EFFECT OF VARYING RATES OF ORGANIC AND INORGANIC FERTILIZERS ON GROWTH, YIELD AND NUTRIENT USE EFFICIENCY OF CLONAL TEA (*Camellia Sinensis L. [O*] Kuntze)

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DECLARATION

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

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DEDICATION

My special dedication goes to my wife, Evaline Akinyi Odero, for her encouragement, patience and assistance both financially and morally throughout this period of study. May the Almighty God bless her.

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ABSTRACT

Small scale tea farmers apply inorganic NPK fertilizers annually in a bid to increase tea yields but the cost of fertilizers has been increasing leading to the reduction in the net returns. A study was conducted to determine the effect of varying rates of organic and inorganic fertilizers on the soil chemical properties, growth, yield and nutrient use efficiencies of clonal tea. Experiments were set up at Kianjokoma in Embu County in 2014/2015 production year. The fertilizers used were organic Rutuba® and inorganic NPK (26.5.5). The treatments comprised: no-fertilizer control, 625 kg NPK/ha, 937.5 kg NPK/ha, 1875 kg NPK/ha, 625 kg Rutuba/ha + 625 kg NPK /ha, 625 kg Rutuba/ha, 937.5 kg Rutuba/ha and 1875 kg Rutuba/ha. These treatments were laid out in a randomized complete block design and replicated three times. Crop data collected comprised green leaf yield, black made tea yield, leaf length and leaf width. Soils data collected at the end of the experiment included pH, exchangeable acidity, organic carbon, micronutrients and macronutrients. Nitrogen, phosphorus and potassium plant use efficiencies were also determined. The cost and net revenue for each of the fertilizer treatments were also calculated. Data were subjected to analysis of variance and mean separation was done using the least significant difference test at $p \leq 0.05$. The use of organic Rutuba increased the soil pH, Mn, Cu, Fe, Zn, Ca and Mg levels. Application of 625 kg Rutuba/ha + 625 kg NPK/ha resulted to increased leaf length, leaf width, fresh green leaf yield and made tea yield relative to the no-fertilizer control and the farmers' practice. The results indicated that the agronomic efficiency, apparent nutrient recovery and partial factor productivity of N, P and K were significantly enhanced by the application of Rutuba fertilizer relative to inorganic NPK fertilizer. The study further demonstrated that use of NPK 26.5.5 rates of more than 625 kg/ha did not increase growth, yield, nutrient use efficiencies and net returns. However, the study concluded that

organic Rutuba may not be used singly in tea production as it has low levels of macronutrients. Further trials to determine the optimal NPK and Rutuba fertilizers combination as well as the effect of organic Rutuba fertilizer on the quality of tea are recommended.

CHAPTER ONE: INTRODUCTION

1.1 Background information

The Kenyan economy depends highly on agriculture which contributes 25% of the Gross Domestic Product (GDP) and 75% of industrial raw materials (MOA, 2013). The sector further accounts for 65% of Kenya's total exports, 18% and 60% of the formal and informal employment opportunities respectively (MOA, 2013). The agricultural sector comprises the following sub sectors: forestry, fisheries, livestock, food crops, horticulture and industrial crops. One of the major industrial crops is tea (*Camellia sinensis L*.). It plays a key role in the Kenyan agricultural economy contributing 4% to the national GDP (Tea Board of Kenya, 2013) and 26% to the total export earnings (Tabu et al., 2015). In 2013 tea earned the country Ksh. 114 billion and Ksh. 22 billion in export earnings and local sales respectively (TBK, 2013) while in 2014 and 2015 the country earned export earnings of Ksh. 94 and Ksh. 123 billion respectively from tea (KNBS, 2016). Tea is also important for the provision of employment directly to over 639,521 farmers in addition to other employment opportunities in the entire value chain (Onduru et al., 2012) and development of infrastructure in the rural areas.

Tea is the most popular and cheapest beverage worldwide next to water (Onduru et al., 2012) and a very important commercial crop in both the subtropical and tropical regions of the world. Globally tea is produced by plantation farmers but the small scale sector is very key in Kenya and Sri-Lanka (Onduru et al., 2012). The principal tea producers in the world are China, India, Sri-Lanka and Kenya (Gunathilaka et al., 2016). India is the world's largest producer of black tea accounting to 25% of the world's production followed by China and Kenya respectively (Gunathilaka et al., 2016). India consumes 21% of the world tea production with nearly almost

70% of the tea they produce being consumed within India while Kenya exports most of her tea (Gunathilaka et al., 2016).

Tea was first introduced in Kenya in the beginning of the 20th Century in 1904 by the Caine brothers in Limuru but its commercial production started in 1924 (Owuor , 2011; Kagira ,2012). A wide range of ecological conditions support tea growing that have enormous effect on the rates of growth and quality of the tea plant hence different regions have different yields and quality of tea. In Kenya tea is grown in the foothills of Aberdare ranges in the West of the Great Rift Valley and Mount Kenya in the East of the Great Rift Valley (Owuor, 2011). The environmental factors that affect tea yield and quality include drought, temperature, frost, high radiation and soil pH. Tea is grown in regions with relatively well distributed rainfall throughout the year in warm humid tropical regions with a range of soils from loamy to red clays of volcanic origin (Owuor 2011). It is adapted to soils that are deep and well drained with a pH of 4.0-5.0 (Mwaura et al., 2007).

1.2 Problem statement and justification

The prices of tea continue to fall steadily with a record lowest average price of USD 2.53, 2.60 and 2.30 per kg of made tea in 2013, 2015 and 2016 respectively (TBK, 2013; KTDA, 2016). The fall in prices coupled with increased cost of production has made the production of tea an unprofitable venture. The cost of inorganic fertilizers in tea production in Kenya is high (Kagira et al., 2012) and it is ranked second after plucking cost (Njogu et al., 2014) at 33% of the total cost of production (Mwaura et al., 2007) and it continues to rise steadily from time to time. For instance in 2009, the average price of a 50 kilogram bag of fertilizer was Ksh. 1836 compared to Ksh. 1296 in 2007 (Kagira et al., 2012). Farmers are advised to apply 100-200 kg N/ha as NPK

26.5.5. (Tabu et al., 2015). Small scale farmers routinely use the recommended fertilizers in their fields on an annual basis even with these high prices in a bid to increase the yields. This high cost of fertilizer significantly reduces the net returns to the farmer. Furthermore excessive use of inorganic nitrogenous fertilizers leads to contamination of soil and ground water (Nath, 2013a) through leaching and surface runoff. Development of a nutrient management strategy will save the farmers from the high cost of imported fertilizer and enable production in a sustainable manner. Integrated soil fertility management that involves the combined use of organic and inorganic fertilizer is recommended for higher tea yields and quality tea (Tabu et al., 2015; Kekana et al., 2012) and it enables production in a more cost effective manner as organic fertilizers cost low compared to the inorganic fertilizers that are imported. Most of the tropical soils are low in organic content and hence the use of organic fertilizer will improve the soil fertility through addition of organic matter into these soils hence ensure sustainable production (Ipinmoroti et al., 2008). The use of organic fertilizer will thus lead to sustainable tea production hence reduce land degradation due to non-judicious use of inorganic fertilizers as excessive use of inorganic nitrogenous fertilizers leads to deterioration of the environment. Additionally the use of organic fertilizers is a strategy of value addition that is likely to attract more customers into buying Kenyan tea (Kagira et al., 2012). Organic tea fetches more returns than conventional tea (Shah et al., 2016) and it is a profitable venture with a growing global market (Sarker et al., 2008). The only agrochemical that is used in growing Kenyan is fertilizers; otherwise Kenyan tea is grown free of agrochemicals (Njogu et al., 2014). Even though it is only inorganic fertilizer that is used as an agrochemical input in the cultivation of Kenyan tea almost all of it is classified as inorganic hence it is a venture that can be exploited to increase returns to the farmer.

