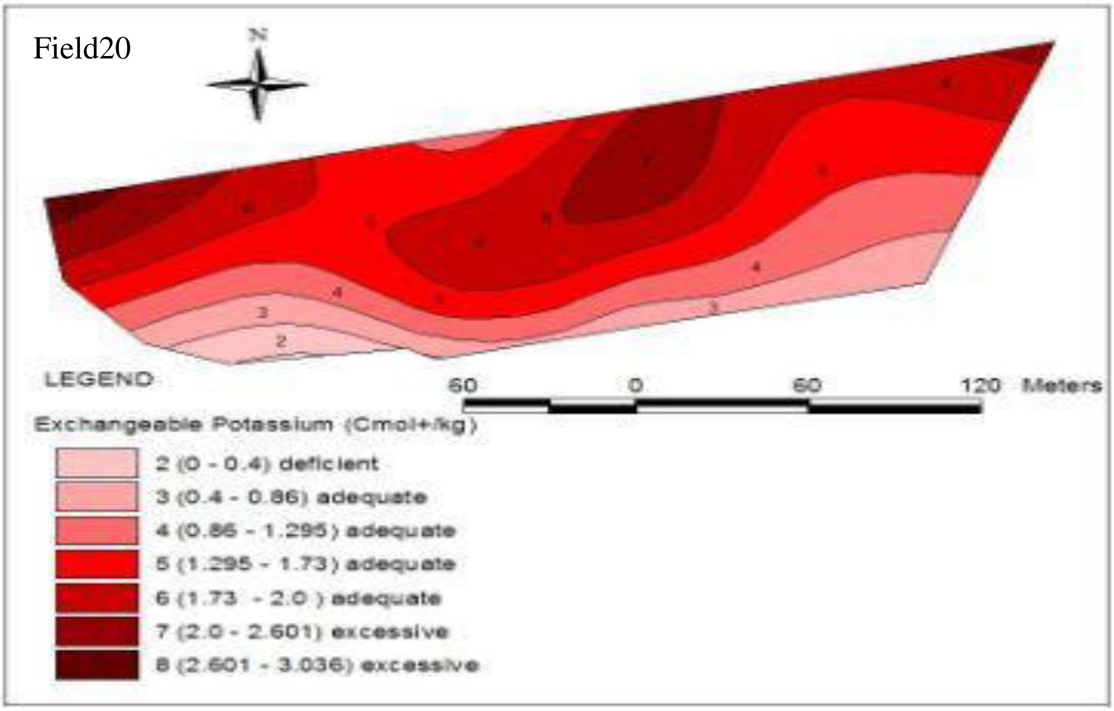

Figure 4.6(d)

Figure 4.6(d): Spatial distribution of exchangeable potassium in field 20

4.2.4.5 Exchangeable magnesium (Mg)

The spatial distribution of exchangeable magnesium in the coffee fields is shown in figure 4.7 (a-d).

The supply of exchangeable Magnesium (Mg) in the soil in the four fields indicates adequacy but with differing degree of variability. The results indicated that magnesium levels in the top 0-15cm of soil depth ranged between 1.6 and 3.1 cmol(+)kg-^{1} while at the lower depths, magnesium ranged from 1.62 to 3.05 cmol(+)kg-^{1} compared to the critical levels of 0.8 to 4.0 cmol(+)kg-^{1}. This could be due to compromised uptake by the critically deficient P in all the fields studied. Magnesium is an important macronutrient in the nutrition of flowering plants, as it is a major constituent of the chlorophyll molecule where it facilitates in trapping of the (photo) radiation from the sunlight. The actively photosynthetic radiation powers the manufacture of glucose from the photo-mediated CO_2 and H_2O combination. Magnesium is known to induce budding of roots and also regarded as an important nutrient in the process of photosynthesis and as a chlorophyll constituent. Its presence is central to photo system of the coffee leaf.

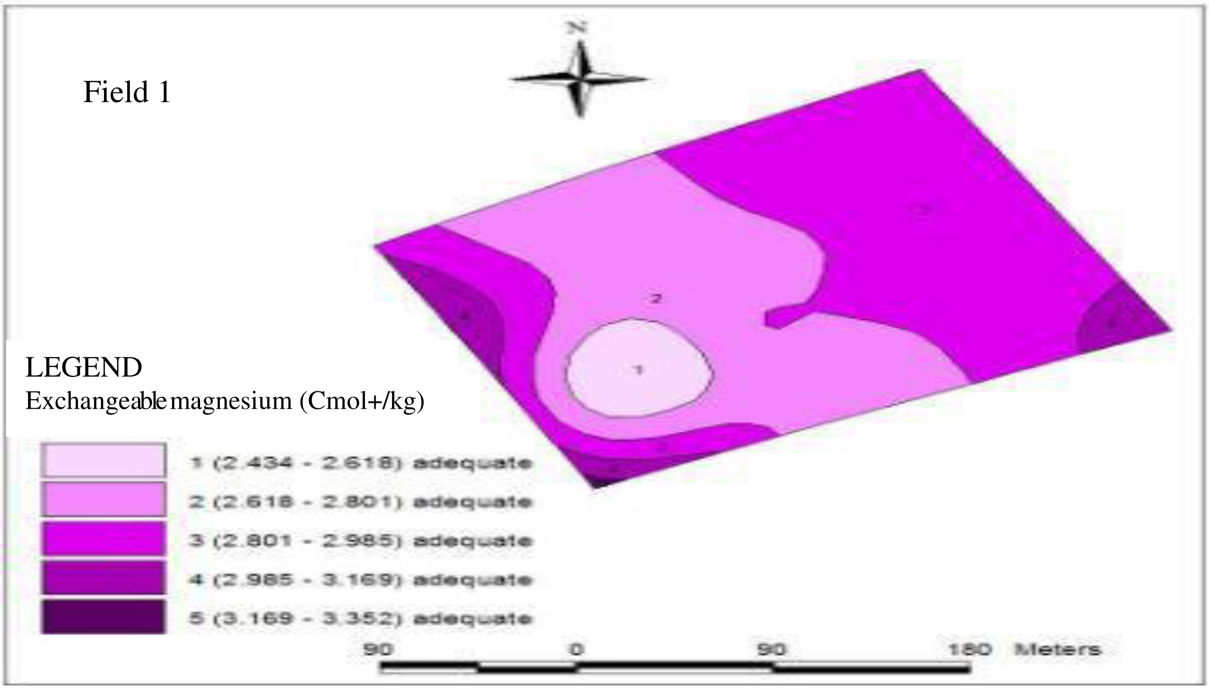

Figure 4.7(a): Spatial distribution of exchangeable magnesium in field 1

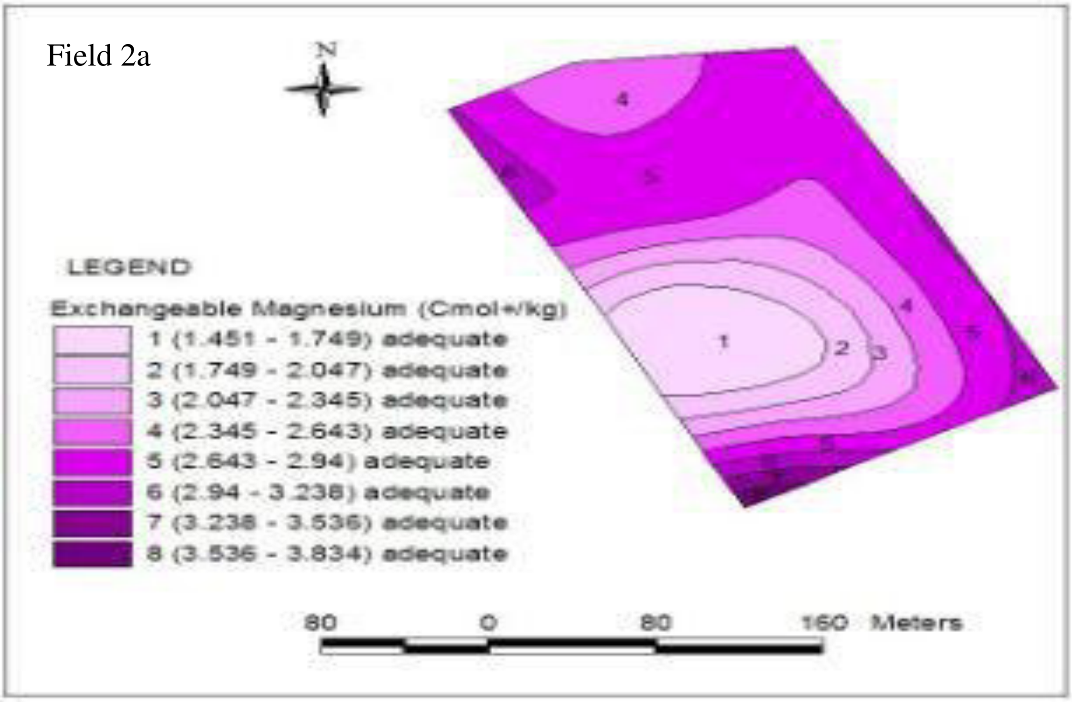

Figure 4.7(b): Spatial distribution of exchangeable magnesium in field 2a

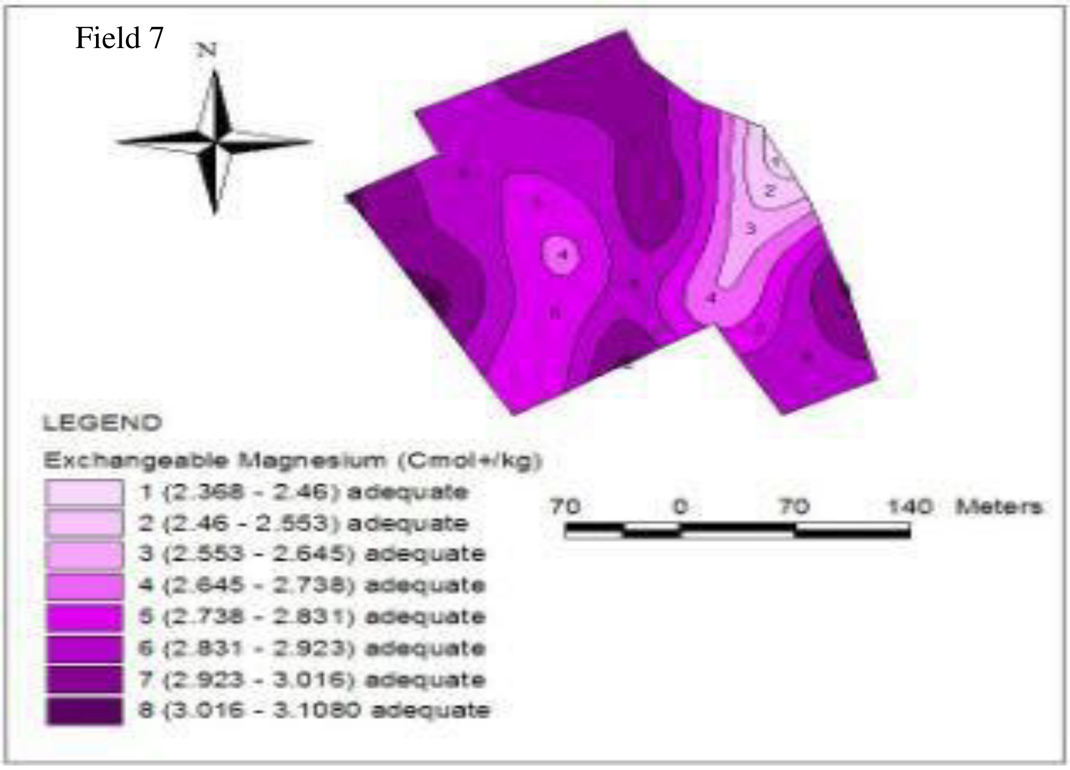

Figure 4.7(c): Spatial distribution of exchangeable magnesium in field 7

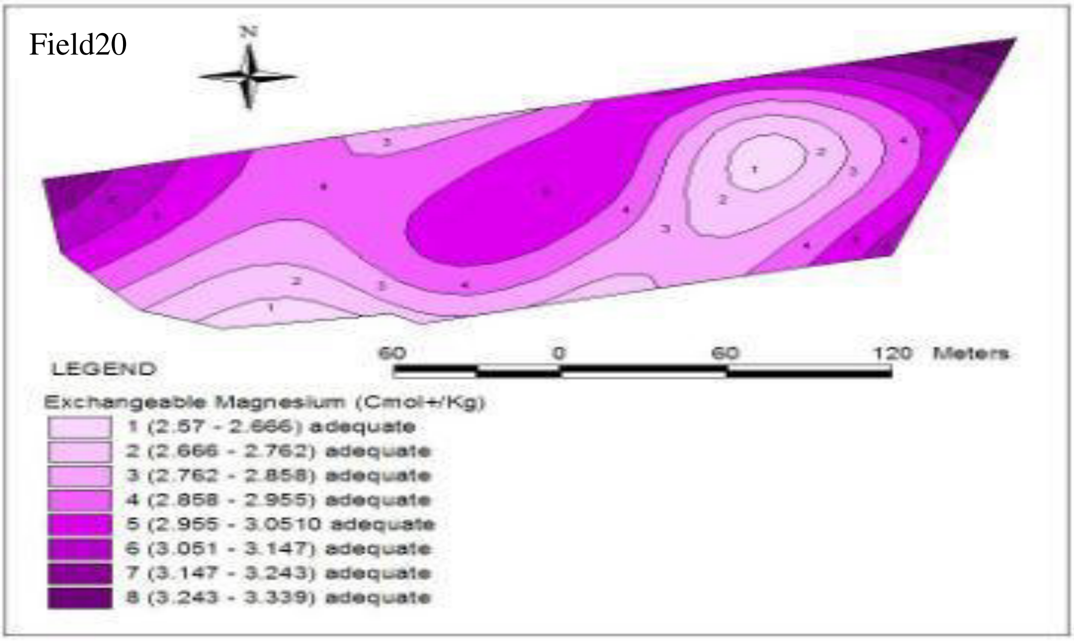

Figure 4.7(d): Spatial distribution of exchangeable magnesium in field 20

4.2.4.6 Exchangeable calcium (Ca)

The spatial distribution of exchangeable calcium in the coffee fields is shown in figure 4.8(a-d). Calcium is in adequate to excess levels (1.17 to14.1 cmol(+)kg^{-1}) compared to the critical levels (1.6 to 10.0 Cmol(+)kg-1) and so does not limit production (Fig.4.8). However,the uptake of calcium is compromised by the deficienct P levels and this means Calcium supply to the plant will be inadequate, hence the expected contribution to root mass extension and higher flowering capacity will not be achieved unless remedial Phosphorus fertilization is carried out to reach optimal P levels in the fields. Phosphorus (P) availability determines the extent to which Ca is absorbed by the roots as it provides the energy for active uptake of mineral nutrients in the soil.