1.3 Objectives of the study

The main objective of the study was to develop low cost and sustainable nutrient management options for enhancing tea yield and profitability.

The specific objectives of the study were:

1. To determine the effect of varying rates of inorganic NPK and organic Rutuba fertilizers on soil nutrients in a clonal tea field.
2. To determine the effect of varying rates of inorganic NPK and organic Rutuba fertilizers on growth and yield of clonal tea.
3. To determine the effect of varying rates of inorganic NPK and organic Rutuba fertilizer rates on N, P and K use efficiencies in clonal tea.

1.4 Hypotheses

1. Organic Rutuba fertilizer will improve the availability of soil nutrients
2. Organic Rutuba fertilizer will enhance the growth and yield of clonal tea.
3. Organic Rutuba fertilizer will improve the nutrient use efficiencies of nitrogen, phosphorus and potassium.

CHAPTER TWO: LITERATURE REVIEW

2.1 Kenyan tea Industry

Agriculture contributes 26% of the Kenya's Gross Domestic Product (GDP), with tea playing a key role. In Kenya, tea growing and manufacturing activities are carried out in the rural areas where the sector has supported the livelihoods of over 560,000 small scale farmers directly. Further, the sub- sector provides employment opportunities to many people along the value chain in addition to the development of infrastructure in the rural areas. Commercial production of tea in Kenya started in 1924. In these early stages tea growing was only restricted to white settlers and multinationals because they wanted to maintain the quality of tea (Kagira et al., 2012). It is only after independence that Africans were allowed to grow the crop and since then small scale production has tremendously grown from 24,448 hectares in 1963 to 124,985 hectares by 2012 (Table 2.1) which represents 65.6% of the area covered by tea while the estates covered 65,732 hectares (TBK, 2013). The rate of growth was high amongst the small scale farmers than the estates because the estates had limited land. Currently Kenya is the 3rd leading producer accounting for about 10% world tea production and the number one exporter of tea responsible for 22% of the total world tea exports (FAO, 2016).

Tea production in Kenya is divided into two sectors: plantation and small scale producers (TBK, 2011). The large plantations belong to large scale producers and multinational companies, for example Unilever, James Finlays, George Williamson, Eastern Produce Kenya Limited, Sotik Tea Company and Sasini Limited (Owuor, 2011), while the small scale producers who are more than 500,000 sell their produce through farmer owned factories that are governed by factory company directors who are elected by the farmers and managed by the Kenya Tea Development

Agency (KTDA) (TBK, 2011). KTDA coordinates production and marketing, provides extension services and makes payments to the small scale farmers. A significant percentage of Kenyan tea is sold through the Mombasa tea auction, the second largest auction centre in the world that is operated by The East African Tea Trade Association (EATTA).

Table 2. 1: Tea industry statistics

Year		**2009**	**2010**	**2011**	**2012**
No of growers	Small holder	560,595	600,066	606,744	595,152
	Plantation	38,271	32,585	32,777	32,786
	Total	598,866	632,651	639,521	627,938
Hecterage	Small holder	107,268	115,023	123,385	124,985
	Plantation	51,126	56,893	64,470	65,732
	Total	158,394	171,916	187,855	190,717
No. of factories	Small holder	58	63	64	64
	Plantation	39	39	40	41
No of brokers		11	11	11	12
No of buyers		58	63	64	72
No of packers		43	64	107	170

Source: Tea Board of Kenya, 2013

Different types of beverages can be processed from tea depending on the method of processing and the standards of harvesting. The common predominant ones include white, green, black, and oolong tea (Owuor et al., 2012; Karori et al., 2014). Green tea is mainly consumed in China, Japan and the Middle East while black tea is consumed in Africa, India, Sri-Lanka and Europe. (Karori et al., 2014). White tea is made by withering and drying young and unrolled leaves and buds in the sun and sorted into their different grades; the tea takes its name from the silver fuzz that covers the buds which turn white after drying. Oxidation is completely avoided by ensuring there is no rolling and bruising (Owuor et al., 2012).

Green tea on the other hand is made from leaves that are steamed and dried while they are still green. The freshly harvested leaves are steamed to arrest fermentation, dried and sorted to different grades. The leaves maintain the original color because the steaming process denatures the enzymes responsible for breaking down the color pigments in the leaves (Chacko et al., 2010; Owuor et al., 2012) and the natural substances like polyphenols and chlorophyll are also retained. Black tea is withered, rolled, fermented and dried. Just like green and oolong tea black tea is obtained from fully mature leaves as opposed to white tea that is obtained from young immature leaves and buds. Black tea undergoes full fermentation and takes more time in processing. Oolong tea on the other hand undergoes shorter fermentation compared to the black teas. It is an intermediate between green and black teas (Owuor et al., 2012).

Value addition is minimal in Kenyan tea due to the exports of semi processed tea which is used to blend other low quality teas **(**Kagira et al., 2012). Thus, the farmer does not get the full benefits of the high quality tea produced in the country and what gets to the final consumer does not reflect the real quality of the Kenyan tea. Sri-Lanka is the leading exporter of value added tea (Ochanda, 2012) as she sells 66% of her tea as bulk and the rest as value added. In comparison, Kenya exports 88% of her tea in bulk form while the rest is sold as value added (TBK, 2013).

Examples of value addition that can be done to tea with an aim of increasing returns to the farmer and even increasing returns to the government through job creation include, ready to drink, organic teas, white, flavored, spiced teas, green and purple tea large-scale processing (Ochanda, 2012; TRFK, 2011). Other value addition techniques include branding, decaffeinated tea production, herbal, scented and various other blends of tea. Tea is harvested periodically by plucking the young shoots that are taken to the factories for manufacturing so as to produce different types of teas. Tea productivity is measured in terms of made tea per given area per year (Njogu et al., 2015). The yield parameters include the shoot weight and the shoot number (De Costa et al., 2007) with a direct relationship between the harvested shoot population and the weight of the harvested shoot and a conversion factor of 0.225 used to convert the green leaf to made tea (TRFK , 2002).

The weight of the shoot harvested is directly affected by the plucking standard which consequently affects the weight of made tea. The plucking standard can either be two leaves, or more and a bud hence the standards of plucking vary (Owuor et al., 2012). The number of plucked shoots per plant at a given time and their subsequent weight depends on the plucking rounds (the duration between two successive harvests) (De Costa, et al., 2007).

The Kenyan tea industry is facing a number of challenges that are affecting the livelihoods of many farmers and others benefiting from the sector in the entire value chain. The decline in the prices of tea attributed majorly to overproduction globally is a major challenge. By 2011 there was a 2% global increase in tea production (Owuor, 2011) and this has a major effect on the global prices. Kenya has a very low local consumption of tea hence relying entirely on the export markets. Thus any increase in production or political instability of the importing country significantly affects the prices. Kenya relies on her traditional markets like Afghanistan, Sudan, United Kingdom, Pakistan, Nigeria, Yemen and Egypt (AFFA, 2016) and has not exploited other new avenues for her teas.

The labor cost of production has tremendously gone high with the overreliance on manual plucking with an aim of increasing the quality (Owuor, 2011) increasing the cost of plucking (Gunathilaka et al., 2016). The use of machine plucking has not been adopted by the small scale farmers. The costs of inputs like fertilizers, labor at the factories are high hence eating up on the net returns to the grower.

There has been a rise of numerous certifications standards that have to be met so as to be competitive in the international market. Some of the certifications include Rainforest Alliance (RA), Fair-trade (FLO), Ethical Tea Partnership (ETP), ISO 9001:2008, ISO 4001:2004 (Maina, 2016) and compliance with labor laws and regulations. All these have an effect in increasing the cost to the farmers (Kagira et al., 2012) and reducing the revenue to the farmer by about 40 % (Ochanda, 2012).

Old tea gardens that are way past their most reproductive stage are also a challenge that is affecting the productivity of the bushes. Most of the tea bushes are as old as 30-40 years (Mwaura et al., 2007; Owuor, 2011) of age and are still intact but with very low productivity.

Change in weather condition levels and their distribution affect tea growth and quality. Tea growing in Kenya is rain fed hence climate stability is very important. For instance prolonged drought has a very high impact on the production thus affecting the return to the growers who are paid according to the weight of the crop they deliver. Other climate change related problems that affect tea production include hails and frost (Cheserek et al., 2015) and emergence of new pests due to climate change. Frost damages accounts for 30% losses whenever it occurs in three consecutive months and drought on the other hand accounts for 14-20% to even 30% in severe periods (Cheserek et al., 2015). Ahmed et al., 2014 found out that the growth of tea is lower during spring drought in comparison to during monsoon which has higher quality tea as there are lower catechin and secondary metabolites during monsoon as compared to drought periods that determine the quality of tea. The two extreme conditions are associated with climate change.

Poor road network in the rural areas where manufacturing factories are situated is also a big challenge leading to loss of quality due to delayed transportation period between the field and the factory. Long distance of transportation leads to overheating of the leaf hence deteriorating the quality of the tea. It also leads to depreciation of the trucks that are used for transportation further reducing the returns to the grower.

Brokerage firms that link the growers to the market also act to reduce the revenue to the farmers. The farmers do not have a direct link to the customers hence paying a lot of money to the brokerage firms in terms of brokerage fees for linkage. There are only 12 brokerage firms in Kenya (TBK, 2013) as indicated in Table 2.1.

Despite the challenges, the small scale tea sector in Kenya has been a success owing to the fact that KTDA has been able to pay farmers on time (Owuor, 2011) and the continuous increase in the productivity of the tea bushes. Tea farmers in Kenya are paid according to the weight of the green leaves they deliver hence the productivity of the tea bushes is very important. In a bid to increase the productivity of their tea bushes the small scale farmers religiously apply inorganic, NPK 26.5.5 fertilizer annually to their bushes as a top dress. For instance in the production year 2015/2016 the Kenya Tea Development Agency (KTDA) imported 77,050 metric tons of NPK, 26.5.5, fertilizer (KTDA, 2015) meant for distribution to small scale farmers that fall under the management of the agency. Since 1970 there has been a reduction in the optimum requirement of nitrogen from 450 N kg/ha/year to between 100-200 N kg/ha/year (Owuor, 2011) but this has not had any significant effect on increasing the net returns to the farmers because of the continuous decrease of the prices of tea at the auction and increase in the cost of fertilizer. Fertilizer is the second largest cost in tea production after plucking (Njogu et al., 2015). Due to the fact that there is a global shortage in the supply of inorganic fertilizer and high procurement costs, the price of inorganic fertilizer is high (Ipinmoroti et al., 2008) for the farmers to afford sustainably. The use of organic sources has not been exploited by tea farmers as a source of nutrients thus there is need to develop alternative sources of nutrients to cushion the farmers against the increased cost of inorganic fertilizer.

2.2 Botany and ecology of tea

Tea (*Camellia sinensis (L)*) belongs to the genus *Camellia*, family *Theaceae*. Botanically it is classified as a tree and for commercial purposes it is grown by pruning and clipping so as to maintain a certain height for easy operations like harvesting. Otherwise tea can grow to a height of 10-15 m or 5-8 m if left uninterrupted depending on the variety (De Costa et al., 2007)

Once tea is grown it gets ready for harvesting after five years and takes seven years to reach maturity (Ochanda, 2012). Tea has a productive lifespan of over 100 years but its peak production period is between 30-50 years (Ochanda, 2012). Tea bushes can be raised from seed, cuttings or tissue culture. Propagation from seed is rare due to the development of vegetative propagation which is considered high yielding, fast cheap and leads to the development of uniform stands (TRFK, 2002). Tea from seed is considered to be less yielding, hardy and no uniform stand. Tissue culture on the other hand is a rapid method of propagation but it is considered expensive and therefore appropriate for breeding purposes (TRFK, 2002). Tea has a very wide adaptability and thus can be grown in a wide range of climatic conditions and soils (Waheed et al., 2013). Kenyan tea is mainly grown in highlands with elevations between 1,500-2700 m (Kagira et al., 2012; Cheserek et al., 2015). The tea growing regions in Kenya include Nakuru,Bungoma,ElgeyoMarakwet,Vihiga,Kakamega,TransNzoia,Nyamira,Kisii,Bomet,Kericho,Nandi,Kiambu,Muranga,Nyeri,Kirinyaga,Embu,Tharaka Nithi and Meru counties (MOA, 2016)

All the tea growing regions were originally equatorial rainforest areas hence watershed sources for many rivers (Mwaura et al., 2007) with well distributed rain throughout the year ranging from 1200 mm to 1400 mm per annum (TRFK, 2012). These regions are endowed with volcanic red soils that are deep and well drained with a pH tending acidic from 4.0 to 5.0 (Mwaura et al., 2007). Kenya's tea growing regions have high agricultural potential of other enterprises like wheat, maize, millet, potatoes, oat, barley, pyrethrum, sugar cane, horticultural crops, dairy and sheep rearing (Mwaura et al., 2007).

Tea is a widely adapted plant and grows in various types of soil conditions. Tea is grown in the soils of the humid tropics and sub tropics but the soils differ from one country to another with the most important feature being the soil pH (De Silva, 2007). The pH requirement for the growth of tea is ranges from 4.5-5.6 (Njogu et al, 2013). The pH levels below 5 lead to deficiency in potassium, calcium, and magnesium among other nutrients. The optimal soil conditions recommended for tea growth include well drained, deep and well aerated soil with more than 2% organic matter (Njogu et al., 2013). In Kenya good soil for tea are those of volcanic origin of

Kericho, Kisii and slopes of Mt. Kenya amongst others (TRFK, 2002). These soils in Kenya are well drained, red, brownish red or dark red in color (TRFK, 2002). For economical tea production other characteristics have to be considered including the slope of the field, graveliness and rockiness of the soil. Soil depth of less than 50 cm, graveliness of more than 50% and rockiness of 20% affects the growth of tea adversely (TRFK, 2002). Tea plants growing in shallow and compacted soils are likely to suffer from drought and water logging during the rainy months (Nath, 2013a).

Annual rainfall of 2500-3000 mm is considered optimal with a minimal of 1200 mm (Waheed et al., 2013; Cheserek et al., 2015). The evenness in the distribution of rainfall is very important in Kenya, Sri-Lanka and India (Waheed et al., 2013). In Kenya, tea is mainly a rain fed crop hence highly depends on the amount and distribution of rainfall.

Tea growing is highly affected by temperature ranges. The important temperatures include air, leaf and soil temperatures. Ideal air temperature should be 18 -25^{0}C (Waheed et al., 2013). Air temperatures below 13^{0}C are likely to damage the tea foliage and above 30^{0}C have been found to reduce shoot growth and extension because of the very low humidities (Waheed et al., 2013; TRFK, 2012). The rate of shoot growth is directly proportional to the increase in temperature up to the optimum temperature (De Costa et al., 2007). Cheserek et al., 2015 noted that there is a positive relationship between mean air temperature and tea yields. The leaf temperature also affects the growth of the shoot. The net photosynthesis of the leaf rises steadily with increase of leaf temperature up to 40˚C then it starts declining (TRFK, 2002). Soil temperature has more influence on plant growth and yield than air temperature. The ideal soil temperature should be

20^0-25^0 C (TRFK, 2002). Increase in altitude leads to decreased yields due to decreased shoot growth but has an effect of increasing the quality of black tea (FAO, 2016)

2.3 Nutritional requirements for the growth of tea

2.3.1 Nitrogen

Nitrogen plays a key role in the growth of plants and it is the most deficient mineral element in the soil (Nath, 2013) but the individual requirements vary from plant to plant and variety to variety. Plants take up nitrogen from the soil in two forms namely ammonium cation (NH_4^+) and nitrate anion (NO_3^-) (Maghanga et al., 2012), but the tea plant prefers NH_4^+ to NO_3^- (Ruan et al., 2007). The process of denitrification and volatilization leads to loss of nitrogen in gaseous form while the nitrate form which is converted from ammoniacal nitrogen is susceptible to leaching along with percolating water (Sitienei et al., 2013).