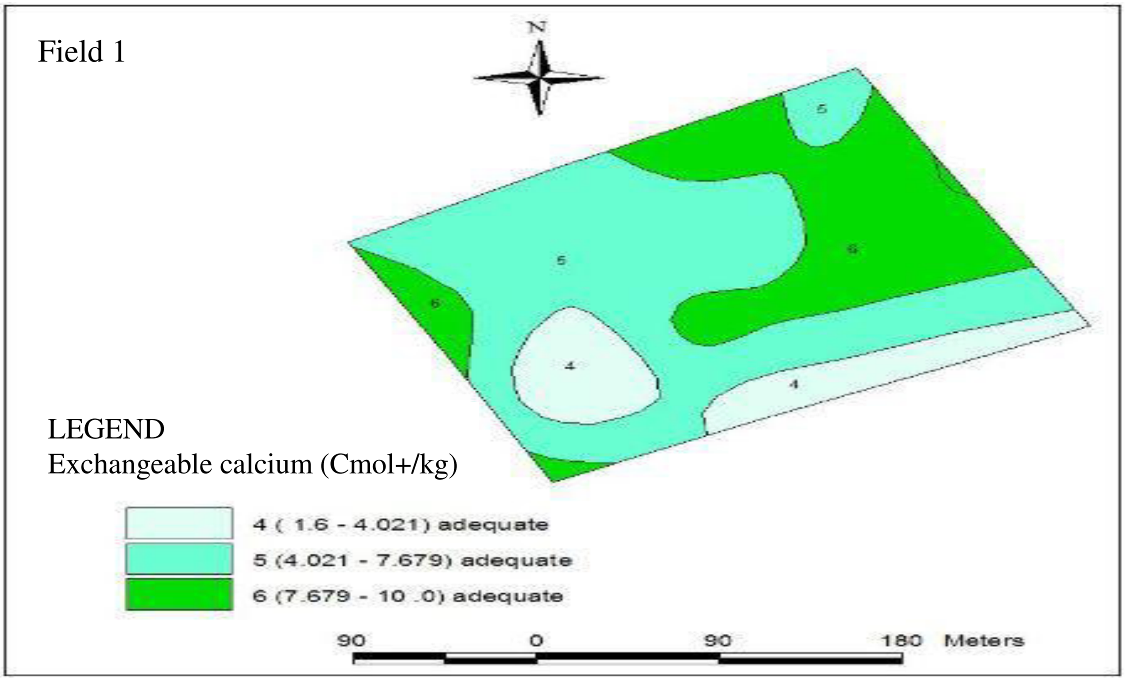

Figure 4.8(a): Spatial distribution of exchangeable calcium in field 1

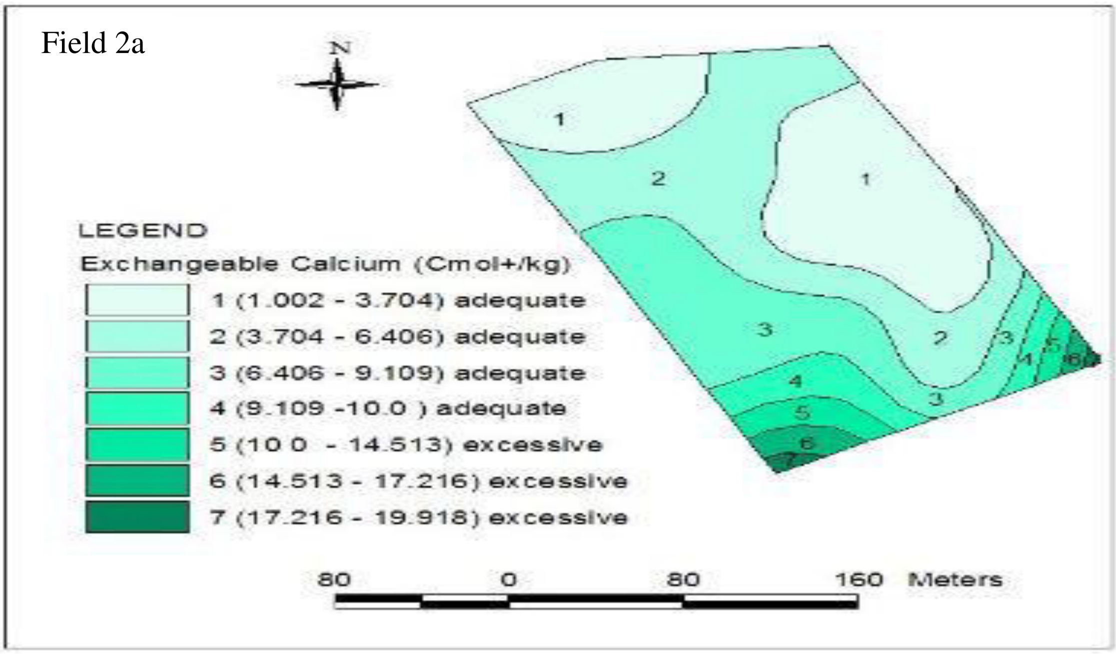

Figure 4.8(b): Spatial distribution of exchangeable calcium in field 2a

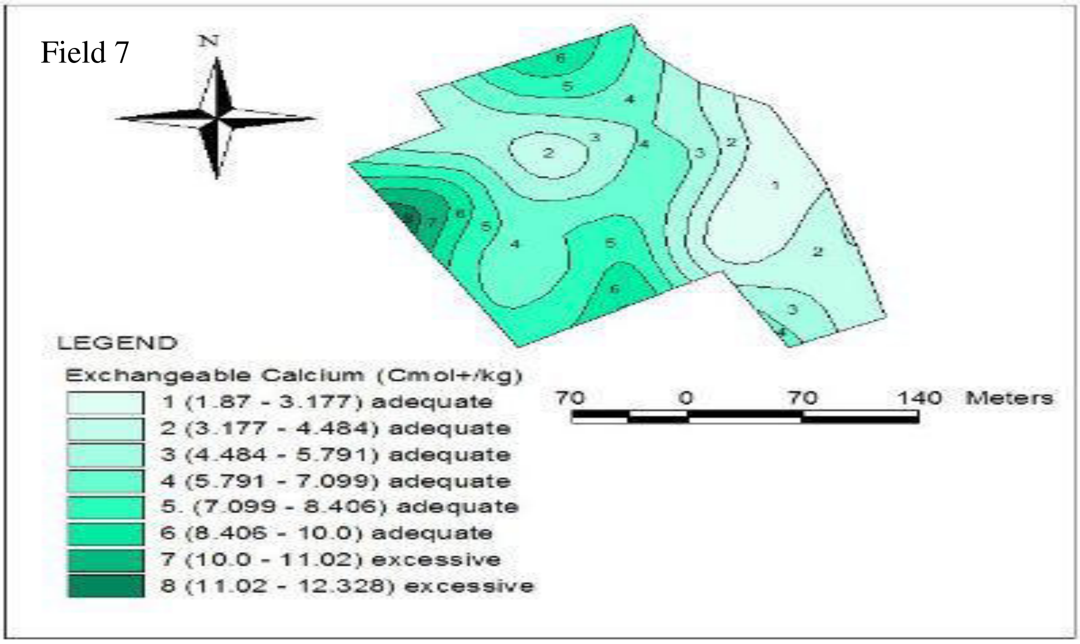

Figure 4.8(c): Spatial distribution of exchangeable calcium in field 7

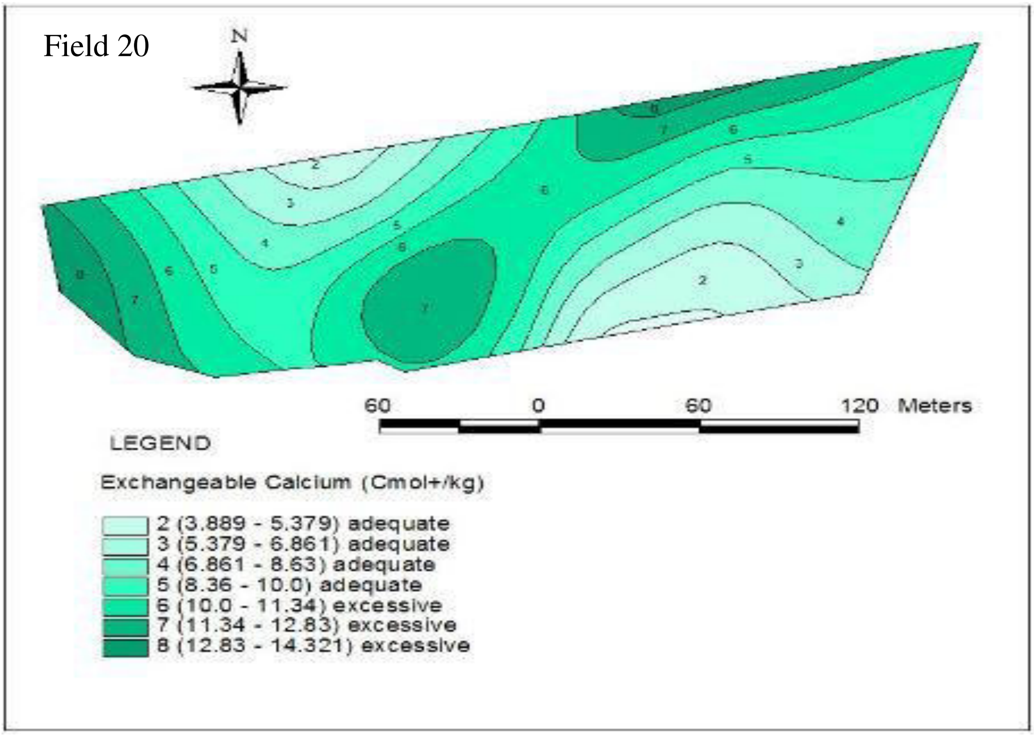

Figure 4.8(d): Spatial distribution of exchangeable calcium in field 20

4.2.4.7 Organic carbon (C)

The spatial distribution of organic carbon in the coffee fields is shown in figure 4.9(a-d). The results show generally low organic matter variability across the four fields (Fig.4.9). The low organic carbon may lower the water retention capacity of coffee soils at the fields and expose the coffee to negative drought effects when the rainy season is short. This low organic matter causes weakening soil structure hence suppressing water and air supply to the roots. Reduced organic matter content progressively reduces the population of soil micro-flora which are useful players in nutrient decomposition mineralization and absorption process. The soil organic carbon is an index of the organic matter/humus content in the soil. The humic/fulvic acids are derived from semi-anaerobic composting process of plant residues and they possess highly-negatively charged sites that give the soil high cation exchange capacity (CEC) to hold divalent and mono-valent cationic mineral nutrients (Mg^{++},$K^{+,}$ Ca^{++}). The organic matter synergizes with the clay colloids to hold large amounts of these cations and reduce their illuviation to deeper soil levels. The fluffy nature of organic matter also increasing soil water holding capacity by increasing the number of macro pores in the top and sub soil layers. Macro-pore components in the porosity of soils have a superior role in water retention by soil.

The observed low carbon (%) in all the study fields may arise from the prevailing imbalance between biomass replenishment and organic matter mineralization. The situation is controlled by the declining biomass from pruning trash and reduced weed proliferation against constant mineralization rate on the biomass balance. The fresh weeds and pruning biomass tend to auto degrade green manure when soil moisture conditions are favourable.

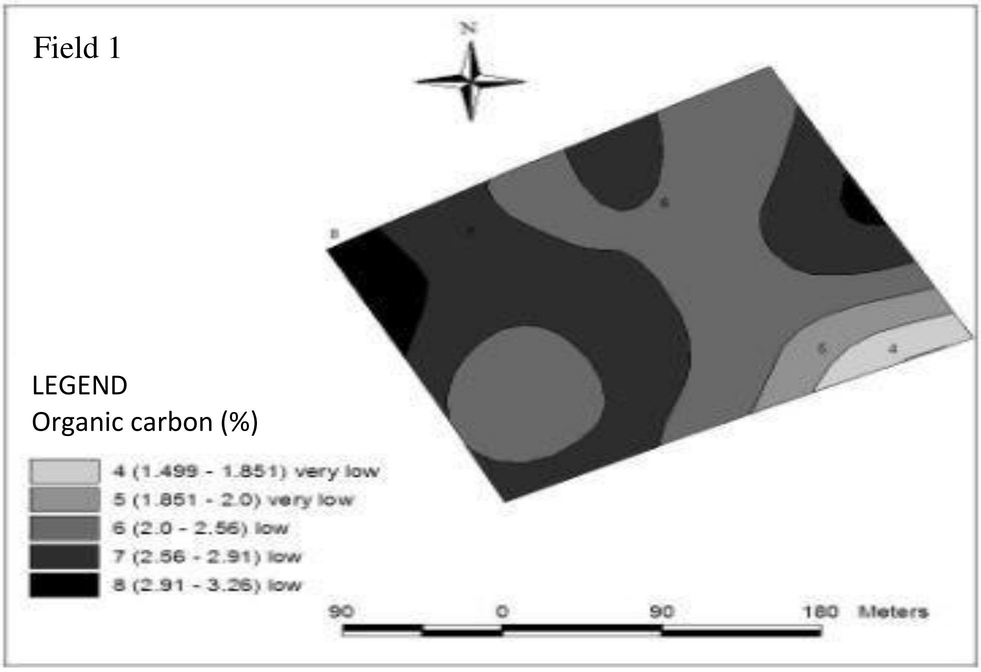

Figure 4.9(a): Spatial distribution of organic carbon in the fields 1

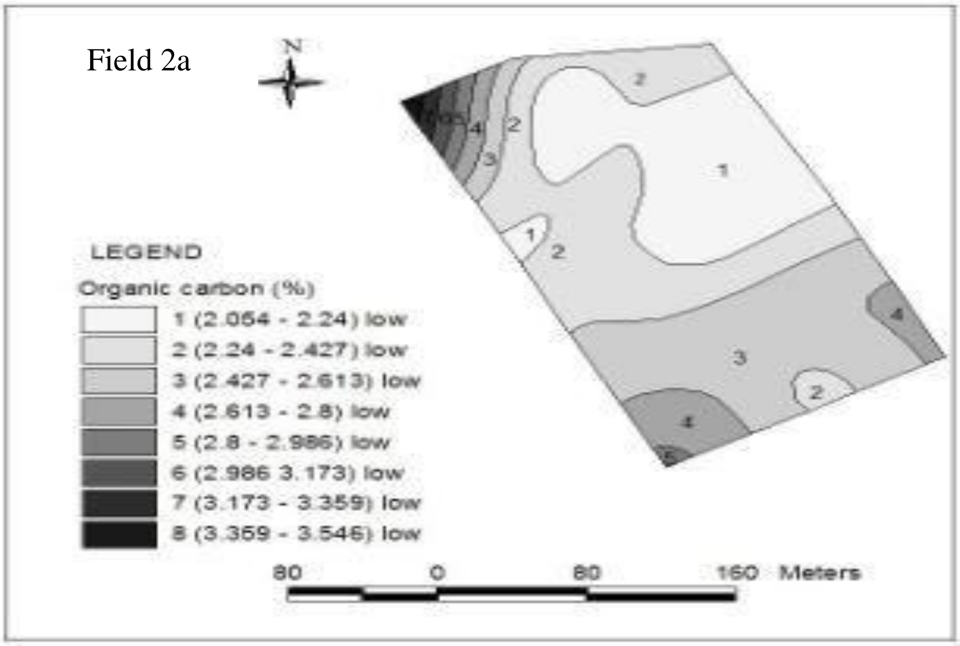

Figure 4.9(b): Spatial distribution of organic carbon in the fields 2a

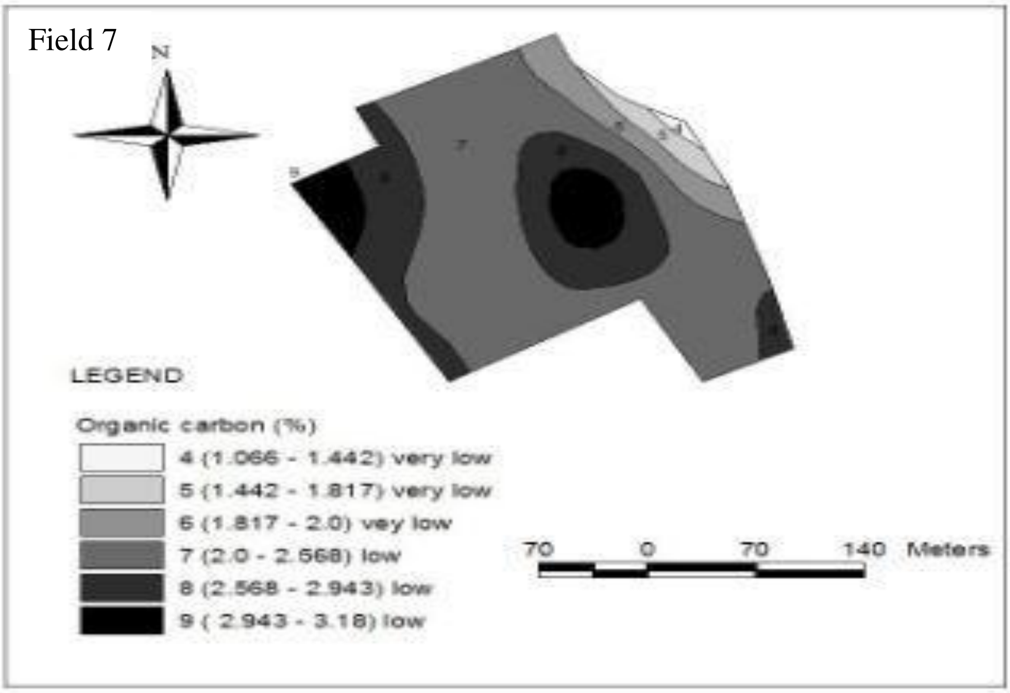

Figure 4.9(c): Spatial distribution of organic carbon in the fields 2a

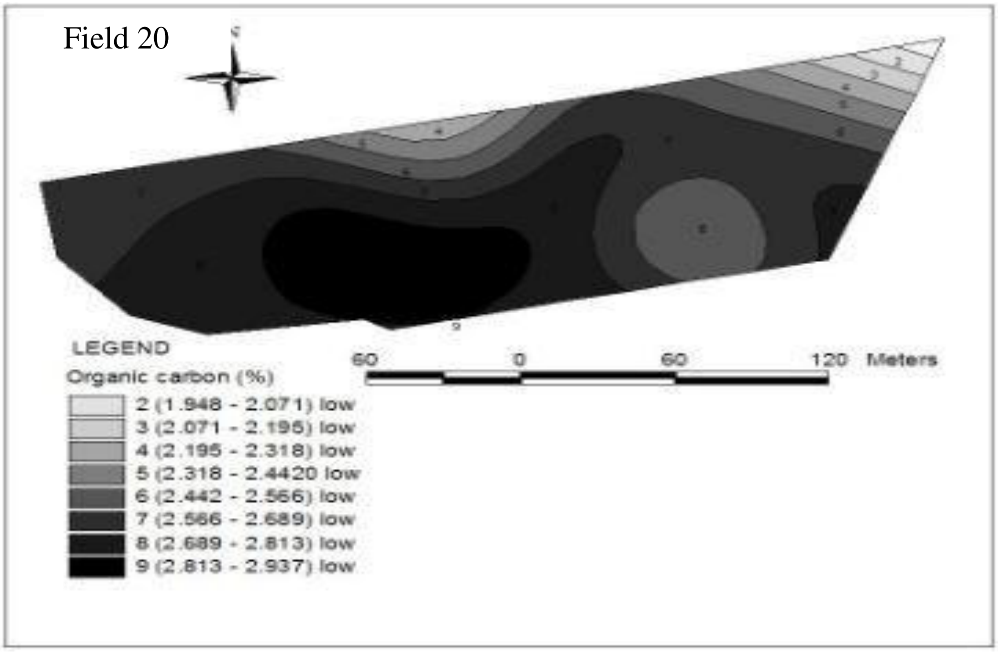

Figure 4.9(d): Spatial distribution of organic carbon in fields 20

4.2.4.8 Yields spatial variability within the fields

The spatial distribution of coffee yield in the coffee fields is shown in figure 4.10(a-d).

Figure 4.10 (a) represents field 1 in which yields are mostly concentrated along the boundaries to the north and western parts of the farm. The trees here were more healthy and robust than those towards the centre and southern section. This section of the farm was weed free during the study time. There is a depression along the centre of the farm running north-south. Yields were variable within the sampled spots of this field, reflecting degree of husbandry management applied. In field 2a, figure 4.10(b) yields are more along the boundaries where it is covered by (10kgs) per spot or 0.5 MT ha-^{1} in the western and northern side of the farm compared to 0.09 MT ha^{-1} in the southern part where land has no tree cover and towards where shade was present. The trees here were bigger and had more branches unlike those in the centre of the farm which were under heavy weeds. Competition from weeds for nutrients probably contributed to the yield decrease. Yields in field 7 fig.4.10(c) follow the topography of the farm. The farm slopes towards the eastern end. The steep slopes have low yields and this can be linked to variability of soil nutrients and moisture availability probably due to lateral erosion. In field 20, fig.4.10(c), yields were high in the flat areas, with a slope of 0-1.5%. The field is flat to gently sloping towards the north-west side. Here yields are low because the trees were under heavy weed and did not have primaries for production. In particular, it highlights the high variability of exchangeable Ca, in contrast to the low variability presented by pH. The variability that occurs in crop development and yield can be attributed to specific ecological conditions of each site, or by other factors specific to the planting material and crop management conditions that depend on the management and/or cultural aspects of the producers (Srinivasan, 2006; Leiva, 1998; Cerri et al., 2004; Jin and Jiang, 2002; Leiva, 2006).