Nitrogen is the most important requirement for tea and it is required in large quantities (Sultana et al., 2014) as it increases the yield and also adds value to tea being an important constituent of protein (Sitienei et al., 2013). Nitrogen is an important constituent of plant parts and it is very key in the physiology of the tea plant (Sedaghathoor et al., 2009). It promotes the formation of chlorophyll, promotes vigorous vegetative growth, plant sugars, amino acid biosynthesis and also for the yield of secondary metabolites (Mukhopadhyay et al., 2014). Nitrogen is found in important compounds in the plant like chlorophyll, nucleotides and hormones. Young plant tissues contain more nitrogen than older tissues. Nitrogen is translocated from older parts of the plant to the growing parts of the plant hence deficiency is first noticed in the older parts of the plant (Mukhopadhyay et al., 2014).

Tea being leafy is very sensitive to nitrogen that induces the growth of the leaves and inhibits the reproductive phase. The economic application levels for nitrogen vary from place to place and country to country because the nitrogen requirement varies locally (Hamid, 2006). The optimal nitrogen requirement vary from clone to clone depending on the location and the range is from 75-150 kg N/ha yr^{-1} (Sitienei et al, .2012). Hamid, (2002) noted that the response of tea to nitrogen fertilizer application increases at a decreasing rate beyond the optimum level hence overuse of nitrogen is not recommended. The availability of nitrogen to plants is affected by other nutrients in the soil and it also affects the availability of other nutrients. Increase of nitrogen leads to a decrease in mature leaf P, K, Ca, and Mg due to the acidification of the soil by the ammonia in the fertilizer (IPCC, 1990) while the decrease in mature leaf K can be attributed to leaching triggered by ammonium-N in NPK fertilizer (IPCC, 2000). Nitrogen deficiency in tea leads to lighter than normal green color in young flush. The younger leaves may end up being yellow in color while the lower mature leaves might remain dark green while they progressively turn yellow as the deficiency increases (TRFK, 2002).Yellowing of the leaves may not necessarily mean that there is deficient nitrogen in the soil but it could be the feeder roots that are not able to take up the nitrogen from the soil for example during the drought season as the roots die out or during the cold season as the rate of growth of the roots is greatly affected. Nitrogen is deficient in the tea plant if N leaf content is less than 3%, mildly deficient when it is between 3-3.5% and sufficiently supplied when it is more than 3.5% (Owuor et al., 1983). Shortening of the internodes can also be attributed to nitrogen deficiency.

2.3.2 Phosphorus

Phosphorus is necessary in plants for activities related to energy transfer and storage. It is an important component of adenosine triphosphate (ATP) and adenosine diphosphate (ADP).In tea it plays a major role in the formation of new wood and roots (Hamid, 2006). Phosphorus is a relatively mobile element in plants and it is normally translocated from old and mature tissues to younger ones. The availability of phosphorus to plants is highest when there is a moderate pH of about 5.5 to 7 and becomes decreasingly available at pH below 5.5 or above 7 (Hamid, 2006). In very acidic soils it combines with hydroxides of iron and aluminum to form compounds that are unavailable to plants.

Deficiency of phosphorus in tea can be seen when there is absence of gloss on the surface as affected leaves appear dull more so the mature leaves .There is also excessive die-back of young and old woody stem (TRFK, 2002) in case of deficiency. Tea plant is an extremely tolerant species to P deficiency due to its high internal use efficiency (Salehi et al., 2008)

2.3.3 Potassium

Potassium is the most important nutrient to tea after nitrogen (Sultana et al., 2014) and equally mobile in the tissues of plant but not as mobile as nitrogen (Hamid, 2006). Potassium helps in activating many enzymatic processes, hydrating of the plant and maintenance of mineral balance in the plant (Shah et al., 2014). The nutrient maintains an optimum turgor for cell division, elongation and growth of the young tissues. Plants do not express visual symptom until it is extremely deficient. When K is not matched with N there is depletion of starch reserve in the roots, degeneration of feeder roots, die back and building up of nitrates as reported by Jessy (2010). A tea bush that is deficient of K has branches that are thin, weak and do not branch freely hence even recovery from pruning can really take time and spreading to form a frame is normally restricted (TRFK, 2000). There is also tip and margin scorch of mature leaves (Jessy, 2010) that become loosely attached to the stem and shaking of the deficient bush leads to fall of leaves. The ratio and source of nutrients that are applied to the plant depends on the soil status and the response of the bush to the applied nutrient will also depend on the potassium status of the soil, age of plants and the productivity of the bushes (Jessy, 2010). Large amounts of potassium are removed from the soil reserves tea through harvesting and tea has a potassium requirement of high to moderate (Sitienei et al., 2015).

2.3.4 Micronutrients in tea growing

Current fertilizer recommendations for tea have always emphasized on macronutrients not taking into consideration the micronutrients despite the continuous removal through harvesting. Plants suffer deficiency when the nutrients are not available to the plant or the nutrients taken up by the plant are below the required quantities for various processes in the plant at various stages of growth of the plant (Rengel, 2015). Availability of micronutrients in the rhizosphere is affected by various factors among them soil and plant properties, interactions of roots with microorganisms and the surrounding soil (Rengel, 2015) and the interactions amongst the micronutrients themselves. For example deficiency of zinc in the soil can be induced by buildup of phosphorus from excessive application of phosphate fertilizer (Nelson, 2006). Application of magnesium, boron and zinc affect the physiological characteristics and the yield of the tea as noted by Kumar et al. (2014). Kumar et al. (2014) noted that by application of zinc, magnesium and boron to tea there was a high net photosynthetic rate, high chlorophyll content and water use efficiency consequently increased made tea yield. Kitundu et al. (2006) found that although iron was observed to be sufficient in soils it was poorly reflected in the leaves because of high levels of zinc in the leaves. Kitundu et al. (2006) further noted that high levels of iron in the soils induce copper deficiency. Zinc deficiency in tea plant leads to stunted growth when severely affected, the young leaves appear narrow, erect and form a rosette at the apex of the stem (Nelson, 2006). Zinc is not easily absorbed by the plant but its deficiency can be corrected by foliar application as ground application is not that effective (Sedaghathoor et al., 2009) and application of swine and poultry manure (Nelson, 2006). High soil pH results to retention of the micronutrients in the soil but limit the uptake of the micronutrients by tea plants (Nath, 2013b). Nath (2013b) reported that the concentration of Mn, Fe, Cu and Zn increases with increase in organic content in the soil because of a complexation reaction that result in the retention of micronutrient in the soil. Low content of exchangeable Al, Zn, and Fe in soils leads to high mortality and stunted growth of tea plant (Sultana et al., 2014). Availability of soil nutrients has an effect on the quality of tea. Ogunmoyela (1994) noted a significant positive relationship with total phenol and tannin content of tea samples. Ogunmoyela (1994) further noted that leaf copper and zinc are important factors in determining the fermenting characteristics of leaf and therefore quality of the final product. Sedaghathoor et al., (2009) in a study on the response to yield and quality by tea plant due to application of fertilizers reported that application of micronutrients resulted to an increase in the percentage of P, Zn and Cu and that a combination of N, K and micronutrients improved caffeine content of tea leaves. In the same study Sedaghathoor et al., (2009) noted an increase in yield due to application of NPK with magnesium and zinc.