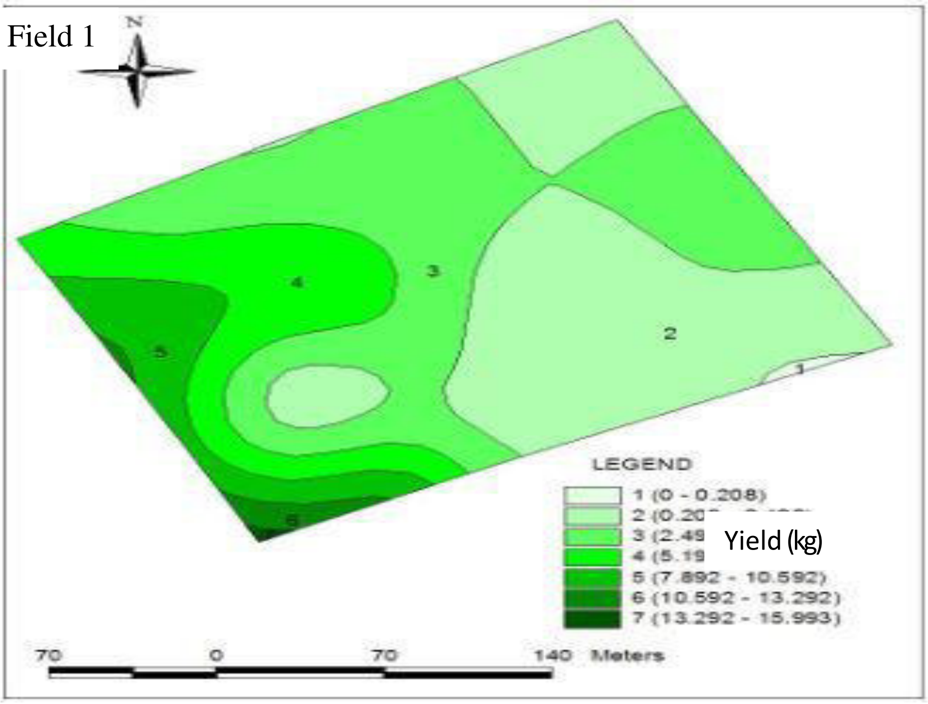

Figure 4.10(a): Spatial yield distribution in field 1

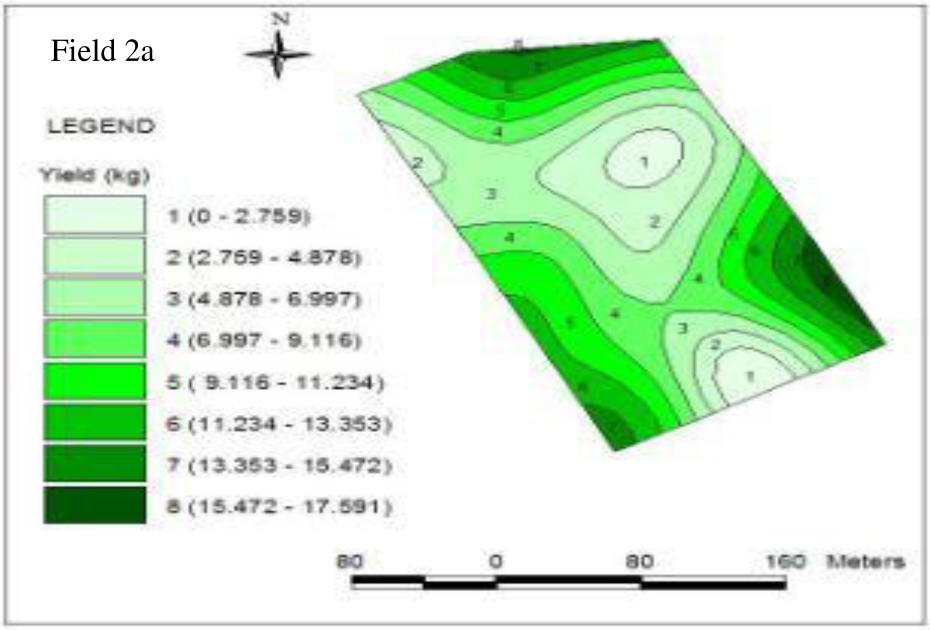

Figure 4.10(c): Spatial yield distribution in field 2a

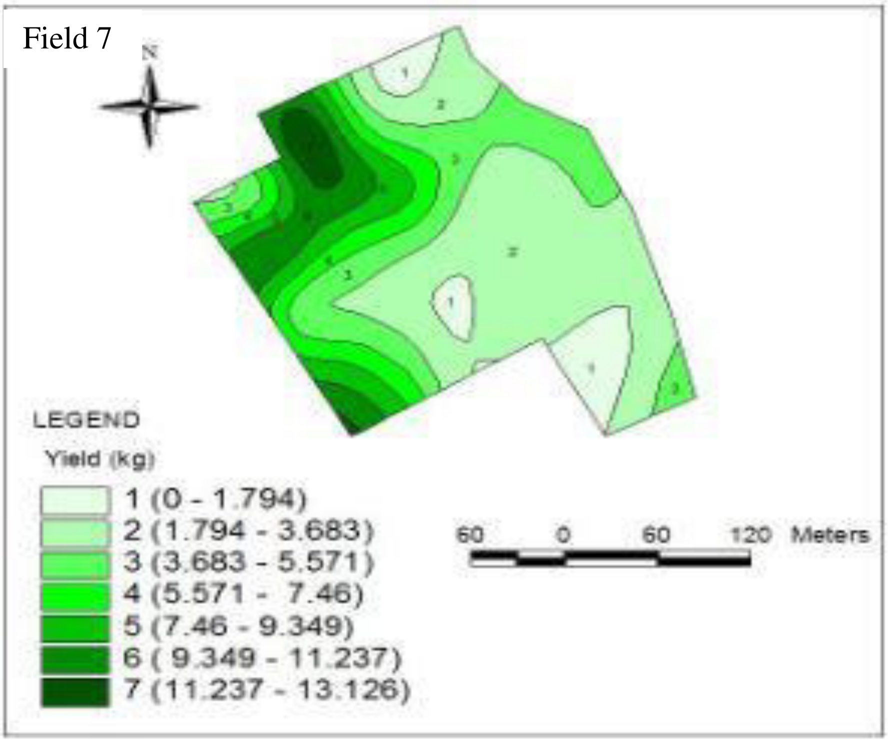

Figure 4.10(c): Spatial yield distribution field 7

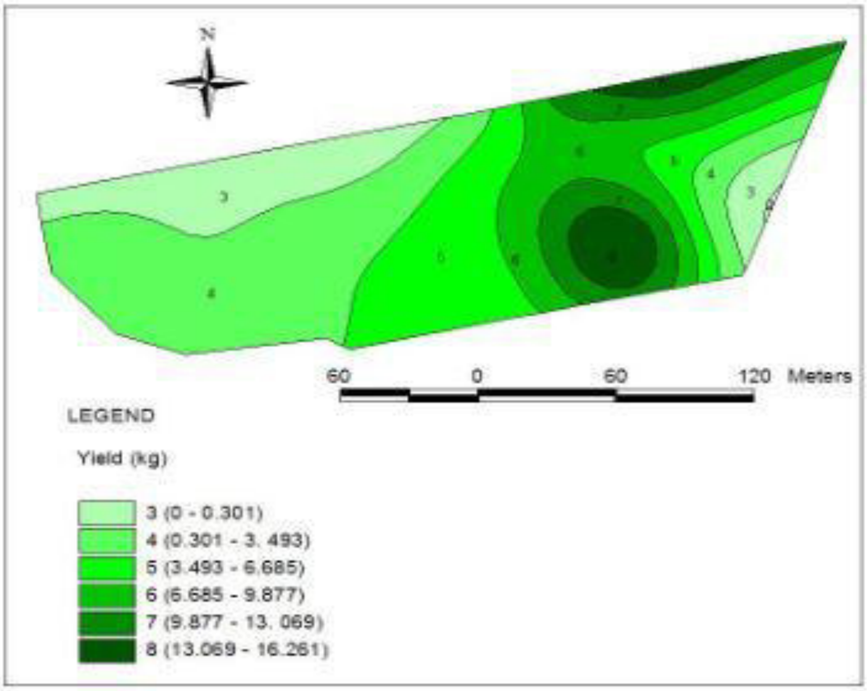

Figure 4.10(d): Spatial yield distribution within field 20

4.3. Factors influencing coffee yield

Selected soil parameters thought to influence coffee yield at Kabete Field Station coffee farm were studied. These were: available phosphorus, soil reaction (pH), total nitrogen, organic carbon, calcium, magnesium and slope. These parameters influenced in one way or the other coffee yield as seen in fig.4.11 (a-d).

4.3.1 Relationship charts of soil fertility factors influencing coffee yield

A spatial analyst extension of Arc-view GIS software was used for the GIS analysis. This analytical tool Arc view 3.3, (ESRI, 1996) was utilized to calculate the mean values for each measurement of the selected soil chemical parameters. A chart relationship of yield re-class map against each of the selected soil chemical properties, suspected to influence yield was done. In this way the relationship charts show how yield is variously influenced by each of the factors in a logical way. According to ESRI, spatial analyst manual (1996) analytical tool, any one factor showing a straight line graph of positive or negative relationship is chosen as a factor influencing yield. The light coloured bars of the charts indicate areas of the field with low yield. The intensity of colour represents increasing yield, so that the dark green colour areas represent good yields.

4.3.1.1 Soil Reaction (pH) and coffee yield

Figure 4.11(a) shows that the lowest yield class has the highest pH and as pH decreases from 5.55 to 4.95, coffee yield is increasing to level 4 and as the pH again increases from 4.95 to 5.25, yield is increasing. But according to the spatial analyst manual (ESRI 1996) This is an illogical relationship hence pH is not a factor influencing yield in field 1.The relationship between soil reaction (pH) and coffee yield in field 2a shows that as pH is decreasing from 4.97 to 4.92, yield is increasing to level 2 but pH starts increasing from 4.92 to 5.1 before decreasing again even as coffee yield is increasing (figure 4.11b). This relationship is illogical. Thus soil pH is not a factor influencing yield in field 2a. Similar trend follows in field 7(figure 4.11c) where as pH is decreasing, coffee yield is increasing to level 2. The relationship is illogical Therefore, soil pH is not influencing yield in field 7. As seen in figure 4.11d, soil pH is increasing from 5.01 to 5.40 as yield is increasing. Again pH starts decreasing from pH 5.14 before increasing arithmetically to pH 5.22. This still is an illogical relationship. Thus soil pH is not influencing yield in field 20

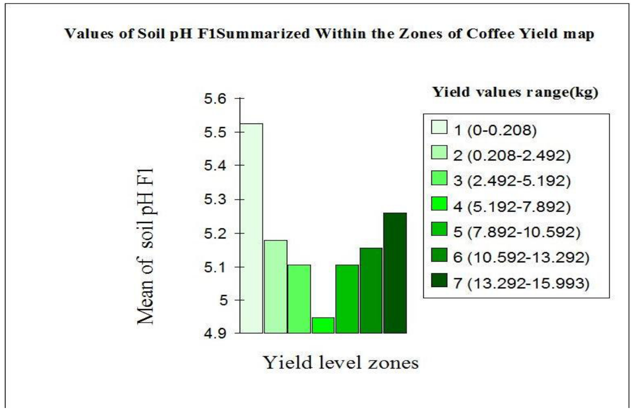

Fig. 4.11(a)

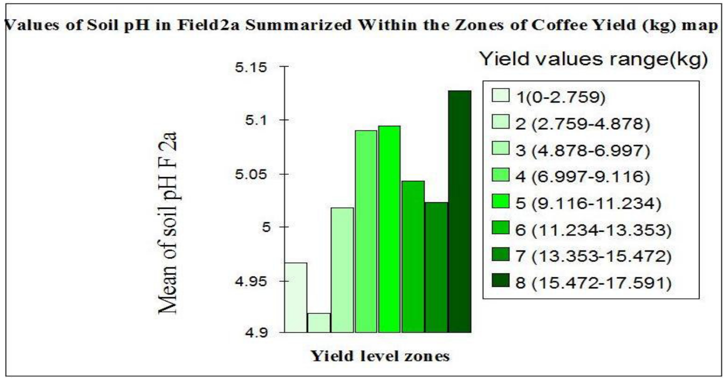

Fig. 4.11(b)

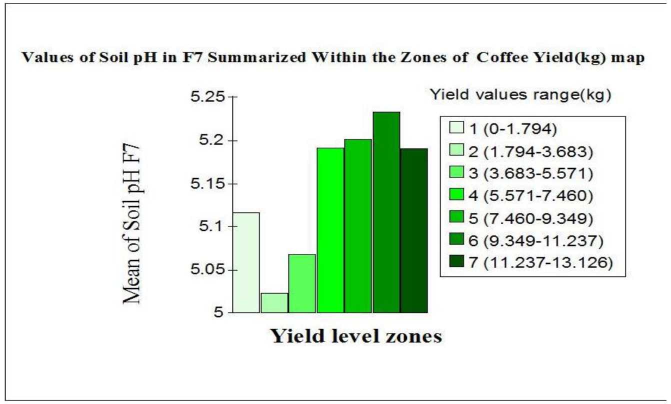

Fig. 4.11(c)

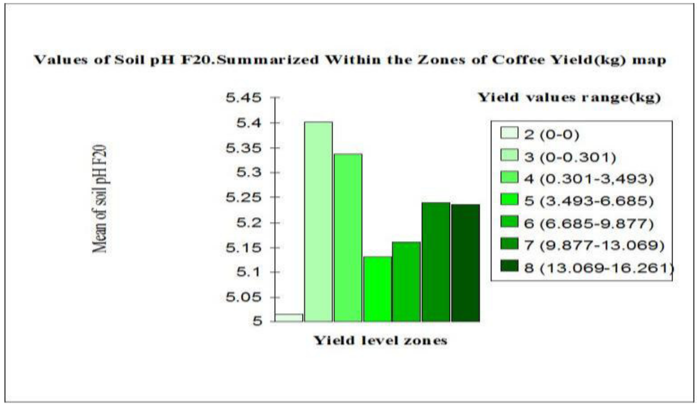

Fig. 4.11(d)

Figure 4.11: Correlation chart between soil reaction (pH) and coffee yield

4.3.1.2 Available phosphorus and coffee yield

The values of available phosphorus were summarized within zones of yield map as shown in figure 4.12 (a-d). As available phosphorus increases, coffee yield is increasing as shown in figure 4.12(a). Available P displayed a linear positive increase with yield levels in field1. This is a logical positive relationship and therefore the available phosphorus is one of the factors influencing coffee yield in field 1. In field 2a, as available phosphorus reduces from 4.95 to 3.855 ppm,(figure 4.12 b) yield is increasing to level 3. Then as available phosphorus increases from 3.855 to 4.95ppm (mg/kg of soil), yield is still increasing (figure 4.12b) to level7. This is illogical relationship. Therefore available phosphorus is not s factor influencung coffee yield in field 2a. In field 7,figure 4.12(c) as phosphorus decreeases from 4.18 to 3.25 ppm, yield increases to level 2 and again as phosphorus increases from 3.25 to 4.6 ppm, yield increases. This still is an illogical relationship therefore phosphorus is not to influence yield in field 7. Finally in field 20 (figure 4.12d) phosphorus increases as yield increases but decreases again as yield continues to increase. This is an illogical relationship and therefore, phosphorus is not a factor influencing yield in field 20. Generally, phosphorus is not the only factor influencing yield in the four fields. It is acutely deficient in all the probed sectors. It is likely that the low P supply was the common denominator causing constrained uptake of Ca, K and Mg. Recharge of phosphorus in the probed sectors of F2A would stimulate/activate uptake of Ca^{++}, Mg^{++} and K^{+} cations if optimal soil pH is sustained. The amount of phosphate removed in the crop is small given that quantity of cherry harvested from the farm was low and it is possible P fixation may also have been responsible for low availability as observed in Kenyan nitisols soils (Michori 1981) may lead to its poor response.