2.4 Use of fertilizers in tea production

Use of fertilizers in crops is important for increasing yields and influencing soil properties (Qiu et al., 2014). Fertilizer application is a common management practice in tea production that has a significant effect on the yield and quality of the final product (Cheruiyot et al., 2009) as it is necessary for improvement of the nutritional status of the soil and the tea plant (Njogu et al., 2014). Harvesting has a significant impact on the availability of nutrients in the soil by removal of the nutrients from the soil through plucking. The rate of nutrient removal depends on the duration of plucking rounds and its intensity hence the need for replenishing of the nutrients lost through fertilizer application. The harvestable portion of the tea plant contains the highest percentage of nutrients (Sultana et al., 2014). Tabu et al. (2015) noted that continuous plucking of the tea leaves leads to mining of the macronutrients N, P and K; hence it is important to replenish the nutrients to the tea plant. For instance harvested tea shoots have levels of about 4% N (Cheruiyot et al., 2009). Njogu et al. (2014) noted in a study that uptake of NPK nutrients significantly correlated with tea yields. The flush shoots of a tea plant has nitrogen as the highest nutrient followed by potassium, calcium, phosphorus, sulfur, magnesium and zinc (Sedaghathoor et al., 2009). The influence of an applied fertilizer on the yield arises from its effects on the shoot extension rate and the rate of regeneration. Soil macronutrients N, P and K are very essential to tea plant growth (Nath, 2013a; Sitienei et al., 2015). Phosphate fertilizer is used during transplanting of seedlings; the fertilizer can be single, double or triple superphosphate. The fertilizer is mixed with the soil before placement of the seedling to be transplanted into the planting whole (TRFK, 2002). For purposes of top dressing, inorganic fertilizer 25.5.5.5s is recommended (Tabu et al., 2015; Kekana, 2012) and this is done either once per year or by splitting to as many as four times however, split application of fertilizer may have no yield benefit (TRFK, 2011). Cheruiyot et al. (2009) noted that application rates of above 200 kg N/ha limits the growth and yield of tea during the drought season hence recommended rate for Kenya of 150-200 kg N/ha (Owuor, 1997) should be done at the right time in the year. Tea plants respond to high nitrogen application under optimal rainfall of 1400 mm-1500 mm that is well distributed in the year (Carr, 1971). The interval of application of nitrogen fertilizer affects the yield response with any period more than 18 months being noted as compromising on the yield (TRFK, 2011).

In Kenya small scale farmers do an annual top dressing of inorganic NPK 26:5:5 based on the number of bushes per bag (50 kg of NPK for 700 bushes) and they account for about 14560, 2800 and 2,800 metric tons of N, P_2O_5, and K_20 respectively metric tons annually (Sitienei et al., 2015). Out of the inorganic NPK applied by tea farmers annually only a small fraction of this fertilizer could be taken up by the plant. The fertilizer nutrients not taken up by the plant can be lost through leaching, erosion and denitrification or volatilization in case of N, or they could be immobilized in soil organic matter to be released at a later time (Roberts, 2008). Nitrogen is the key element that is required by green plants like tea and it is often deficient in plants (Nath, 2013), however continuous use of nitrogenous fertilizers in tea field leads to lower pH, degradation of some base elements in the soil (potassium, magnesium and calcium) and increases the levels of manganese and aluminum causing nutrient imbalance in the soil (TRFK, 2012). Nitrogen highly leaches to the ground because it is loosely bound hence has a pollutant effect to water masses (Tabu et al., 2015). Morita, (2007) found out that a high concentration of nitrate was drained back to ponds around tea fields hence possible pollution of ground water by the application of the fertilizer. Excessive leaching leads to underground water pollution (Ipinmoroti et al., 2008). Nitrate levels above 10 mg/L causes methemoglobinemia which is fatal (Maghanga et al., 2012).

2.4.1 Effects of fertilizer on the quality of tea

Tea has a chemical composition of about 2000 components (Yashin et al., 2015). Different types of teas differ depending on the phytochemical composition. The same type of tea can have varied chemical composition depending on various factors including soil, climate, altitude, and degree of oxidation and storage condition (Yashin et al., 2015). Tea shoots have got catechins that are important in determining the quality of tea. The harvested part of the leaves affect the quality of the tea because the age of the leaf is an important factor that affects the chemical composition in terms of the catechin content. The upper younger shoots have higher levels of catechin hence for high quality teas two or three leaves and a bud are preferred (De Costa et al., 2007). Maceration of tea shoots initiates oxidation of catechins by enzyme polyphenol oxidase (PPO) (TRFK, 2011) leading to the formation of theaflavins (TFs) and thearubigins (TRs). Black tea contains the lowest levels of catechins due to the level of oxidation during processing. The briskness and brightness of tea liquor in fermented black tea is contributed by Theaflavins (Karori et al., 2007). Thearubigns, the orange brown compounds are responsible for the color, body and taste of tea (TRFK 2011; Kumar et al, 2011). Thearubigns contribute approximately 35% of total color and also play a significant role in brown color of tea, as also strength and mouth feel of tea liquor (Kumar et al., 2011). The type and rate of fertilizer affects the quality of tea as noted by Tabu et al., (2015). Theaflavins and thearubigins decreases with an increase in fertilizer rate irrespective of fertilizer type (Tabu et al., 2015). Tabu et al. (2015) further found out that enriching organic manures with organic fertilizers reduced the quality. Njogu et al. (2014) found out that foliar fertilizers increased the total polyphenol content of the samples they used in the study. An optimal rate of 100-200 kg N/ha as NPK or NPKs is recommended as a compromise between quality and yield (Tabu et al., 2015). In a comparative study between organic and conventional farming systems by Chin et al. (2010) it was found that organic farming systems had significantly higher polyphenol content in shoots but no significant difference in the caffeine, epicatechin, epicatechin gallate and epigallocatechin content. Bagchi et al. (2015) found that content of secondary phenolics in tea grown was higher in tea grown organically than that grown conventionally.

2.5 Nutrient use efficiencies of nitrogen, phosphorus and potassium

Nutrient use efficiency of a crop is the yield obtained per unit of available nutrient in the soil supplied by both the fertilizer and the soil (Hirel et al., 2011). Nutrient use efficiency of a crop can be improved by enhancing the uptake of the nutrients from the soil (Weih, 2014). However 25 to 50% of the compound applied through fertilizers is taken up by the plant even when efficiencies are high and the rest of the nutrients end up in pollution probably (Sitienei et al,. 2013). Nutrient efficiency varies from nutrient to nutrient depending on various factors including the rate of application, the time of application, the place of application, interaction amongst the various compounds and the form of the nutrient. The form of the fertilizer nutrient affects the agronomic efficiency, apparent recovery and partial productivity of nutrients as noted by Jagadeeswaran et al. (2005). Jagadeeswaran et al. (2005) found out that the nutrient use efficiency of NPK was significantly enhanced by the application of tablet form of NPK sources than other slow release forms. Nutrient use efficiency can be affected by the ability of the plant to take up the nutrient from the soil and the utilization ability to increase the yield (Chatterjee. 2014**)**. Sufficient amount of nitrogenous fertilizer may be applied to a crop sometimes at amounts that are more than what the crop needs for increasing yields but the amount of nutrient absorbed may be low because of low efficiency of absorption (Sitienei et al., 2013). The anatomy of the plant leaves have an effect on the uptake of nutrients by the plant. Njogu et al., 2014 found out that there was a positive significant correlation between the stomatal leaf count and the first mature leaf nutrients (NPK). Amongst N, P and K nutrients K is considered to have higher use efficiency because of its immobility in most soils and it is not subject to gaseous losses or fixation challenges that affect N and P respectively (Roberts, 2008). Low potassium efficiency is a result of leaching of potassium especially in the sub tropical areas (Sitienei et al., 2013). Nitrogen and potassium efficiency in tea fields leads to reduction of environmental degradation due to acidification of soil, water contamination and emission of gases to the environment (Sitienei et al., 2013). The agronomic efficiency (AE) is the additional yield obtained per unit of the applied nutrient. The AE is affected by the ability of the plant to take up the nutrient and the ability to utilize the nutrient to yields. The interaction amongst nutrients has an effect on the efficiency of the nutrients. Sitienei et al. (2013) noted that increasing levels of nitrogen from 0 to 200 kg/ha increased the agronomic efficiency of nitrogen and potassium, partial factor productivity and apparent nutrient recovery of potassium but reduced the estimated apparent nutrient recovery and the partial factor productivity of nitrogen at the given potassium rates. Sitienei et al. (2013) further noted that increased rates of potassium reduced the apparent nutrient recovery of nitrogen and potassium. Negative agronomic efficiency indicates that the levels of immobilization were higher than mineralization hence less net mineralization (Sitienei et al., 2013).