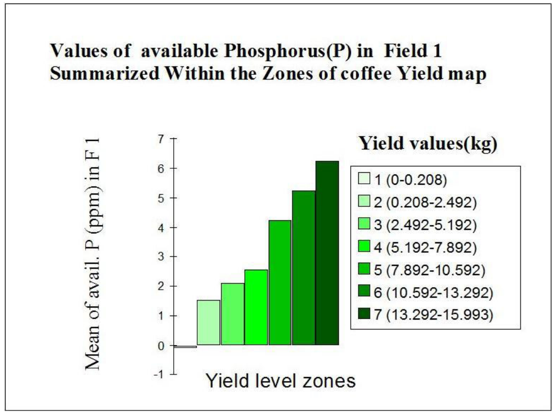

Figure 4.12(a)

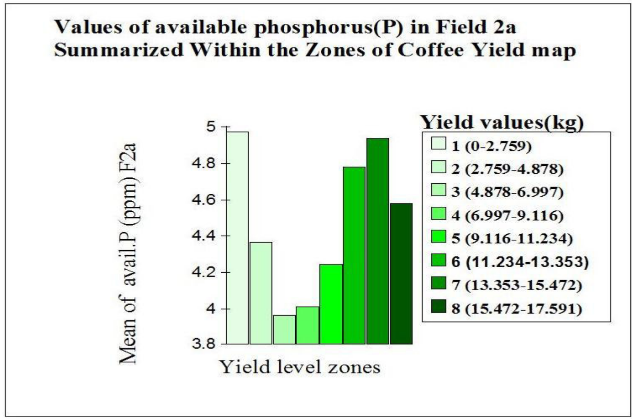

Figure 4.12(b)

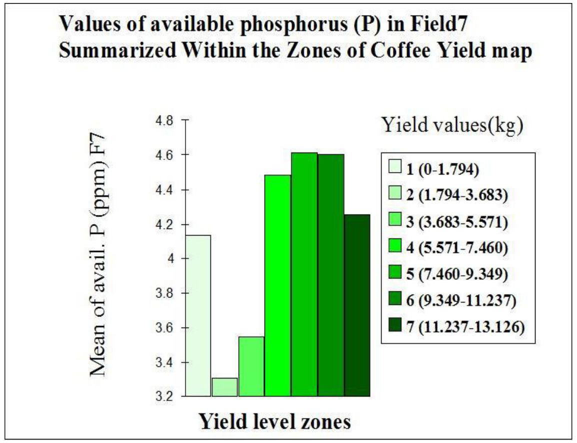

Figure 4.12(c)

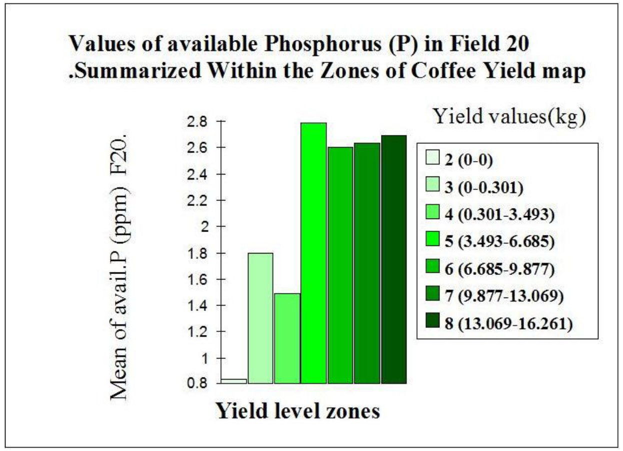

Figure 4.12(d)

Figure 4.12: Correlation chart between available phosphorus and coffee yield

4.3.1.3 Exchangeable calcium and coffee yield

The values of exchangeable calcium were summarized within zones of yield maps as shown in figure 4.13(a-d). Based on best line of fit, increase in exchangeable calcium increases coffee yield in field 1 and field 2a, figure 4.13(a) and (b). This is a logical positive relationship. Therefore exchangeable calcium is one of the factors influencing coffee yield in field 1 and field 2A. In field7, exchangeable calcium reduces, as yield is increasing to level 2. This is illogical relationship and therefore exchangeable calcium is not a factor influencing coffee yield in field 7 (figure 4.13(c) while in field 20, as exchangeable calcium reduces from 7.95 $mgkg^{-1}$ of soil, yield is increasing to level 2. Then as yield is increasing, exchangeable calcium increases to a peak of 10.4 mg/kg of soil before reducing gradually as yield is increasing. This is an illogical relationship hence exchangeable calcium is not a factor influencing yield in field 20. However, based on best line of fit, it is seen that exchangeable calcium depicts a negative relationship with coffee yield to a level 10.5 mg/kg of soil, then reduces steadily as yield increases (figure 4.13(d). This level seems to be the maximum tolerated by the coffee plant as confirmed by levels documented by coffee research foundation appendix 1(a).

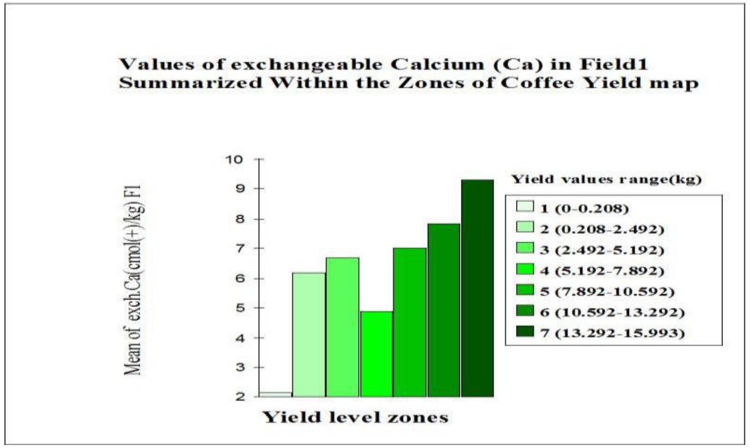

Figure 4.13(a)

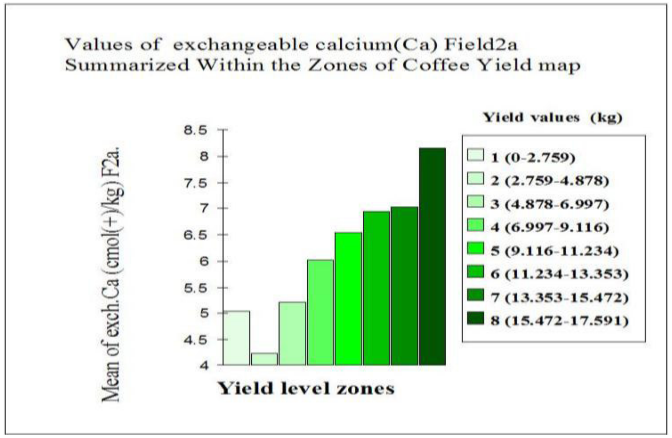

Figure 4.13(b)

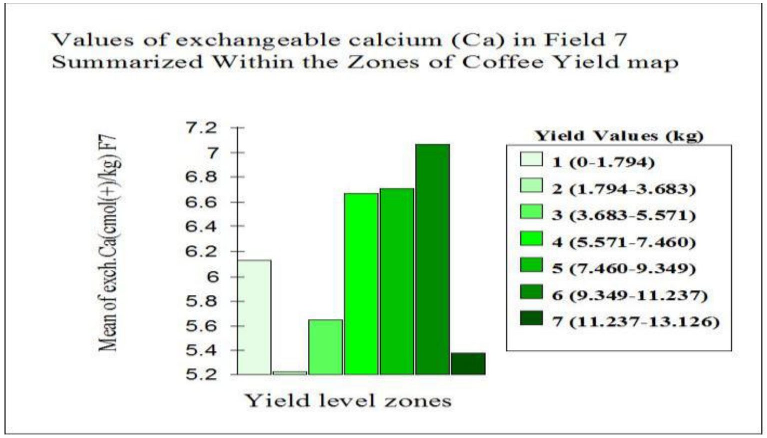

Figure 4.13(c)

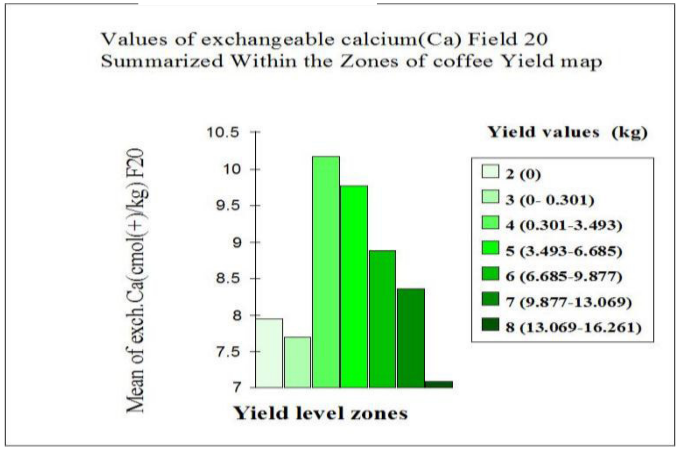

Figure 4.13(d)

Figure 4.13: Correlation between exchangeable calcium and coffee yield

4.3.1.4 Organic carbon and coffee yield

The values of organic carbon were summarized within zones of yield maps as shown in figure 4.14. Based on best line of fit, increase in mean of organic carbon increases coffee yield in field 1, figure 4.14(a). This is a logical positive relationship and therefore the organic carbon is one of the factors influencing coffee yield in field 1. Again in field 2a it is seen that as organic carbon is increasing, coffee yield is increasing, as shown in figure 4.14(b). This is a logical positive relationship and therefore the organic carbon is one of the factors influencing coffee yield in field 2a. In field7, organic carbon is reducing, as yield is increasing and increases again before reducing then increases. This is illogical relationship and therefore organic carbon is not a factor influencing coffee yield in field 7, figure 4.14(c). While in field 20, as organic carbon reduces, coffee yield is increasing to level 3.Then as yield is increasing, organic carbon is increasing. This is an illogical relationship hence organic carbon is not a factor influencing yield in field 20. The results of this analysis indicate very low to low levels of organic carbon within the study area. In addition low organic carbon is indicative of excessive mineralization of the organic matter. This may cause reduced macro- porosity and increased micro- porosity leading to low water retention and hence low nutrient uptake. Low organic matter is also an indication of constrained production of plant biomass due to the suppressed coffee canopy and root mass. Overall the declining organic carbon creates a poor environment for micro- flora population of growth and hence weakened nutrient supply conduits. Although the organic matter levels seem moderate (2-3%) which is substantial it could be as a result of accumulation from pruning's and weeds bio mass serving as surface mulching which was observed by (Tebrugge and During, 1999) that organic surface mulching increase soil organic matter. There has been observed cases of downward distribution of organic matter in the nitisols (red clays) of which Kabete enjoys dominance. Improvement in soil management at the Kabete site could result in increased organic matter content.

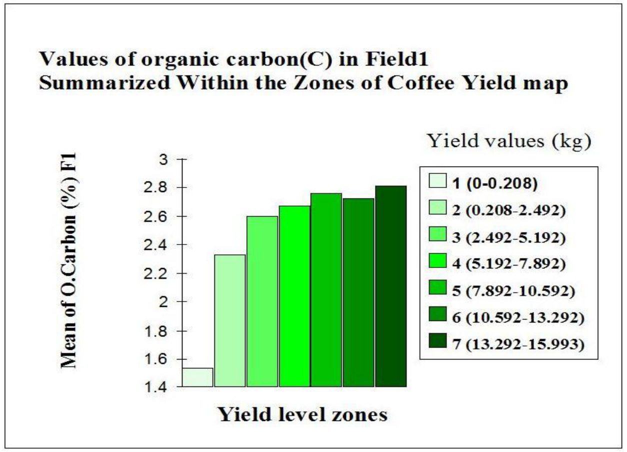

Figure 4.14(a)

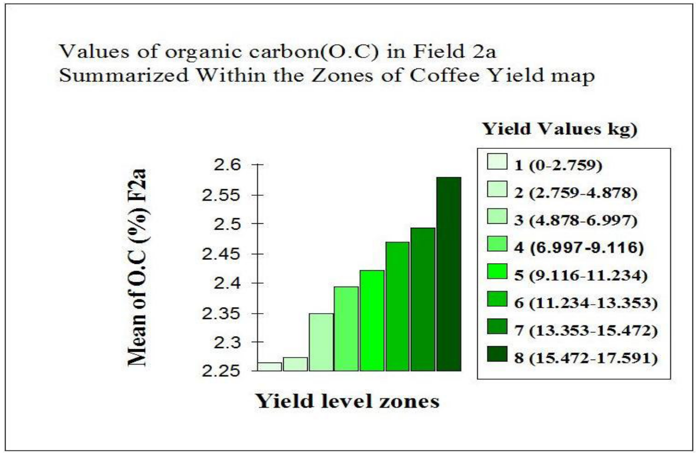

Figure 4.14(b)

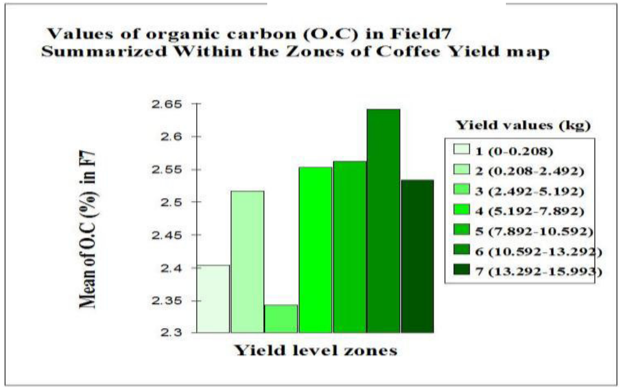

Figure 4.14(c)

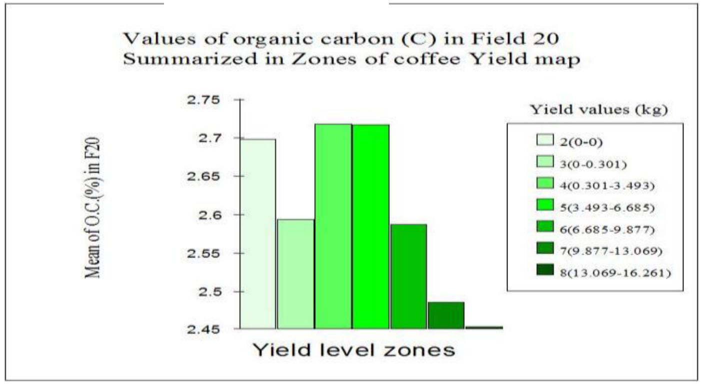

Figure 4.14(d)

Figure 4.14: Correlation between organic carbon and coffee yield

4.3.1.5 Total nitrogen and coffee yield

The values for total nitrogen were summarized within zones of yield maps as shown in Figure 4.15 (a-d) for all the fields. The productivity of coffee trees is dependent on soil nitrogen availability. The N availability is low in the farm (figure 4.4) and as observed by Wrigley, 1988, organic matter impoverished soil generates poor coffee growth and low yields. In figure 4.15(a) it is seen that as total nitrogen is increasing, coffee yield is increasing also. This is a logical positive relationship and therefore total nitrogen is one of the factors influencing coffee yield in field 1. Equally, in figure 4.15(b), as total nitrogen increases yield is increasing too. This is a logical positive relationship and therefore total nitrogen is one of the factors influencing coffee yield in field 2a. Figure 4.15(c) shows that, as total nitrogen reduces, yield is increasing to level 2 then increases before it decreases again even as yield increases. This is illogical relationship and therefore total nitrogen is not a factor influencing coffee yield in field 7. Similarly figure 4.15(d) shows that as total N is increasing, yield is increasing to level 4, and then decreases as yield is increasing. This is illogical relationship and therefore total N is not one of the factors influencing yield in field 20. The main sources of soil nitrogen are nitrogen fixers, nodulating legumes, green manures and exogenous sources like farm yard manure and other livestock derived manures. Litter fall is another source of nitrogen generated by the decomposing foliage. Nitrogen compounds are highly soluble in water and can be subjected to rapid leaching under heavy rain downpours through vertical and slope induced water runoffs. Overnight rain of high intensities can cause huge nitrogen loss through these mass flow channels. It therefore becomes very imprudent to dependent on any form of N quantities measured prior to a rain downpour as a basis of constructing a nitrogen (partial) budget. The only N source that can be factored in the N (partial) budget is legume (based) forced N in the short run. The basis of creating an N (partial) budget remains restricted to crop estimates at the fruit set and first expansion rates of the young berries.

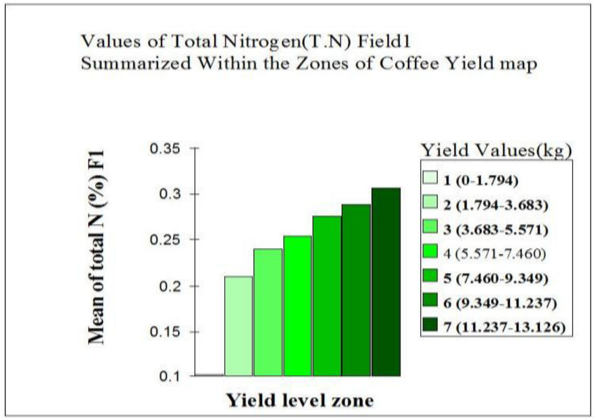

Figure 4.15(a)

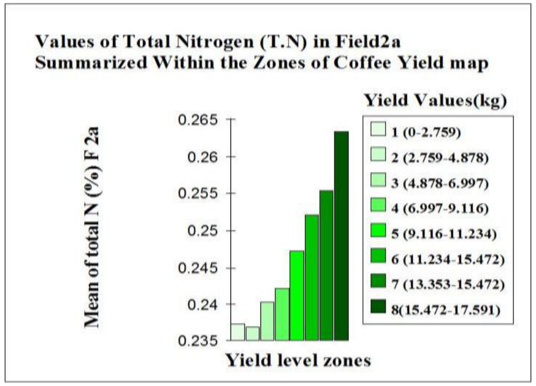

Figure 4.15(b)

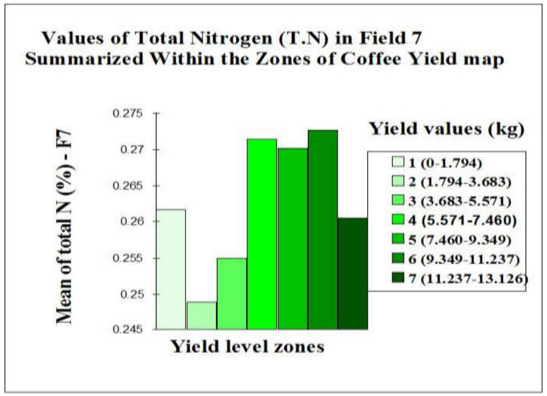

Figure 4.15(c)

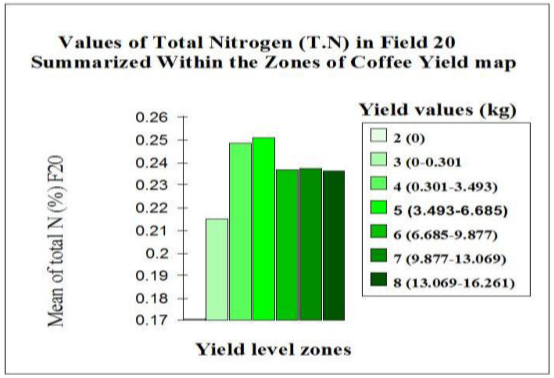

Figure 4.15(d)

Figure 4.15: Correlation between total nitrogen and coffee yield in the four fields

4.3.1.6 Exchangeable magnesium and coffee yield

Magnesium is known to be essential for chlorophyll formation and production of good quality coffee. The concentrations of exchangeable magnesium are within the critical ranges optimal for coffee production as adopted at Coffee Research Foundation (appendix 1a). To see how this element correlates with coffee yield at the fields, values of exchangeable magnesium were summarized within zones of yield maps to produce the correlation charts shown in figure 4.16. As seen in figure 4.16(a), as soil exchangeable magnesium reduces from 3 to 2.755 cmol(+)kg^{-1} of soil,coffee yield is increasing to level 4. Then as exchangeable magnesium increases from 2.755 to 3.2 yield is still increasing.This is illogical relationship. Therefore exchangeable magnesium is not s factor influencung coffee yield in field 1.In field 2a,fig.4.16(b) as soil exchangeable magnesium is reducing,coffee yield is increasing to level 4 and again soil exchangeable magnesium increases as coffee yield is increasing. This is illogical relationship.Therefore exchangeable magnesium is not s factor influencung coffee yield in field 2a. In the same manner,figure 4.16(c) shows that soil exch.magnesium is reducing as coffee yield is increasing to level 2 before increasing again,as coffee yield is increassing.This again is an illogical relationship hence exchangeable magnesium is not a factor influencing coffee yield in field 7. In field 20,fig.4.16(d),and based on best line of fit, reduction in mean of exchangeable magnesium decreases coffee yield. This is an illogical negative relationship and therefore exchangeable magnesium is not one of the factors influencing coffee yield in field 20. In F20, exchangeable magnesium is higher in low yield areas of the farm and as its concentrations decrease, yield increases (darker green bars indicate more yield compared to the lighter bars). The low yield areas of the field are on the northern side where it slopes but the flat area, (southern part) is more fertile as seen from the darker green bars. Magnesium is adequate in all the probed sectors. The topographic depression also gives depressed Mg levels. This is expected due to high possibility of illuviation of Mg under conditions of low organic and high soil water potential during the wetter months. The prolonged soil wetness may be facilitating more Mg uptake by the roots.

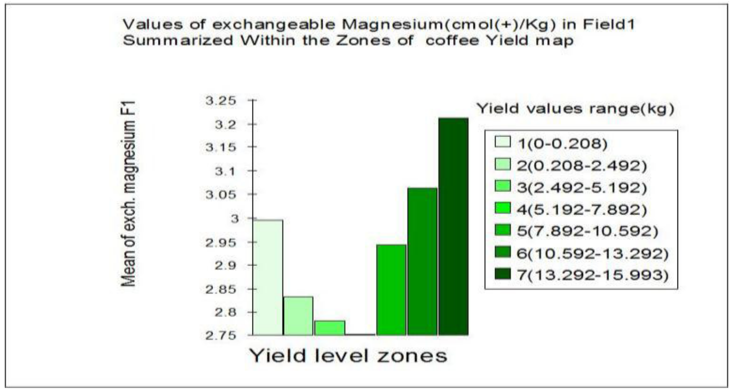

Figure 4.16(a)

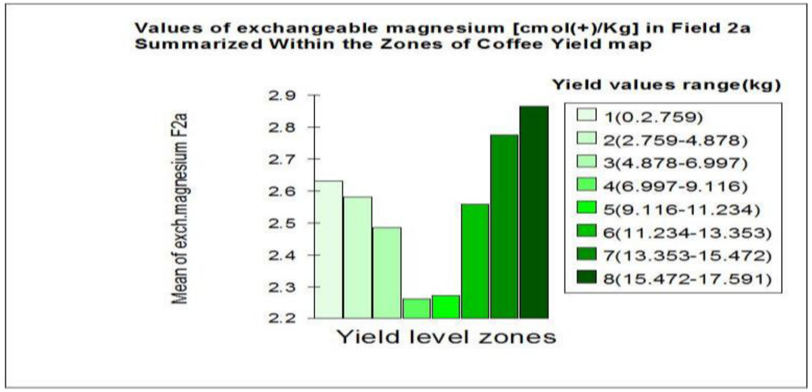

Figure 4.16(b)

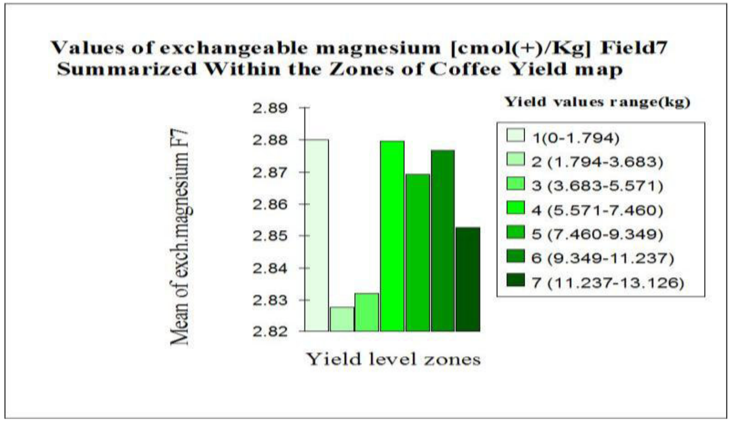

Figure 4.16(c)

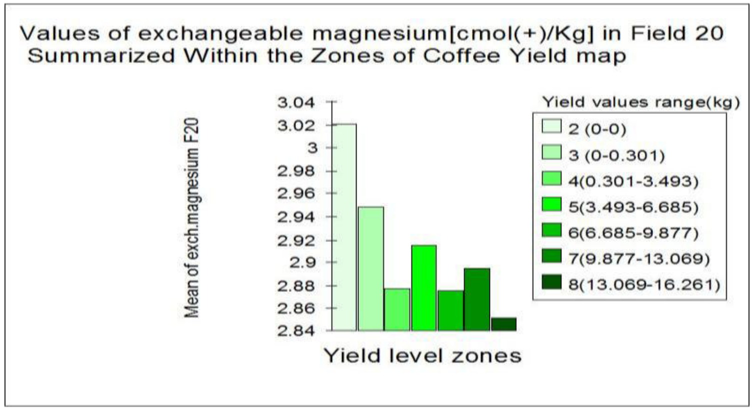

Figure 4.16(d)

Figure 4.16: Correlation between exchangeable magnesium and coffee yield

4.3.1.7 Exchangeable potassium and coffee yield

Exchangeable potassium averaged 1.425 cmol (+) kg^{-1} of soil with a range of 0.6 cmol (+) kg-1 to 2.4cmol (+)kg^{-1}). The values of exchangeable potassium were summarized within zones of yield maps as shown in Figure 4.17 (a-d). Based on best line of fit, figure 4.17(a) shows that as exchangeable potassium increases, coffee yield is increasing. This is a logical positive relationship though this relationship is weak but positive. Therefore exchangeable potassium is a factor influencing coffee yield in field1. In field 2a it is seen that as exchangeable potassium decreases minimally, yield level is increasing, figure 4.17(b). This is illogical relationship and therefore exchangeable potassium is not a factor influencing coffee yield in field 2a In field 7, it observed that as exchangeable potassium reduces, yield is increasing to level 2, before increasing as coffee yield increases. This is illogical relationship. Therefore, exchangeable potassium is not a factor influencing coffee yield in field 7, figure 4.17(c). The same applies to field 20, whereas exchangeable potassium reduces, yield is increasing marginally before increasing and again decreasing while coffee yield is increasing(figure 4.17d). This is illogical relationship, hence exchangeable potassium is not a factor influencing yield in field 20.In general, exchangeable magnesium does not influence coffee yields in the study fields. These results are confirmed by Willson (1985) who observed that potassium is the most important nutrient exported with harvested coffee beans and no decline of soil K levels induced by coffee cultivation was observed. This may be due to low productivity levels and comparatively large soil reserves. A study by Karim et al. (1999) revealed that soil K concentrations did not decline at yield levels of 1,000 kg per hectare. In Kabete Field Station coffee farm, annual production averaged 350 kg ha^{-1}

Field 1

Field 2a

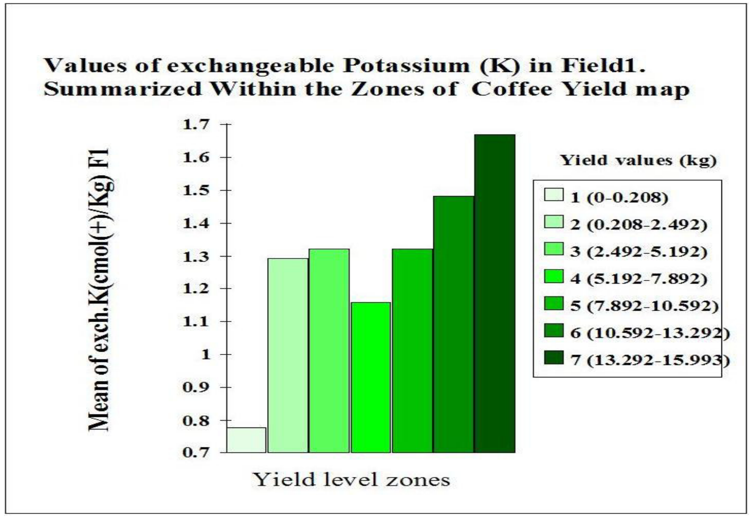

Figure 4.17(a)

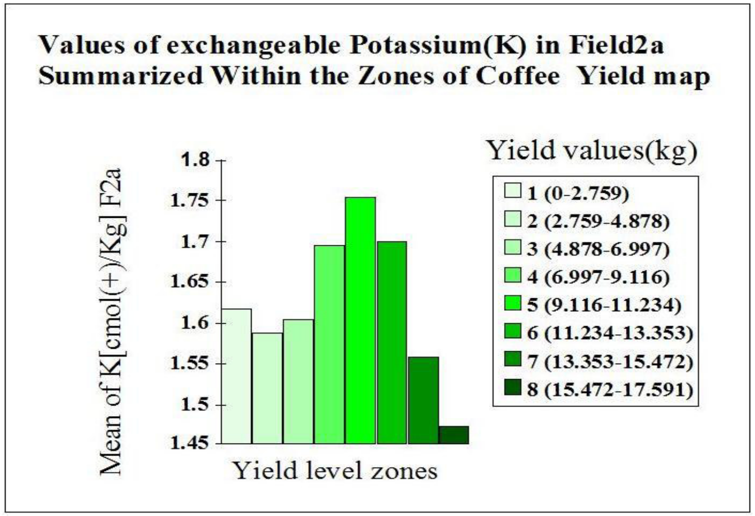

Figure 4.17(b)

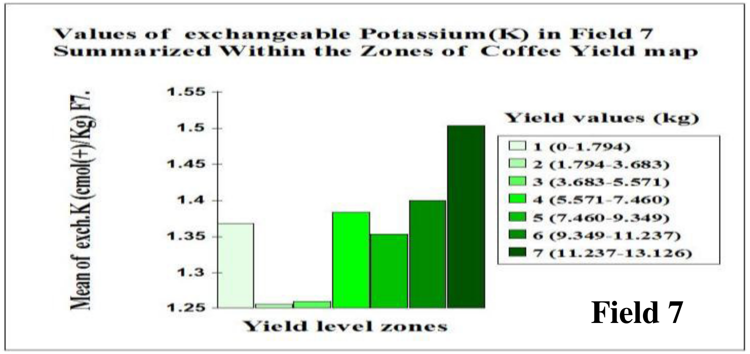

Figure 4.17(c)

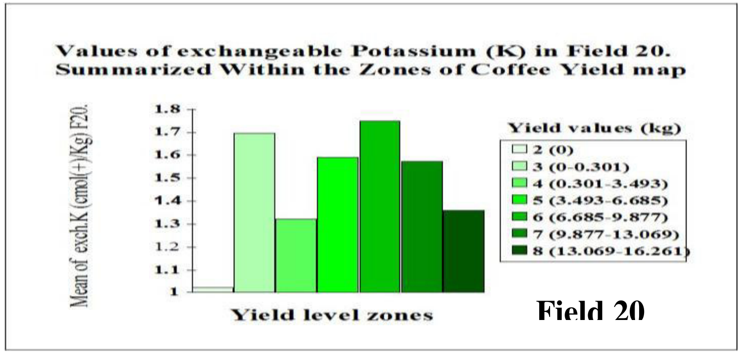

Figure 4.17(d)

Figure 4.17: Correlation chart between of exchangeable potassium and coffee yield

4.3.1.8 Slope and coffee yield

Most coffee plants in Kenya are grown in fields of varying topography (slope). Information on this is necessary since soil fertility is very often influenced by the slope of the land on which coffee is grown. In this study, field 1 and field 2a were generally flat and not much slope influence on yield was expected. The values of % slope were summarized within zones of yield maps as shown in Figure 4.18 (a-d). As seen in figure 4.18(a), as slope reduces, yield is increasing to level 2 before increasing again. This is illogical relationship hence % slope is not a factor on its own influencing yield in field1. This is expected because the field is flat. Similarly, infield 2a, it is seen that as slope increases, coffee, yield is increasing. However, slope decreases again as yield increases, figure 4.18(b). This is illogical relationship hence slope is not a factor influencing coffee yield in field 2a. In field 7, it is seen that as %slope decreases, yield is increasing. This is a logical negative relationship. Therefore, slope is a factor influencing coffee yield in field 7. This is true as the area with low yield (light bars) corresponds to steep areas of field 7, fig.4.18(c). In field 20, fig.4.18(d) it is observed that based on best line of fit, as % slope decreases, yield is increasing. This is a logical negative relationship, hence % slope is a factor influencing coffee yield in field 20. This means that there is less harvest of coffee from slopping part of field in field 7 and field 20. There are no soil conservation structures undertaken in these two fields

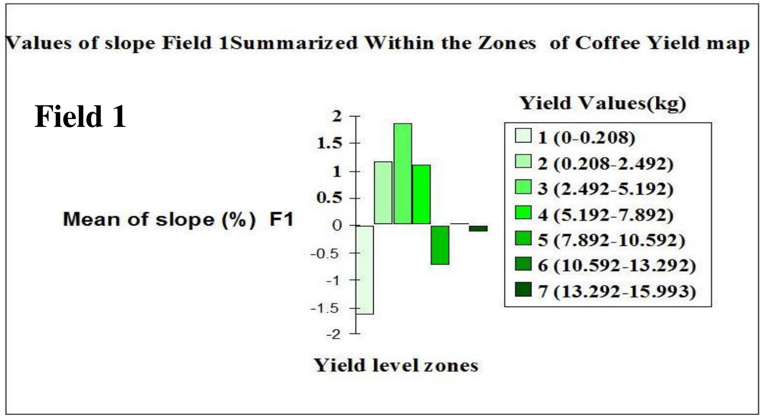

Figure 4.18(a)

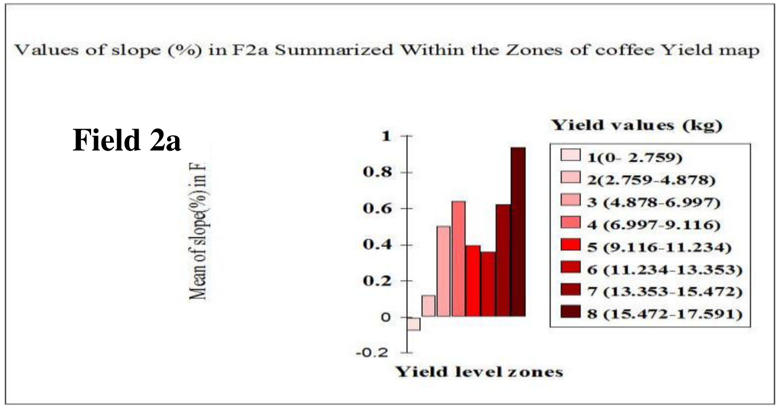

Figure 4.18(b)

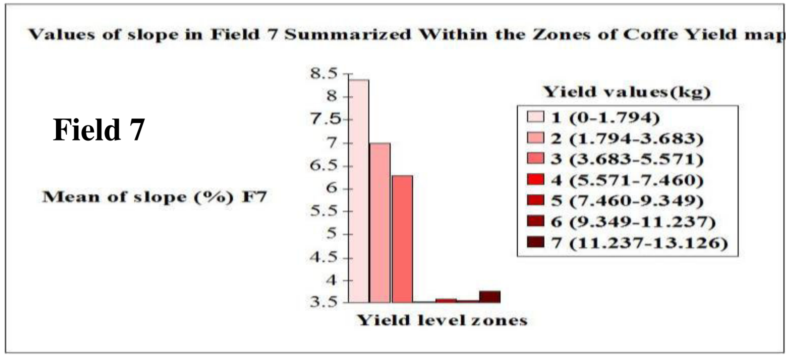

Figure 4.18(c)

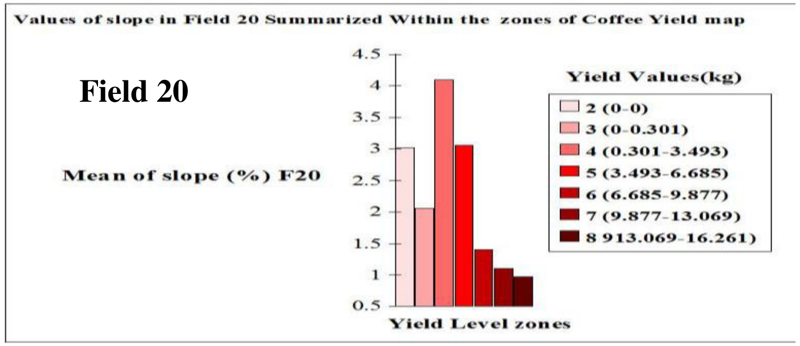

Figure 4.18(d)

Figure 4.18: Correlation between slope and coffee yield in the studied field

4.3.1.8.1 Spatial variability of crop yield and soil chemical properties

To determine the degree to which spatial variability in yield can be explained by the varaiations in chemical properties of the soil, a Pearson', a multivariate correlation analysis was performed indicating that 92 % ,37%,32% and 67% (R^2) of varaition in coffee yield is explained by all the parameters combined in F1, F2a, F7 and F20 respectively (appendix 4). The results are shown in appendices 5(a-d) and shows that there exist a significant difference between coffee yield and the main attributes of soil quality in a coffee field.