2.6 Organic tea production

The International Federation of Organic Agriculture Movements (IFOAM) states that organic agriculture promotes environmentally, socially and economically sound production of food and fibers. The systems work in harmony with nature without harming the natural environment and or the people living in it (Chin et al., 2010). By respecting the natural capacity of plants, animals and the landscape, organic agriculture aims to optimize quality in all aspects of agriculture and the environment (IFOAM 1998). Organic agriculture refrains from the use of chemo-synthetic fertilizers, pesticides, and pharmaceuticals and allows increase in agricultural yields and disease resistance by laws of nature (IFOAM, 2000).

According to Wanyoko et al. (2011) an organic product is one that is free of extraneous chemicals, antibiotics, synthetic hormones, genetic modifications, sewer sludge and is minimally processed without artificial additives, preservatives or irradiation in order to preserve its integrity. Organic agriculture minimizes the pollution to air, soil and water and optimizes the interdependence of communities of plants, animals and people. Through organic agriculture there is enhanced sustainability thus provision of quality products to present and future generations is assured. Organic management of the production process results to increase in soil fertility, better soil stability, and water retention hence conservation of water because there is reduced need for use of irrigation (Scialabba, 2013). In organic agriculture the main sources of nutrients include animal dung, compost, green manure and oil cakes. Increasing awareness on health and environmental issues has been a driving force for the growth in the sales of organic food by 17-22% (Sarker et al., 2008). Organic foods are considered to be more nutritious than conventional for example organic crops tend to have more vitamin C and 10-50 more secondary metabolites (Scialabba, 2013). Bagchi et al., 2015 noted the antioxidant property of tea extract from organically grown tea was high hence higher radical scavenging property. The Kenya Organic Agricultural Network (KOAN) coordinates the organic activities in the country and has both individual and corporate membership. Kenya produces various organic products including vegetables, pulses, tea, cotton and macadamia nuts (Sarker et al., 2008). Globally IFOAM sets the basic organic standards for regions, countries and organizations from which the standards are got. IFOAM is amongst other sustainability bodies that are involved in the tea industry. Other sustainable bodies involved in the tea sector are: Rainforest alliance (RA), The Ethical Tea Partnership (ETP) and UTZ.

For a product to be declared as organic it has to be certified by a state or private agency that has been accredited by state. Therefore, organic tea gardens are certified by a recognized organic certification body stating that the garden has met the requirements of organic agriculture and cultivation in harmony with nature and ecological disciplines (Ping et al., 2014). The certification process ensures that a product is produced under the minimum standards of producing organic products. The third party certifier investigates the whole process from the point of production, the environment it is produced to the point it reaches the consumer to ensure that the standards are met. There are three recognized third party certification bodies in Kenya namely Encert Ltd, Africert Ltd and Nesvax control (Wanyoko et al., 2011) that use the same process of application, inspection and certification. For easy access of markets especially to the developed countries the organic product must meet the minimum set standard for the country.

Since the introduction of organic tea production in the world there has been an increasing demand for organic tea compared to conventional tea (Williges, 2004). In Kenya there is some little practice of organic tea production though it is practiced amongst the estate subsector because this sector has control in their production processes. Amongst the small scale farmers who collect their green leaf together at a common point to a given factory for processing it is a bit difficult to practice organic production of tea because all the farmers have to embrace the whole idea of organic production and the farmers have to be managed in a way that assures control of the production processes.

Kenyan tea is produced free of pesticides and in an ideal environment that deters pests and attack by diseases (Karori et al., 2014). This ensures production of safe teas to the customers in a sustainable way with an objective of conserving the ecosystem and natural habitat without polluting air, water and soil. Organic production of tea starts right from the field site selection, agronomic practices in the field, manufacturing at the factory, packaging till the product reaches the end user. The site selected for organic tea cultivation should be isolated such that there is no possibility of any drift reaching the field hence there should be a buffer zone separating organic farms from the conventional ones**.**

Organic fertilizer improves the chemical, physical and biological characteristic of soil hence increasing the yields and subsequently ensuring sustainability. According to Ping et al. (2014) organic agriculture improves soil bulk density and soil porosity. Sources of organic material in organic tea production include animal manures, crop residues, compost and green manures (Sultana et al., 2014). The use of these organic sources of nutrients in tea production is cheap as it is easily available and does not affect the environment negatively (Kurual et al., 1990). Although organic fertilizer is available in form of animal waste, compost or maize stalks it is not widely used by farmers in Kenya (Waarts et al., 2012). The manure should be kept moist under a roof to avoid volatilization of nitrogen in gaseous forms (Sultana et al., 2014).

In organic tea production weeds are controlled by hand pulling, slashing and other cultural practices that reduces the emergence of the weeds for example, mulching (Kutama et al., 2013) by use of the pruning. Weed control in young tea is more difficult than in mature tea because of the exposure to sunlight when tea is still young hence rejuvenation of the weeds is high compared to mature tea. Late removal of weeds in young tea has a significant effect on the maturity stage of the crop (TRFK, 2002). Weeds can be removed by hoes, jembes or fork jembes but this leads to enormous damage of feeder roots. Perennial grasses such as *Digitaria scalarum* (couch grass) have a significant effect on the growth of tea plants and hand weeding may not be appropriate (TRFK, 2002). Despite the effects of weeds on tea crop there is minimal use of herbicides on Kenyan tea amongst the small scale holders with many of them preferring to use hand weeding. However, some farmers use still use chemicals like Roundup, and weed all, to control weeds (Waarts et al., 2012). Globally 1031 species of arthropods are associated with intensively managed tea (Hazarika et al., 2009) and they affect all parts of the tea plant including the leaf stem, root flower and seed hence decreasing yield if left unchecked (Hazarika et al., 2009). A number of pests affect tea production in Kenya including tea mites, aphids, moths and butterflies, thrips, common cutworms, faggot worm beetles, tea weevils amongst others (TRFK, 2002). In China there has been development of bio-pesticides for controlling of pests like green leaf hopper and development of pest resistant cultivars in Japan (FAO, 2014) though research is on-going. According to FAO, (2014) the use of certain agrochemicals mainly of plant and mineral origin may be permitted in case of imminent threat by pests.

There are major challenges that affect the adoption of organic tea farming**.** According to the certification standards the farm has to remain in production without use of any inorganic input for three years before being declared organic. In this period the green leaf from such a field that is to be declared organic is not classified as organic and there is a decline in the yield as indicated by Karki et al., (2011) before the field recovers and starts benefitting from the organic practices.