The general expression equation/model for predicting yield is expressed as:

Total yield = pH + K coml. (+)/Kg + Ca coml. (+)/Kg + Mg coml. (+)/Kg+ P ppm+ % N+ % C +% slope

The coefficient of Mg coml. (+)/Kg, P ppm, % N, % C and % slopes are found to be positive for total yield. In particular, Mg coml. (+)/Kg, % C and % are positive and highly significant at 0.1% probability level while % N is significant at 0.5% and P ppm at 1%. This implies that an increase in these nutrients is likely to lead to an increase in the total yield in field1. However, pH, K coml. (+)/Kg and Ca coml. (+)/Kg are negative and significant at 0.1%, 0.5% and 1% respectively. The negative coefficient indicates that application of the elements, may not coffee yields in field 1. The results reveal that in field 2a, pH, % N and % C all have positive relationship with the total yield (kg) per sample spot. Soil pH is significant at 0.5% while % N and %C are both significant at 1%. An increase in these parameters would result in an improved total yield (kg) per sample spot. Unlike, field 1, % slope exhibits a negative relationship with total yield. This implies that further decrease in % slope would lead to a decrease in the output (yield). K coml. (+)/Kg, Ca coml. (+)/Kg, Mg coml. (+)/Kg and P ppm also show negative relationship with yield. A decrease in the amount of these items would lead to a decrease in yield per sample plot

Using adjusted critical value of 1.00, %N, % C and P ppm in field 7 are all positively significant with the total yield (kg) per sample spot at 1% probability level while pH is positive and significant at 0.5% probability level. Hence any addition of these parameters would increase the total yield (kg) per sample spot. These results show that the total yield is negatively affected by K coml. (+)/Kg, Ca coml. (+)/Kg, Mg coml. (+)/Kg and % slope in field 7.

In field 20, only K coml. (+)/Kg and % N are positively significant with total yield at probability level of 1% and 0.5% respectively. The rest of parameters, pH, Ca coml. (+)/Kg, Mg coml. (+)/Kg, P ppm, % C and % slope are all negatively significant with the total crop yield.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

This study showed that there was substantial variation in the measured soil properties within the four fields. The existence of this spatial variability of soil fertility parameters that influence coffee yield in Kabete field station coffee farm discourages a blanket application of inputs. Precision agricultural techniques if adopted provide onsite- specific use or application of these inputs. KFS has favourable soils, precipitation, location and infrastructure to produce the quantity and quality coffees required for profitable and sustainable economic production of coffee. Site specific soil management coupled with good coffee management practices such as site-specific fertilizer application, good canopy management and control of pests and diseases may help enhance coffee yield. The generated nutrient distribution maps could be helpful in managing the existing variability within the fields. Results of this study indicate that coffee varietal differences were very significant in the farm. Ruiru 11 was a better yielder (0.9 MT/Ha) than S.L.28 variety (0.4 MT/Ha). This is based on spot recordings where the geo-referenced soil samples were taken.

The university may invest in the coffee enterprise by allocating financial and enterprise specific trained personnel for successful implementation of the proposed farm input and labour program of farm operations. Coffee production and productivity at the farm has declined over time from 0.88MT ha^{-1} in 1998 to 0.35MT ha-1 in 2011. The average yields recorded in this study were 0.6 MT ha^{-1} from ruiru11 variety and 0.2 MT ha^{-1} from S.L.28 variety. This could have been due to low use of fertilizer, lack of disease and pest control, poor canopy management hence the trees have become smaller and smaller. Basal minerals like Ca, K, and Mg have remained on the credit side while the soil reaction (pH) is within the required range (4.4-5.4) but on the upper optimal sufficiency level because demand for these elements by the coffee trees is reduced. The trees carry few berries which could have otherwise created demand for uptake of these elements. Trees had few berries on them though they still remained healthy (See Plate 4.2; 4.3 and 4.4).

It emerged that allocation of resources within the coffee fields like, weeding, fertilizers and manure application as well as canopy management was focused upon improving returns in areas viewed as having greatest potential productivity, rather than attempting to ameliorate those areas undergoing decline. Canopy management (light pruning, and main pruning) which is an annual mandatory activity be carried out regularly to improve the bearing wood for sustained quality production and save on losses for spraying unnecessary foliage/wood. The level of adoption of various practices and input usage are the main factors influencing coffee production and profitability at Kabete field station coffee farm. The crop yields presented spatial variability within the fields, which was explained jointly by the spatial distribution of soil reaction (pH), the soil content of nitrogen, phosphorus, potassium, calcium and magnesium nutrients that are indicators of soil fertility and are important to development, growth and productivity of coffee.

It was observed that the coffee fields have been undergoing drop in yield levels over time which is indicated / justified by the prorated decline in organic matter. The results of this study indicated that phosphorus (P) was acutely deficient in all fields sampled. P is responsible for wood development and root establishment. Deficiency of this nutrient within the soil results in poor root development and low yield with scanty flowering, light small rugged, shriveled beans, poor rooting, weak branches, leaf defoliation(bronze to pale yellow leaves. It was also observed that the farm uses tractor drawn implement to mechanically control weeds leading to frequent chopping of the surface feeder roots. This deprives the plant of important nutrients, like P whose rate of uptake is dependent on root density. Mineral nutrients like Ca, Mg, and K to remained on the credit side possibly because of reduced root density. This has been demonstrated by the results of this study as the concentrations of these elements were adequate to excess like potassium. Most of other parameters were on the credit side because the trees had no fruits/berries on them hence demand for these elements was low.

Mulching is important for the purposes of soil moisture conservation, weed control and consequent conversion to nutrients in the soil, though supply of suitable materials for mulching was the main obstacle to a wider adoption of the practice at the farm. Herbicides offers considerable advantages in terms of ease of weed control and possible improvement in surface root distribution but was applied late, making costs high. Wheeled vehicles used in the farm and trampling pickers operating in the crop, could have led to serious surface compaction hampering root development.

Yields in fields 1 and 2a increased with increasing organic carbon, total nitrogen and exchangeable calcium. Variable application of fertilizers containing these nutrients might increase coffee yield in the two fields.

It is observed that coffee yields decreased with increasing slope in field 7 and 20. The terrain in field 7 was characterized by moderately gentle slope while that of field 20 slope was partly flat with steep slope towards the north and western side. The low yields could be attributed to depletion of soil organic matter through soil erosion.

5.2. Recommendations

- Addition of an acidifying N fertilizer like Ammonium Sulphate Nitrate (ASN) in two equal splits at the onset of rains in April and May is recommended to reduce the pH level to optimal soil condition. Apply 40% of N requirements as maintenance and add 1 unit for every 10kgs of production per ha
- In order to raise P in the soil to the required level, variable rate of P application according to the existing ppm in the soil is recommended. Raise the phosphorus in the soil to 50 ppm by adding the difference in the soil. Therefore, for every 1ppm to be added to raise the phosphate level of the soil to the required level, multiply by 8 Kgs of P_2O_5. However, there should be no application of any calcium containing fertilizer in field 20 since a decrease in the nutrient corresponded to increase in coffee yield.
- To maintain soil fertility, it is recommended that soil conservation measures be adopted in fields 7 and 20 since both fields are susceptible to soil erosion. Conventional soil conservation measures safeguard the soil by reducing water runoff along the slopes. Mulching would provide a better protective cover against the destructive impact of raindrops and help maintain high infiltration rates.
- Disease and pest preventive measures should be adopted at the farm to prevent losses and improvement of coffee quality.
- Utilize the suggested inputs requirement and implementation schedule chart given in appendix 8 as a guide in the field application schedule for any period.
- Digitization of farm records for ease of retrieval, and monitoring performance of the farm is recommended.
- It is recommended that performance of previous production trends be maintained to guide future decisions on enterprise choice, as it will provide data for use in making alterations

to the existing farm enterprise combinations, and provide planning and improved profitability.

- Since variety plays a significant role in determining coffee yield output, possibilities of transforming the S.L 28 variety plantation into Ruiru 11 stand through top working can be looked into.
- Having considered the prevailing management practices at the farm during this research, it is recommended that the farm manager utilizes the coffee Research Foundation (CRF) supported control points based guidance, GAP.
- Adoption of timely applications of appropriate inputs and implementation of best practice agronomic operations to realize good economic yields is key in improving productivity at the farm.
- To correct any adverse effect in the soil, it may be necessary to have continuous soil and leaf analysis once every two years and subsequently correcting for any observed nutrient imbalances and deficiencies that may be observed
- Skills utilization on key operations like canopy management, trained plant operators, sprays supervisors, as well as employment of a technically proficient estate manager.
- Appraise annual farm production through yield charting and cost benefit analysis to develop data for decision making and resource allocation basis.
- Finally, the farm may be translated into a model coffee farm for training agriculture students in line with the university's vision of being the 'universal centre of excellence in training, research, outreach and consultancy services in agriculture if the above recommendations are considered.

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APPENDICES

Appendix 1(a): Comparative interpretation of analysis for use in coffee

SOIL			
ANALYTE	**READING OBTAINED**		
	DEFICIENT	**ADEQUATE**	**EXCESSIVE**
pH	<4.4	4.4 – 5.4	> 5.4
Hp	-	≤ 0.5 C mol(+)kg^{-1}	>0.5 C mol(+)kg-^{1}
Na	-	≤ 0.20 C mol(+)kg^{-1}	>0.2 C mol(+)kg^{-1}
K	< 0.4 C mol(+)kg^{-1}	0.4 – 2.00 C mol(+)kg-^{1}	> 2.0 C mol(+)kg^{-1}
Ca	< 1.6 C mol(+)kg^{-1}	1.6 -10.0 C mol(+)kg^{-1}	> 10.0 C mol(+)kg-^{1}
Mg	< 0.8 C mol(+)kg^{-1}	0.8 – 4.0 C mol(+)kg^{-1}	> 4.0 C mol(+)kg^{-1}
P	< 20 ppm	20 – 100 ppm	>100 ppm
Mn	-	Up to 1 C mol(+)kg^{-1}	>1 C mol(+)kg^{-1}
$\frac{Ca + Mg}{K}$	< 4	4 - 10	>10

Source: Bould, C. (1974) - long Ashtonne

Appendix 1(b): Soil critical ratings for carbon (%c) and nitrogen (%n)

Rating	Carbon (%)	Total Nitrogen (%)
Very high	>20	>1.0
High	10 – 20	0.6 – 1.0
Medium	4 – 10	0.3 – 0.6
Low	2 – 4	0.1 – 0.3
Very low	< 2	< 0.1

Source: NARI-

Appendix 2: Application rates for Nitrogen based on production

Amount of crop estimated in the current season	**Kg N/ha per year**	**Gm of fertilizer/tree**		**Kg of fertilizer/ha**	
		21% N	26%N	21% N	26% N
0-5 kg of cherry per tree	80	330	260	390	310
5-7 kg of cherry per tree	100	358	290	476	385
7-10 kg of cherry per tree	100-150	358-538	290-434	476-715	385-577
Above10 kg of cherry per tree	Up to 300	716	578	952	769

Source: CRF Production Recommendation Handbook, 2013

Appendix 3: KFS 15 year coffee production (1997/98 to 2011/2012)

YEAR	Area under coffee (Ha)	Kgs(GBE)
1997/1998	47	2,375
1998/1999	47	41,495
1999/2000	47	25,391
2000/2001	47	37,665
2001/2002	47	37,492
2002/2003	47	25,639
2003/2004	47	23,186
2004/2005	47	17,666
2005/2006	47	9,994
2006/2007	47	21,632
2007/2008	47	5,572
2008/2009	47	35,517
2009/2010	47	19,291
2010/2011	47	11,033
2011/2012	47	16,240

Appendix 4: Coefficient of determination (R^2) of the different fields

Regression	**Fields**			
	F1	**F2A**	**F7**	**F20**
R^2 (multivariate regression coefficient)	92 %	37 %	32 %	67%

Appendix 5(a): Relationship between coffee yield and chemical soil properties in field 1

ANOVA-Field 1

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	2966.140	8	370.767	10.429	.003[a]
	Residual	248.860	7	35.551		
	Total	3215.000	15			

a. Predictors: (Constant), % slope, % C, pH, % N, K coml.(+)/Kg , P ppm, Ca coml.(+)/Kg, Mg coml.(+)/Kg b. Dependent Variable: Total yield (kg) per sample spot

Coefficients[a]

Model		Un standardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-13.824	7.234		-1.911	.098
	pH	-3.062	1.297	-.818	-2.360	.050*
	K coml.(+)/Kg	-.295	.293	-.279	-1.007	.347**
	Ca coml.(+)/Kg	-.004	.267	-.004	-.014	.989***
	Mg coml.(+)/Kg	1.908	.621	.957	3.071	.018*
	P ppm	.943	1.890	.121	.499	.633***
	% N	1.289	1.049	.245	1.229	.259**
	% C	.817	.362	.486	2.257	.059*
	% slope	.810	.474	.353	1.709	.131*

a. Dependent Variable: Total yield (kg) per sample spot

*, **, and *** - mean significant at 0.1%, 0.5%, and 1 % probability level, respectively

Appendix 5(b): Relationship between coffee yield and chemical soil properties in field 2a

ANOVA[b]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1590.879	8	198.860	.673	.706[a]
	Residual	1772.854	6	295.476		
	Total	3363.733	14			
a. Predictors: (Constant), % slope, K coml.(+)/Kg , Mg coml.(+)/Kg, P ppm, pH, % C, % N, Ca coml.(+)/Kg b. Dependent Variable: Total yield (kg) per sample spot						

Co-efficients[a]						
Model		Un-standardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	32.081	38.735		.828	.439**
	pH	3.385	4.420	.981	.766	.473**
	K coml.(+)/Kg	-.739	.640	-.468	-1.154	.292**
	Ca coml.(+)/Kg	-.927	1.134	-1.125	-.817	.445**
	Mg coml.(+)/Kg	-.441	.695	-.297	-.635	.549**
	P ppm	-1.548	4.234	-.180	-.366	.727***
	% N	5.894	4.886	.711	1.206	.273**
	% C	.915	.896	.529	1.022	.346**
	% slope	-.366	2.250	-.071	-.163	.876***
a. Dependent Variable: Total yield (kg) per sample spot						

* t values significant at 0.1%, ** t values significant at 0.5% and *** t values significant at 1 % probability level

Appendix 5(c): Relationship between coffee yield and chemical soil properties in field 7

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1134.008	8	141.751	.499	.830[a]
	Residual	2557.603	9	284.178		
	Total	3691.611	17			

a. Predictors: (Constant), % slope, Mg coml.(+)/Kg, % C, P ppm, K coml.(+)/Kg , Ca coml.(+)/Kg, % N, pH b. Dependent Variable: Total yield (kg) per sample spot

Model	Un-standardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	46.701	43.025		1.085	0.306**
pH	1.846	2.903	0.501	0.636	.541**
K coml.(+)/Kg	-0.045	0.63	-0.032	-0.071	.945***
Ca coml.(+)/Kg	-0.424	0.745	-0.453	-0.57	.583***
Mg coml.(+)/Kg	-0.309	0.916	-0.166	-0.337	.744***
P ppm	-0.65	2.054	-0.122	-0.316	.759*
% N	0.836	3.908	0.136	0.214	.835***
% C	0.222	0.493	0.174	0.449	.664***
% slope	-1.046	1.36	-0.36	-0.769	.461**

a. Dependent Variable: Total yield (kg) per sample spot

* t values significant at 0.1%, ** t values significant at 0.5% and *** t values significant at 1 % probability level

Appendix 5(d): Relationship between coffee yield and chemical soil properties in field 20

ANOVA						
Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	3728.858	8	466.107	1.012	.554[a]
	Residual	1382.142	3	460.714		
	Total	5111.000	11			
a. Predictors: (Constant), % slope, K coml.(+)/Kg , % C, % N, Mg coml.(+)/Kg, P ppm, Ca coml.(+)/Kg, pH b. Dependent Variable: Total yield (kg) per sample spot						

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	167.938	82.063		2.046	.133**
	pH	-5.201	5.479	-.638	-.949	.413**
	K coml.(+)/Kg	.052	.778	.042	.067	.951***
	Ca coml.(+)/Kg	-.056	.873	-.039	-.064	.953***
	Mg coml.(+)/Kg	-.988	1.187	-.403	-.833	.466**
	P ppm	-5.133	4.936	-.532	-1.040	.375**
	% N	5.561	4.692	.591	1.185	.321**
	% C	-1.914	1.422	-.730	-1.346	.271**
	% slope	-1.486	2.474	-.423	-.601	.590***
a. Dependent Variable: Total yield (kg) per sample spot						

* t values significant at 0.1%, ** t values significant at 0.5% and *** t values significant at 1 % probability level