In a study by Karki et al. (2011) on the factors influencing the conversion to organic farming in Nepalese tea farms it was noted that there is a relationship between the size of land and the willingness of the farmer to adopt the organic farming. Farmers with large acres of land were ready to take the risk and the initial cost of certification that comes with organic farming. If this can be compared to Kenya where majority of tea growers are small scale holders then adopting of organic tea production will be a challenge.

The level of education amongst the farmers is a hindrance as adoption of a new technology is faster amongst the farmers who are literate. Organic agriculture involves a lot of record keeping for certification purposes (Karki et al., 2011) and this is likely to put off many farmers who are illiterate. Age is also a factor that is likely to affect the adoption of organic farming. According to Karki et al. (2011) older farmers are likely to adopt organic farming compared to younger ones. Going by this study then the Kenyan case could have an advantage as tea farmers are elderly ones.

2.7 Effects of soil pH on the growth of tea

Tea is grown in highly acidic soils of 4.5-5.6 (Njogu et al., 2013) but the pH is further decreased by continuous use of nitrogenous fertilizers (Sultana et al., 2014) leading to decrease in tea yield. Increase in the pH to the optimum leads to increase in yield (Fig 2.1).

Farmers tend to use the recommended fertilizer non- judiciously and this leads to acidification of the soil and pollution of water masses posing sustainability threats to the tea sector (Tabu et al., 2015). Continuous use of ammonium nitrogen fertilizer tends to acidify the soil and this affects the microorganisms adversely (Thenmozhi et al., 2012) and hence decreases productivity. Further, excessive use of inorganic fertilizers leads to increased cost of production, a decline in organic matter, leaching that leads to loss of N and P nutrients, fixation of P, microorganisms reduction and acidification (Sultana et al., 2014). Nath, (2013a) in a study on the macronutrients status of long term tea cultivated soils in India found out that the availability and concentration of macronutrients increased with an increase in the soil pH. Chong et al. (2008), in a study on the soil nitrogen, soil phosphorus and tea leaf growth in organic and conventional cropping systems fields at Sabah Tea Plantation slope found out that the conventional farming system had an effect of increasing the soil acidity. Organic sources of fertilizer can go a long way in ensuring sustainability in tea production. Inorganic fertilizer requirement for young tea plants can be reduced by use of poultry manure while the mature tea chemical fertilizer requirement can be minimized or avoided by use of cow dung as the mature tea plants require more N and P compared to the younger ones (Sultana et al., 2014). However, cattle manure that is generally recommended for tea in Kenya is not sufficient in quantity and quality at the farm level.

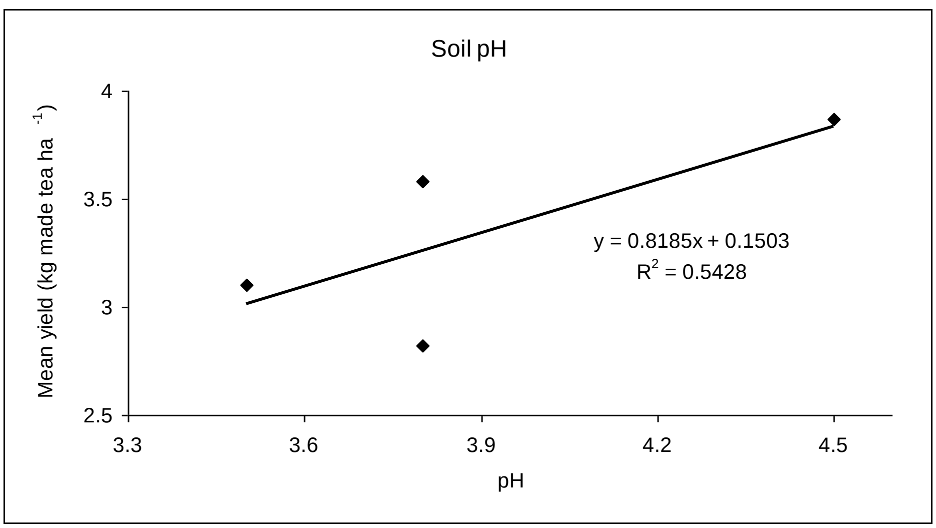

Figure 2.1: Relationship between soil pH and productivity of tea.

Source: Tea Research Institute (TRI, Kenya, 2015)

Aluminum is the third most abundant metallic element however it is only available to plants under low pH of 5.5 and below (Silva, 2012). In acidic soils aluminum becomes increasingly available leading to toxicity except for tea and pineapple plants (Silva, 2012). Most plants do not contain more than 200 ppm of aluminium but mature tea leaves contain as much as 20,000 ppm of aluminium (Sivasubramaniam et al., 1972). Aluminium toxicity decreases the uptake and utilization of phosphorus by fixing the phosphorus by an absorption-precipitation reaction. Aluminium promotes the growth of tea under acidic conditions and it is accumulated in the leaves (Yokota et al., 2004). In tea plant there is no aluminium toxicity and Morita et al. (2008) noted that oxalate is a key compound in the mechanism of Al detoxification in the tea root. The tea plant absorbs aluminum from the roots and then combines it with oxalic acid inside its body in order to inhibit the aluminum's toxicity (Morita et al., 2008; Morita et al., 2011). Caffeine is also secreted by tea roots in response to Al exposure as noted by Morita et al. (2011). The caffeine excretion from the roots of tea plants may stimulate root growth root by inhibiting callose formation on the growing tips of the tea plant (Morita et al., 2011). Aluminium causes calcium deficiency in plants due to the disruption on the adsorption and translocation of calcium. Manganese toxicity and deficiency is rife as the soil becomes more acidic and neutral respectively.

CHAPTER THREE: MATERIALS AND METHODS.

3.1 Description of the experimental sites

The experiment was established at Kianjokoma, Embu county agro-ecological zone (AEZ) UM1 (Sombroek et al., 1984) situated 20 km from Embu town and 152 km from Nairobi. The experiment took place during the production year 2014/2015 starting from June 2014 to June 2015. The site is positioned to the North East on the tea growing slopes of Mt. Kenya at an elevation of 1831m above sea level and geographically located on latitude $0^{0}23^{0}$S and longitude $37^{0}17.3^{0}$E. The site experiences an average temperature ranging from 17.4 to 24.5^{0} C and an average annual rainfall of 700 to 900 mm. The site receives a bimodal pattern of rain with the long rains occurring in April to May and short rains from October to December. The soils in this area are red clays classified as ando- humic nitsols (FAO-UNESCO, 1988). Soils were analyzed for pH, exchangeable acidity, total nitrogen, total organic carbon, phosphorus, potassium, calcium, magnesium, manganese, copper, iron, zinc and sodium (Table 3.1).

Table 3. 1: Soil analysis before fertilizer application

Chemical component	Value
Ph	4.39
Exchangeable acidity	0.50
Total nitrogen (%)	0.34
Total organic carbon (%)	3.51
Phosphorus (ppm)	35.00
Potassium (Me %)	0.80
Calcium (Me %)	4.90
Magnesium (Me %)	0.19
Manganese (Me %)	0.24
Copper (ppm)	2.91
Iron (ppm)	62.8
Zinc (ppm)	3.12

Sodium (Me %)	0.22

The rainfall was evenly distributed during the experiment period. The period between July 2014 to December 2014 represented the short rains with the Month of November 2014 receiving the highest amount of rainfall during this period. January 2015 and February 2015 received little or no rain, significantly affecting the plucking rounds hence impacting heavily on the productivity of the bushes. March 2015 to May 2015 represented a period of high amount of rains with the month of May 2015 receiving the highest amount of rainfall. The rainfall, minimum and maximum temperatures during the period of the experiment were as indicated in table 3.2 below.

Table 3. 2: Monthly rainfalls and maximum and minimum temperature at Kianjokoma from June 2014 to June 2015.