Appendix 9: Rainfall records for 35 years at Kabete meteorological station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2012	0	16	5	353	262	39.9	23.4	42.4	8.9	241.5	261.8	244.7	**1498.2**
2011	4.2	66.3	148	80.7	93.9	47.8	14.3	26.9	32.5	154.2	175.7	245.5	**1089.7**
2010	143.5	73.8	250	253	266.1	51.9	2	29.9	19.9	64.3	93.3	74.5	**1322.3**
2009	42.8	18.1	76.6	75.7	84.1	23.8	6.8	2.3	6.3	141.8	110.2	185.7	**774.2**
2008	51.4	31.6	178	158	19	5.7	64.7	9.1	46.6	165.1	209.6	5.3	**944.4**
2007	30.2	90	52.6	348	184.2	83.1	25.2	52.6	89.1	25	66.6	42.4	**1089.4**
2006	15	25.9	207	276	209.7	7.2	5.2	26	22.1	60.2	346	246.1	**1446.2**
2005	77.8	45.7	105	210	254.3	27.2	26.8	8.5	28.2	32.7	88.6	0.5	**905.2**
2004	189.5	45.3	87.2	412	190.3	10.4	6.2	0.2	16.1	82	115.4	58.1	**1212.3**
2003	28.4	12	61.6	219	318.9	30.2	3.1	54.3	27.8	54.7	117.1	14.1	**941.4**
2002	52	69.1	90.2	279	134.3	1.6	6.6	4.1	22.3	59.1	157.2	230.9	**1106.1**
2001	371.6	3.2	167	119	87.3	79.4	16.2	23.4	19.5	95.3	181.7	13.3	**1176.1**
2000	5.4	0	41.7	254	95.1	57.9	4.1	6.1	53.5	18.4	187.7	111.3	**835.6**
1999	16	0.9	180	180	31.2	2.7	11.9	29.6	35.1	21.4	44.6	228	**780.9**
1998	327.6	274.2	101	152	327.2	63.1	22.6	21.3	33.4	54.8	60.9	11.3	**1449.5**
1997	4.7	0	29.2	541	105.8	23.1	21.5	164	0	158.6	324.4	219.8	**1592.3**
1996	12.9	36.4	110	91.1	89.2	51.5	35.6	36.6	37	1.3	209.7	2.6	**714.0**
1995	8.6	139.7	166	259	244.4	124	19.2	30.8	51.4	104	149.2	62.2	**1358.3**
1994	4.9	35.5	56.3	237	84.4	44.4	19.5	33.9	1.3	87.8	301.1	64.7	**971.0**
1993	203.4	53.1	61.4	45.9	41.4	61.1	3.5	3.9	0	30.9	108.4	180.2	**793.2**
1992	5	70.2	5.6	402	216.5	20.6	29.4	3.8	16.3	70.5	112.6	86.4	**1038.6**
1991	33.9	0.4	84.8	158	281.4	12.5	12.9	40.3	2.8	21.6	199.4	50.7	**899.0**
1990	51.6	47.8	200	275	309.3	6.5	13.6	21	31.8	90	126	74.6	**1247.1**
1989	134.6	45.1	94.1	210	496.8	27.5	44.2	25.2	91.1	84.3	102.9	186	**1541.7**
1988	96	20.5	172	466	245.9	50.9	18.7	46.9	27.1	167	105.3	139.1	**1555.4**
1987	79.5	95.5	15.4	279	145	95.1	10.4	13.4	17.4	5.7	182.1	15.3	**953.7**
1986	6.4	0.2	62.8	238	314.4	29.5	6.2	2.3	4.3	40.4	202	91.5	**997.6**
1985		94.1	171	200	80.4	16.2	30.1	8.7	37.3	42.1	137.9	72.8	**891.1**
1984	3.7	0.7	17	53.8	9.7	6.1	23.4	15.3	24.3	138.7	132.3	64.7	**489.7**
1983	3.4	180.7	54.5	234	45.8	52.5	17.7	41.1	99	52.7	34.8	320.9	**1136.7**
1982	0.5	13.4	49.9	242	243.2	14.9	29.7	11	41.5	140	233.6	112.6	**1132.1**

Source: Kabete Meteorological Station

Appendix 10: 12 year records of maximum and minimum temperatures

	YEAR	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
JAN	**Max**	22.9	24.6	24.3	24.5	25.4	25.2	23.6	24.5	24.8	23.7	25.3	
	Min	13.6	13.8	13.6	14.3	14.3	13.7	14.3	13.3	13.8	14	13.3	11.9
FEB	**Max**	24.2	26	26.7	24.1	27.6	26.5	25.4	25.1	25.2	24.9	26.5	26.4
	Min	14	13.5	13.6	14.3	13.9	14.3	13.9	13.3	14	15	13.6	13.5
MAR	**Max**	24.2	24.5	26.4	25.2	25.8	25.2	25	25.5	26.7	23.9	25.7	26.6
	Min	13.9	14.4	14.5	15.3	15.1	15.1	14.4	14.5	14.7	14.8	14.6	13.9
APR	**Max**	23.1	22.8	25	23.5	24.3	22.3	24.2	23.1	24.7	23.8	24	23.9
	min	14.9	15.1	15.2	14.9	14.9	14.9	14.9	14.1	15.2	15.5	15.3	15
MAY	**max**	22.5	22.8	22.3	23	23.1	22.6	22.6	22.4	23.2	22.5	23.3	23.5
	min	14.1	14.3	14.6	14	14.6	14	14.5	13.6	14.7	14.8	14.7	14.2
JUN	**max**	21.3	21.7	21.3	18.3	20.9	22.2	22.2	21.4	22.7	21.5	23.2	
	min	12	12.2	12.8	11.5	12.8	12.4	12.7	11.7	13.2	13.5	13.5	
JUL	**max**	20.3	22.2	20.6	22.6	20.1	19.9	20.5	20.2	24.1	21.1	23.4	21.4
	min	11	10.9	11.3	10	11.4	12	12.1	11.7	10.7	11.5	11.3	12
AUG	**max**	22.4	20.7	21.1	22.3	20.9	22.9	20.9	21.8	21.6	21.5	21.2	
	min	11.4	12.2	11.5	11	11.6	11.5	12.5	12.5	12.5	11.8	12.7	
SEP	**max**	24.5	23.8	23	24.5	23.2	22.7	22.6	24.5	25.1	23.8	23.9	
	min	12.2	12.3	12.6	12.5	12.1	12.4	16.4	12.1	12.8	12	13.2	
OCT	**max**	24.3	24.3	24.3	23.8	24.8	24.8	23.6	24.3	23.7	24.8	23.9	
	min	13.4	14.1	13.4	13.9	13.5	14	14	14.4	14.1	13.8	14.5	
NOV	**max**	21.9	23	22.8	22.7	23.2	22	22.8	23.4	23.2	22.5	23	
	min	14	14.8	14.4	14.5	14.2	14.7	14.5	14.4	14.7	14.4	14.6	
DEC	**max**	22.9	22.9	23.8	23.8	24.8	22.9	23.1	24.3	23.4	23.7	23.2	
	min	13.8	14.3	13.3	14.4	13.5	14.6	13.6	14	14.4	13.8	14	

Source: Kabete Meteorological Station

Appendix 11: Records of relative humidity of the study area between 2001-2012

	YEAR	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
JAN	**600**	81.5	79	77	81	71	76	81	75	72	76	68.5	63
	1200	63.9	53	49	56	43	44	60.3	48	45	57	40.5	41
FEB	**600**	80	69	69	79	65.4	73.4	73.5	70	78.4	83	66.6	67.2
	1200	46	42	41	55	38.1	42.3	49.7	30	43	59	39.8	39
MAR	**600**	82	86	76	81.6	79.7	82.1	78.6	80.6	75.6	83.6	77	69.9
	1200	49	55	41	50	45.6	46.5	48.5	49	37.8	60.9	46.3	36.9
APR	**600**	88	90	82	88	84	87	88.3	88.9	83	87.3	84.2	85.9
	1200	62	63	52	64	57	67	58.8	57.2	51	61.8	55.7	62.6
MAY	**600**	84	88	87	83	85	86.5	83.7	84	87	86	87.5	85.1
	1200	62	64	67	60	65	63.3	64.8	57.3	64	67	62.7	67.5
JUN	**600**	86	86	86	83	88	82	85.3	85	83	87	88	
	1200	60	59	63	55	64	61	62.2	58	55	65	66.2	
JUL	**600**	88	85	79	80	86.5	88	87	88	83.4	85.7	84	89.1
	1200	65	53	63	49	78.2	65	67	63	54.1	59.5	63.3	66.4
AUG	**600**	82	87	68.4	82	88.6	83.3	88	84	86	88	87.2	
	1200	53	60	66.6	52	73.4	52.3	66	61	60	61	63.3	
SEP	**600**	82	80	85.3	80	81	83	83.3	79	44	81.8	83.3	
	1200	47	46	56.5	43	53	53	54.8	49	77	51.6	53.5	
OCT	**600**	83	83	82	82	80	77.8	84.8	87	83.9	80	86.4	
	1200	50	50	52	52	47	44.5	51.3	53	52.2	48	56.7	
NOV	**600**	89	88	84	87	84	91	88	82	85	88.4	88.1	
	1200	67	59	60	59	54	68	59	58	56	60.5	63.9	
DEC	**600**	83	86	76	83	69	85	76	76	84	78	81	
	1200	59	62	51	56	42	68	51.9	46	60	54	58	

Source: Kabete Meteorological Station

Appendix 12: Proposed matrix model of inputs application for KFS Coffee Estate

INPUT	**RATE**	**MONTH**											
		June	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
(a)Nutrition													
Lime	As per Soil test		x							x			
Urea	5kg / Ha		x		x		x	x		x	x		x
Epsom	2kg /Ha	X					x				X		X
NPK	250g/ tree			X									
CAN / ASN	450g / tree	X									X	X	X
TSP												X	
MOP	3kg /Ha		x		x		x	x		x	x		x
Boron	3kg /Ha		x						x				
Zinc	3kg/ Ha		x						x				
Phosphoric acid	3 litres/Ha		x		x		x	x		x	x		x
Manure									x	x			
(b) Protection													
Dursban	1000ml/Ha	X						x					
Touch Down	1 lt / Ha												
Daconil (.22)	2.2lts/Ha	X					x					x	x
Copper	5.5kg/Ha	X	x		x		x			x			x
Round Up	1L/Ha	X			x			x			x		

Adopted from CRF with modification by the author, 2014

Appendix 13: Proposed labour utilization model chart for KFS coffee estate

ACTIVITY	TASK	MONTH OF APPLICATION	TARGETED AREA	TOTAL *M/D/cherry debes	COST
1. Pruning (a) Handling (b) Desuckering (c) Main Pruning (d) Change of cycle	30-35 trees per mndys 180 trees per *m/d 27 trees per *m/d 189 trees per mndys	 March/April, July/August May/June December/January January	 79,728 79,728 79,728 4,414	 2,006 **m/d 245 *m/d 817 *m/d 23 *m/d	
2. Weed Control (a) Slashing (b) Herbicide Spray	190 trees per mndys 189 trees per mdys	Nov/Dec, March/April, Aug/Sept, Dec/Jan, May/June	 Whole farm Whole farm	 348 *m/d 350 *m/d	
3. Disease Control (a) Fungicide Spray	189 tree per mndys	Dec/Jan, Feb/Mar, Apr, May, June, Jul, Sept/Oct. and Nov.	 3,000	 127 *m/d	
4. Insecticide	189 tree per *m/d	Feb/March, May/June	22,070	78 *m/d	
5. Fertilizer (a) NPK/AN (b) Urea /AS/CAN (c) Foliar feeds	3 bags /*m/d 3 bags/*m/d 190 trees/*m/d	September March/Apri, May/June Feb, March, June, Aug & Nov.	22,070 22,070 22,070	37 *m/d 44 *m/d 580 *m/d	
6.Coffee Processing (Factory Labour) (a) Early Crop (b) Main Crop (c) Mbuni Stripping	2 *m/d 7 *m/d 2 *m/d	March , April, May &June July, August, Sept. Oct. & Nov December/August		240 *m/d 1050 *m/d 120 *m/d	
7.Coffee Cherry Picking (a) Early picking (b) Late picking (c) Mbuni		March/early August Sept. – December December - January	7.5 tonnenes 18 “ 4.5	3750 debes 9000 “ 2250 debes	
8. Coffee Infilling Hole making Hole filling Manure application Planting seedlings Seedling Attendants	25 holes/*m/d 50 holes *m/d 100 holes/ *m/d 90 seedlings/ *m/d 2 *m/d running/1yr	Jan/Feb Early March Jan/Feb March/April One year	…. in fills		 26 *m/d 13 *m/d 7 *m/d 7 *m/d 520 *m/d
9.Diversification Estates Maintenance	 1 *m/d running				 260* *m/d
Office Maintenance	1 *m/d running				260
Machinery Factory facility repair	Service contract	Feb/March, Aug/September	Main Pulping System, Water Recirculation system, sorting and Pulp Composting Yard and rehabilitation of Storage Facility		780

Adopted from CRF annual report (2012) and modified by the author *m/d= mandays

Appendix 14: Table of coffee production and earnings from 1963 to 2012

Year	Estate(MT)	Co-operative(MT)	National(MT)	Value(kshs. Billions)
1963/64	28,405	15,373	43,778	0.29
1964/65	22,393	14,774	37,167	0.3
1965/66	25,683	25,523	51,206	0.39
1966/67	35,231	27,558	62,789	0.31
1967/68	13,246	20,515	33,761	0.27
1968/69	22,242	23,264	45,506	0.3
1969/70	26,521	26,275	52,796	0.4
1970/71	28,600	26,302	54,902	0.42
1971/72	29,984	28,362	58,346	0.49
1972/73	40,207	35,770	75,977	0.67
1973/74	32,131	41,150	73,281	0.8
1974/75	30,293	35,828	66,121	0.61
1975/76	38,076	36,520	74,596	1.64
1976/77	51,662	49,556	101,218	3.97
1977/78	35,159	49,833	84,992	2.19
1978/79	27,343	46,994	74,337	1.94
1979/80	39,398	52,284	91,682	2.26
1980/81	35,084	64,633	99,717	2.11
1981/82	34,595	52,842	87,437	2.42
1982/83	33,218	52,846	86,064	2.98
1983/84	54,546	75,084	129,630	4.72
1984/85	29,061	65,028	94,089	4.36
1985/86	45,914	68,957	114,871	6.24
1986/97	36,606	68,332	104,938	3.38
1987/88	44,774	84,863	129,637	5.63
1988/89	38,867	78,782	117,649	3.75
1989/90	34,589	69,954	104,543	4
1990/91	35,452	51,839	87,291	4.35
1991/92	37,903	52,419	90,322	4.24
1992/93	32,781	42,426	75,207	8.62
1993/94	33,369	40,147	73,516	13.71
1994/95	32,948	62,858	95,806	15.8
1995/96	40,351	57,225	97,576	16.95
1996/97	30,034	38,644	68,678	18.35
1997/98	22,050	33,584	55,634	13.23
1998/99	28,591	40,086	68,677	11.71
1999/00	38,585	62,265	100,850	10.5
2000/01	26,743	23,800	50,543	8.57
2001/02	23,073	28,822	51,895	6.76
2002/03	21,417	34,026	55,443	5.7
2003/04	18,473	29,958	48,431	6.7
2004/05	20,745	24,500	45,245	8.33
2005/06	21,975	26,860	48,835	9.7
2006/07	25,190	29,150	54,340	8.7
2007/08	19,740	23,260	43,000	9
2008/09	24,640	29,360	54,000	10
2009/10	19,720	20,280	40,000	16
2010/11	16,660	19,662	36,322	22
2011/12	21,982	27,978	49,960	19

Source: CBK annual reports as compiled by the author

Appendix 15(a): Grid Point Laboratory Test results for KFS coffee farm 2013-Top Soil

Grid point	Alt(M)	Y	X	Lab No	Depth	pH	Hp me%	Na me%	K me%	Ca me%	Mg me%	Mn me%	P ppm	%N	% C	C:N ratio	Ca+Mg/K
38	1851	1.24457	36.74255	1043	0 - 15 cm	5.3	-	0.33	1.81	8.40	3.05	0.54	3	0.24	2.36	10	6.33
39	1854	1.24462	36.7421	1045	0 - 15 cm	5.4	-	0.27	1.93	12.70	2.97	0.56	3	0.26	2.67	10	8.12
40	1859	1.24402	36.74202	1047	0 - 15 cm	4.9	-	0.17	0.91	4.30	2.55	0.34	2	0.22	2.63	12	7.53
41	1856	1.24436	36.74109	1049	0 - 15 cm	5.2	-	0.24	1.20	6.41	2.90	0.49	4	0.24	2.15	9	7.76
42	1851	1.24370	36.74061	1051	0 - 15 cm	5.3	-	0.29	0.82	9.30	2.74	0.42	1	0.25	2.94	12	14.68
43	1853	1.24399	36.74006	1053	0 - 15 cm	5.5	-	0.45	1.76	11.10	2.97	0.47	1	0.26	2.63	10	7.99
44	1851	1.24381	36.74089	1055	0 - 15 cm	5.2	-	0.25	1.68	13.50	2.94	0.37	1	0.27	2.94	11	9.79
45	1854	1.24431	36.74147	1057	0 - 15 cm	5.0	-	0.34	2.51	11.00	3.03	0.70	2	0.22	2.6	12	5.59
46	1856	1.24406	36.74222	1059	0 - 15 cm	5.2	-	0.22	1.09	7.60	2.91	0.38	1	0.19	2.56	13	9.64
47	1852	1.24420	36.74071	1061	0 - 15 cm	5.4	-	0.25	1.77	7.11	2.90	0.58	2	0.18	2.63	15	5.66
48	1855	1.24383	36.74166	1063	0 - 15 cm	5.2	-	0.29	1.31	5.41	2.94	0.29	4	0.24	2.75	11	6.37
49	1850	1.24441	36.74202	1065	0 - 15 cm	5.2	-	0.29	1.69	8.59	3.02	0.61	3	0.26	2.71	10	6.87
50	1855	1.24644	36.74278	1097	0 - 15 cm	5.2	-	0.16	1.41	5.22	2.85	0.51	4	0.26	2.4	9	5.72
51	1854	1.24682	36.74256	1099	0 - 15 cm	5.4	-	0.27	1.40	7.86	2.98	0.61	4	0.26	2.63	10	7.74
52	1853	1.24724	36.23700	1101	0 - 15 cm	5.2	-	0.05	1.19	7.71	2.84	0.36	5	0.30	2.83	9	8.87
53	1847	1.24753	36.74233	1103	0 - 15 cm	5.2	-	0.19	1.73	7.28	2.96	0.61	5	0.30	2.87	10	5.92
54	1853	1.24798	36.74258	1105	0 - 15 cm	5.0	-	0.18	1.62	4.98	2.94	0.62	4	0.28	2.72	10	4.89
55	1850	1.24753	36.74315	1107	0 - 15 cm	5.0	-	0.17	1.52	4.25	2.67	0.60	5	0.27	2.52	9	4.55
56	1852	1.24715	36.74315	1109	0 - 15 cm	5.0	-	0.17	1.75	7.58	2.60	0.54	4	0.28	2.44	9	5.82
57	1848	1.24656	36.74346	1111	0 - 15 cm	5.2	-	0.17	1.54	7.20	3.01	0.56	5	0.29	2.67	9	6.63
58	1846	1.24644	36.74421	1113	0 - 15 cm	5.0	-	0.19	1.49	4.69	2.87	0.51	6	0.27	2.44	9	5.07
59	1849	1.24691	36.74391	1115	0 - 15 cm	4.9	0.25	0.17	1.11	2.84	2.68	0.39	4	0.24	2.98	12	4.97
60	1849	1.24738	36.74366	1117	0 - 15 cm	4.7	0.25	0.02	1.21	5.84	2.95	0.42	4	0.25	2.87	11	7.26
61	1849	1.24788	36.74346	1119	0 - 15 cm	5.0	-	0.01	1.46	6.63	2.96	0.75	4	0.28	2.63	9	6.57
62	1854	1.24827	36.743	1121	0 - 15 cm	5.2	-	0.16	1.21	7.98	2.91	0.50	4	0.29	2.29	8	9.00
63	1845	1.24860	36.74334	1123	0 - 15 cm	5.2	-	0.16	1.46	8.12	2.92	0.52	4	0.26	2.29	9	7.56
64	1854	1.24815	36.7437	1125	0 - 15 cm	5.0	-	0.18	1.07	5.38	2.89	0.56	4	0.25	2.27	9	7.73
65	1850	1.24769	36.74422	1127	0 - 15 cm	4.8	0.55	0.01	0.88	2.11	2.52	0.46	1	0.22	2.29	10	5.26
66	1847	1.24705	36.74449	1129	0 - 15 cm	4.9	0.35	0.15	1.13	3.57	2.83	0.29	1	0.22	2.13	10	5.66
67	1845	1.24621	36.74472	1131	0 - 15 cm	4.9	0.35	0.01	1.41	3.55	2.85	0.01	1	0.26	2.94	11	4.54
68	1853	1.25088	36.74482	1011	0 - 15 cm	4.9	0.20	0.24	1.22	4.34	2.78	0.77	5	0.26	2.63	10	5.84

69	1849	1.25126	36.74516	1013	0 - 15 cm	4.9	0.15	0.17	0.93	4.20	2.64	0.67	1	0.25	2.6	10	7.35
70	1847	1.25151	36.74561	1015	0 - 15 cm	4.8	0.40	0.13	1.16	3.91	2.63	0.53	1	0.22	2.56	12	5.64
71	1850	1.25181	36.74613	1017	0 - 15 cm	5.4	-	0.20	1.23	6.27	2.88	0.78	1	0.20	2.09	10	7.44
72	1855	1.25129	36.74455	1019	0 - 15 cm	4.7	0.65	0.19	0.83	1.17	2.43	0.76	2	0.22	2.32	11	4.30
73	1845	1.25153	36.74501	1021	0 - 15 cm	5.0	-	0.15	0.82	5.05	2.53	0.37	1	0.24	2.75	11	9.24
74	1846	1.25181	36.74548	1023	0 - 15 cm	5.0	-	0.17	1.36	5.30	2.67	0.65	1	0.24	2.56	11	5.86
75	1849	1.25212	36.74607	1025	0 - 15 cm	5.4	-	0.21	1.61	12.80	2.99	0.74	1	0.22	2.32	11	9.81
76	1846	1.25252	36.74564	1027	0 - 15 cm	5.3	-	0.19	1.63	6.18	2.82	0.60	3	0.22	2.63	12	5.52
77	1845	1.25225	36.74513	1029	0 - 15 cm	4.9	0.30	0.20	1.42	4.01	2.74	0.80	2	0.23	2.6	11	4.75
78	1860	1.25194	36.74460	1031	0 - 15 cm	4.9	0.25	0.20	1.03	4.42	2.72	0.72	1	0.25	2.79	11	6.93
79	1859	1.25167	36.74407	1033	0 - 15 cm	5.2	-	0.24	1.26	8.85	2.99	0.64	2	0.25	2.72	11	9.40
80	1850	1.25226	36.74405	1035	0 - 15 cm	4.9	0.35	0.21	1.47	3.62	2.68	0.66	3	0.26	2.87	11	4.29
81	1846	1.25265	36.74449	1037	0 - 15 cm	4.9	0.25	0.18	1.13	3.89	2.54	0.57	2	0.25	2.6	10	5.69
82	1845	1.25292	36.74496	1039	0 - 15 cm	5.4	-	0.37	2.04	8.69	2.94	0.93	4	0.26	2.75	11	5.70
83	1846	1.25326	36.74553	1041	0 - 15 cm	5.4	-	0.38	2.42	6.41	2.94	0.83	5	0.27	2.44	9	3.86
84	1846	1.25310	36.74463	1067	0 - 15 cm	5.4	-	0.28	2.40	14.10	3.03	0.60	10	0.29	2.71	9	7.14
85	1845	1.25332	36.74501	1069	0 - 15 cm	5.2	-	0.25	2.09	8,18	2.29	0.69	5	0.24	2.48	10	5.01
86	1852	1.25369	36.74548	1071	0 - 15 cm	5.2	-	0.18	1.60	10.30	2.82	0.55	5	0.28	2.75	10	8.20
87	1849	1.25400	36.74512	1073	0 - 15 cm	4.9	0.25	0.27	1.56	3.27	2.65	0.52	5	0.23	2.94	13	3.79
88	1851	1.25380	36.74464	1075	0 - 15 cm	5.3	-	0.27	1.94	7.44	1.65	0.38	5	0.26	2.71	10	4.69
89	1848	1.25352	36.74420	1077	0 - 15 cm	5.2	-	0.22	2.38	9.10	1.70	0.56	4	0.26	2.75	11	4.54
90	1849	1.25406	36.74401	1079	0 - 15 cm	5.4	-	0.22	2.39	7.88	1.68	0.69	5	0.25	2.32	9	4.00
91	1846	1.25428	36.74447	1081	0 - 15 cm	4.8	0.45	0.13	1.62	3.68	1.58	0.46	4	0.21	2.01	10	3.25
92	1847	1.25457	36.74499	1083	0 - 15 cm	5.0	-	0.17	1.71	3.27	2.88	1.06	2	0.21	2.32	11	3.60
93	1848	1.25498	36.74463	1085	0 - 15 cm	5.0	-	0.10	1.68	3.07	2.78	0.96	5	0.24	1.9	8	3.48
94	1852	1.25475	36.74417	1087	0 - 15 cm	5.0	-	0.18	1.78	5.93	2.93	0.86	3	0.25	2.29	9	4.98
95	1850	1.25449	36.74363	1089	0 - 15 cm	5.0	-	0.09	1.49	5.98	2.78	0.16	4	0.25	2.36	9	5.88
96	1847	1.25496	36.74339	1091	0 - 15 cm	4.8	0.55	0.06	1.56	2.57	2.85	0.01	4	0.24	2.83	12	3.47
97	1850	1.25519	36.7438	1093	0 - 15 cm	4.7	0.65	0.10	1.12	2.31	2.25	0.06	4	0.23	2.29	10	4.07
98	1851	1.25551	36.74438	1095	0 - 15 cm	4.9	0.30	0.10	1.40	3.42	2.69	0.73	4	0.25	2.44	10	4.36

Appendix 15(b): Grid Point Laboratory Test results for KFS coffee farm 2013-Sub Soil

Grid point	Alt(M)	Y	X	Lab No	Depth	pH	Hp me%	Na me%	K me%	Ca me%	Mg me%	Mn me%	P ppm	%N	% C	C:N ratio	Ca+Mg/K
38	1851	1.2446	36.74255	1044	15 - 30 cm	5.3	-	0.27	1.64	10.50	3.04	0.55	2	0.22	2.32	11	8.26
39	1854	1.2446	36.7421	1046	15 - 30 cm	5.5	-	0.27	1.55	10.30	2.87	0.41	2	0.24	2.29	10	8.50
40	1859	1.244	36.74202	1048	15 - 30 cm	5.4	-	0.28	1.34	6.19	2.95	0.53	3	0.24	2.29	10	6.82
41	1856	1.2444	36.74109	1050	15 - 30 cm	5.4	-	0.29	1.83	11.00	2.92	0.43	5	0.25	2.6	10	7.61
42	1851	1.24370	36.74061	1052	15 - 30 cm	5.4	-	0.19	0.63	10.80	2.73	0.36	1	0.25	2.75	11	21.48
43	1853	1.244	36.74006	1054	15 - 30 cm	5.4	-	0.25	1.87	10.70	2.99	0.63	1	0.26	2.75	11	7.32
44	1851	1.2438	36.74089	1056	15 - 30 cm	5.3	-	0.26	1.60	11.60	2.94	0.39	2	0.27	2.87	11	9.09
45	1854	1.2443	36.74147	1058	15 - 30 cm	5.0	-	0.23	2.22	10.80	3.02	0.62	2	0.22	2.79	13	6.23
46	1856	1.2441	36.74222	1060	15 - 30 cm	5.0		0.25	0.89	5.55	2.79	0.31	2	0.21	2.63	13	9.37
47	1852	1.24420	36.74071	1062	15 - 30 cm	5.5	-	0.26	1.50	6.14	2.85	0.38	1	0.21	2.75	13	5.99
48	1855	1.2438	36.74166	1064	15 - 30 cm	4.9	0.30	0.19	0.78	3.96	2.61	0.20	4	0.23	2.56	11	8.42
49	1850	1.2444	36.74202	1066	15 - 30 cm	5.3	-	0.27	1.50	9.30	2.29	0.48	3	0.26	2.52	10	7.73
50	1855	1.2464	36.74278	1098	15 - 30 cm	5.4	-	0.13	1.06	8.30	2.81	0.16	4	0.25	2.63	11	10.48
51	1854	1.2468	36.74256	1100	15 - 30 cm	5.2	-	0.47	1.45	8.09	3.00	0.67	4	0.26	2.56	10	7.65
52	1853	1.2472	36.237	1102	15 - 30 cm	5.4	-	0.18	1.61	12.40	3.04	0.68	5	0.29	3.02	10	9.59
53	1847	1.2475	36.74233	1104	15 - 30 cm	5.2	-	0.15	1.71	6.27	2.89	0.80	6	0.32	2.98	9	5.36
54	1853	1.248	36.74258	1106	15 - 30 cm	5.4	-	0.01	1.54	5.57	2.77	0.50	4	0.24	2.36	10	5.42
55	1850	1.2475	36.74315	1108	15 - 30 cm	4.9	0.25	0.14	1.13	4.11	2.96	0.33	5	0.24	2.32	10	6.26
56	1852	1.2472	36.74315	1110	15 - 30 cm	5.0	-	0.12	0.96	4.95	2.85	0.07	3	0.26	2.32	9	8.3
57	1848	1.2466	36.74346	1112	15 - 30 cm	5.4	-	0.02	1.71	10.10	2.87	0.45	3	0.25	2.29	9	7.58
58	1846	1.2464	36.74421	1114	15 - 30 cm	5.0	-	0.17	1.13	4.19	2.77	0.39	4	0.25	2.32	9	6.16
59	1849	1.2469	36.74391	1116	15 - 30 cm	4.8	0.55	0.15	1.04	2.56	2.66	0.35	4	0.22	2.44	11	5.02
60	1849	1.2474	36.74366	1118	15 - 30 cm	5.5	-	0.01	1.29	6.66	2.99	0.47	4	0.26	3.44	13	7.48
61	1849	1.2479	36.74346	1120	15 - 30 cm	5.1	-	0.02	1.32	5.05	2.90	0.01	6	0.28	2.67	10	6.02
62	1854	1.2483	36.743	1122	15 - 30 cm	5.5	-	0.01	1.12	8.53	2.97	0.54	3	0.24	2.29	10	10.27
63	1845	1.24860	36.74334	1124	15 - 30 cm	5.3	-	0.17	1.40	7.95	3.01	0.38	4	0.22	1.94	9	7.83
64	1854	1.2482	36.7437	1126	15 - 30 cm	5		0.01	0.94	5.26	2.94	0.40	4	0.21	1.74	8	8.72
65	1850	1.2477	36.74422	1128	15 - 30 cm	4.8	0.50	0.16	0.74	2.84	2.44	0.34	1	0.18	1.28	7	7.14
66	1847	1.2471	36.74449	1130	15 - 30 cm	4.9	0.25	0.01	1.31	3.79	2.93	0.63	1	0.23	2.63	11	5.13
67	1845	1.2462	36.74472	1132	15 - 30 cm	4.9	0.25	0.01	1.52	3.92	2.94	0.45	1	0.25	2.27	9	4.51
68	1853	1.2509	36.74482	1012	15 - 30 cm	5.0	-	0.21	1.04	5.90	2.90	0.57	1	0.23	2.63	11	8.46
69	1849	1.2513	36.74516	1014	15 - 30 cm	5.0	-	0.14	0.78	5.41	2.80	0.56	1	0.19	2.63	14	10.53
70	1847	1.2515	36.74561	1016	15 - 30 cm	5.2	-	0.17	1.19	7.15	2.91	0.62	1	0.21	2.09	10	8.45
71	1850	1.2518	36.74613	1018	15 - 30 cm	5.3	-	0.20	1.28	6.83	2.96	0.47	1	0.16	2.21	14	7.65

72	1855	1.2513	36.74455	1020	15 - 30 cm	4.7	0.70	0.14	0.62	1.83	2.44	0.54	2	0.22	2.19	10	6.89
73	1845	1.2515	36.74501	1022	15 - 30 cm	5.4	-	0.26	1.32	11.00	3.01	0.87	2	0.26	2.72	10	10.61
74	1846	1.2518	36.74548	1024	15 - 30 cm	5.4	-	0.29	1.47	11.20	2.97	0.62	1	0.20	2.29	11	9.64
75	1849	1.2521	36.74607	1026	15 - 30 cm	5.0	-	0.22	1.50	5.66	2.76	0.62	3	0.24	2.94	12	5.61
76	1846	1.2525	36.74564	1028	15 - 30 cm	5.2	-	0.17	1.30	11.80	2.97	0.66	1	0.22	2.44	11	11.36
77	1845	1.2523	36.74513	1030	15 - 30 cm	5.2	-	0.18	1.04	6.27	2.79	0.48	1	0.20	2.4	12	8.71
78	1860	1.2519	36.7446	1032	15 - 30 cm	4.9	0.20	0.15	0.83	4.63	2.65	0.45	1	0.23	2.52	11	8.77
79	1859	1.2517	36.74407	1034	15 - 30 cm	5.0	-	0.29	1.06	4.94	2.81	0.54	5	0.28	2.79	10	7.31
80	1850	1.2523	36.74405	1036	15 - 30 cm	5.0	-	0.27	1.47	5.96	2.82	0.62	3	0.27	2.72	10	5.97
81	1846	1.2527	36.74449	1038	15 - 30 cm	5.4	-	0.28	1.31	7.01	2.84	0.56	1	0.24	2.4	10	7.52
82	1845	1.2529	36.74496	1040	15 - 30 cm	5.3	-	0.27	1.44	10.00	2.94	0.51	2	0.24	2.52	11	8.99
83	1846	1.2533	36.74553	1042	15 - 30 cm	5.2	-	0.26	1.42	7.46	2.87	0.62	2	0.22	2.29	10	7.27
84	1846	1.2531	36.74463	1068	15 - 30 cm	5.3	-	0.26	1.93	14.10	3.00	0.48	6	0.28	2.6	9	8.86
85	1845	1.2533	36.74501	1070	15 - 30 cm	5.0	-	0.24	1.25	5.41	2.74	0.44	5	0.22	2.36	11	6.52
86	1852	1.2537	36.74548	1072	15 - 30 cm	5.4	-	0.28	1.50	12.50	2.94	0.69	5	0.28	2.48	9	10.29
87	1849	1.254	36.74512	1074	15 - 30 cm	4.8	0.55	0.17	1.25	2.40	2.42	0.44	5	0.23	2.13	9	3.86
88	1851	1.2538	36.74464	1076	15 - 30 cm	5.3	-	0.28	1.57	7.92	1.66	0.50	2	0.21	2.25	11	6.10
89	1848	1.2535	36.7442	1078	15 - 30 cm	5.2	-	0.32	1.65	7.31	1.64	0.72	3	0.24	2.25	9	5.42
90	1849	1.2541	36.74401	1080	15 - 30 cm	5.2	-	0.39	1.69	7.82	1.62	0.42	3	0.26	2.36	9	5.59
91	1846	1.2543	36.74447	1082	15 - 30 cm	4.7	0.65	0.08	1.21	2.22	2.55	0.55	5	0.23	2.32	10	3.94
92	1847	1.2546	36.74499	1084	15 - 30 cm	4.9	0.3	0.07	1.23	3.06	2.72	0.01	3	0.20	1.98	10	4.70
93	1848	1.255	36.74463	1086	15 - 30 cm	4.8	0.55	0.07	1.40	2.47	2.55	1.03	5	0.24	2.25	9	3.59
94	1852	1.2548	36.74417	1088	15 - 30 cm	4.9	0.20	0.10	1.76	3.90	2.85	0.56	5	0.26	2.25	9	3.84
95	1850	1.2545	36.74363	1090	15 - 30 cm	5.2	-	0.06	1.19	6.16	2.76	0.47	3	0.25	2.17	9	7.50
96	1847	1.255	36.74339	1092	15 - 30 cm	4.9	0.35	0.08	1.84	4.47	2.99	0.01	3	0.22	2.83	13	4.05
97	1850	1.2552	36.7438	1094	15 - 30 cm	4.8	0.50	0.08	1.57	3.16	2.79	0.37	4	0.22	2.05	9	3.79
98	1851	1.2555	36.74438	1096	15 - 30 cm	5.2	-	0.11	1.4	5.82	2.85	1.24	3	0.25	2.29	9	6.19