Month	Monthly rainfall (mm)	Max. monthly temperature (^{0}c)	Min. monthly temperature (^{0}c)
June	59.7	21.4	12.9
July	68.9	25.4	11.7
August	76.5	28.5	12.9
September	150.1	25.4	12.0
October	100.7	23.2	13.3
November	200.7	16.8	14.9
December	154.5	19.2	14.4
January	0.0	16.9	14.1
February	25.3	21.3	15.7
March	150.9	18.7	15.1
April	191.0	17.3	15.7
May	234.4	18.6	14.3
June	50.7	17.1	14.5
Monthly mean	112.6	20.8	14.0

3.2 Experimental design, treatments and crop husbandry

The experiment was laid out in a randomized complete block design and replicated three times. The treatments comprised: 1. No –fertilizer control; 2. Application of 625 kg NPK/ha (26.5.5) (farmer practice); 3. Application of 937.5 kg NPK/ha (26.5.5); 4. Application of 1875 kg NPK/ha (26.5.5); 5. Application of 625 kg Rutuba/ha + 625 kg NPK/ha(26.5.5); 6. Application of 625 kg Rutuba/ha; 7. Application of 937.5 kg Rutuba/ha (Recommendation to farmers); and 8. Application of 1875 kg Rutuba/ha.

Each plot consisted of 20 tea bushes with a spacing of 1.5 m by 0.762 m. The tea bushes of clone TRFK 6/8 were already established and were 20 years old. The plots were prepared by ensuring one guard row of mature grown bushes between the plots to avoid interaction with neighboring plots. There was minimal weeding of the plots because the bushes had developed a full canopy hence no or minimal weeds were growing during that period. However before application of fertilizer, weeds at the edges were removed by hand. The experiment involved the use of inorganic NPK, 26.5.5 and Rutuba® organic fertilizer from Rutuba Bio Agric & Organic Fertilizers CO.LTD. The inorganic fertilizer NPK, 26.5.5 is the type of fertilizer that tea farmers affiliated to KTDA use annually for top dressing their tea. Complete analysis was done for Rutuba® fertilizer (Table 3.3).

Table 3. 3: **Analytical results of the organic Rutuba fertilizer that was used during the experiment**

Chemical component	**Value**
Nitrogen (%)	2.1
Phosphorus (%)	1.0
Potassium (%)	1.2
Calcium (%)	3.1
Magnesium(%)	0.4
Iron (mg/kg)	5233.0
Copper (mg/kg)	26.7
Manganese (mg/kg)	512.0
Zinc (mg/kg)	427.0
pH	8.2
Total organic carbon (%)	2.1

3.3 Data collection

The data collected comprised soil chemical properties, length and width of the second leaf, green leaf yield, made tea yield, N P and K use efficiencies and profitability of each fertilizer regime.

Soil chemical data

Soil samples for laboratory analysis were collected randomly from 30 different spots in the experimental field. Roots and other plant residues were removed before scooping the soil using a soil auger at a depth of 30 cm. The samples were thoroughly mixed together to obtain a composite sample of approximately 500 g for analysis. At the end of the experiment (June 2015) soil samples were scooped from each plot at a depth of 30 cm using a soil auger at three different spots and thoroughly mixed to obtain a composite sample from each plot. The samples were then packed in a plastic bag, labeled and transported the same day to the National Agricultural Research Laboratories (NARL), Nairobi, Kenya for analysis. The soil samples were analyzed for pH, total organic carbon, exchangeable acidity, available micronutrients and macronutrients.

The soil samples that had been passed through a 2 mm sieve were oven dried at 40^0C and the elements were extracted in a 1:5 ratio (w/v) with a mixture of 0.1 N HCl and 0.025 N H_2SO4. Sodium, calcium and potassium were determined with a flame photometer. Phosphorus, magnesium and manganese were determined by AAS (Mukai et al., 1992).

Total organic carbon was determined using the calorimetric method. Organic carbon in the oven – dried soil sample was oxidized by acidified dichromate at 150° C for 30 minutes for complete oxidation. Barium chloride was added to the cool digests. The cool digests were allowed to stand overnight after mixing thoroughly. The carbon concentration was read on the spectrophotometer at 600 nm (Walkley et al., 1934).

Total nitrogen was determined using the Kjeldahl method. The soil samples (< 0.5 mm) were oven - dried at 40^0C and digested with concentrated sulphuric acid containing potassium sulphate, selenium and copper sulphate hydrated at approximately 350˚C. Total N was determined by distillation followed by titration with diluted standardized 0.007144N H_2SO4. (Okalebo et al., 2002).

Exchangeable acidity was determined by placing 5 g of oven – dried soil sample (< 2 mm) at 40^0 C into a 50 ml container into which 12.5 ml of 1 M KCl was added and the contents were stirred using a clean glass rod then left to stand for half an hour. A funnel was used to filter the solutions. Five successive 12.5 ml aliquots of 1 M KCl were used to leach the solutions. Phenolphthalein indicator solution was added and titration was done with 0.1 M NaOH till the first permanent pink color was obtained. The volume of the NaOH used was recorded. Available trace elements (Cu, Fe and Zn) were determined by extraction with 0.1 M HCl. The elements were extracted in a 1:10 ratio (w/v) with 0.1 M HCl. Elements were determined with AAS (Mukai et al., 1992). Soil pH was determined in a 1:1 (w/v) soil – water suspension with pH meter.

Length and width determination

At the time of harvesting, a sample of 100 shoots comprising two leaves and a bud were taken randomly from the harvested shoots from each plot. The length and width of the second leaf taken using a ruler and the average length and width recorded for each plot 20 times in duration of 7-10 days depending on the availability of crop.

Assessment of yield

Plucking of leaves from each plot started two weeks after applying the fertilizers. The tea was plucked by hand using the standard method of harvesting two leaves and a bud at an interval of 7-10 days depending on the availability of crop to a total of 20 harvests. The plucked leaves were weighed and data recorded.

The green leaves harvested per plot was converted to made tea (kg/ha/year) using the equation below (Sitienei et al., 2013). Made tea refers to the form of tea obtained after the harvested green shoots have gone through the manufacturing processes i.e. withering, fermentation and drying (De Costa et al., 2007)

$$\text{Made tea yield/ha/year} = \frac{N*a*0.225}{b}$$

Where: **a** is the plant population per hectare, **N** is the green leaf yield per plot, **b** is the number of tea bushes per plot and **0.225** is the factor converting green leaf to made tea.

Determination of leaf nutrient and nutrient use efficiencies

One hundred mature leaves were sampled from each plot for nutritional analysis to be used for calculating nutrient use efficiencies. The leaf samples were oxidized by hydrogen peroxide at 100^0C. Digestion was completed by concentrated H_2SO_4 at 330^0C under Se as a catalyst after decomposition of the excess hydrogen peroxide and the evaporation of water. Nitrogen was then determined by distillation followed by titration with standardized 0.3 N HCl. Potassium, phosphorus and nitrogen were determined by flame photometer, spectrophotometrically and Kjeldahl methods respectively.

Nutrient use efficiency was obtained by calculating the apparent nutrient recovery, agronomic efficiency and partial factor productivity of nitrogen, phosphorus and potassium. Efficiencies were determined using the equations below (Sitienei et al., 2013; Jagadeeswaran et al., 2005).

$$\text{Agronomic efficiency (AE)} = \frac{\text{Yield in fertilized plot (kg/ha) -yield in control plot (kg/ha)}}{\text{Quantity of fertilizer nutrient applied (kg/ha)}}$$

Apparent nutrient recovery efficiency (**ANR)** was used to determine the ability of the plant to acquire nutrient from the soil.

$$ANR = \frac{\text{Nutrient uptake in the fertilized plot (kg/ha)-Nutrient uptake in control plot (kg/ha)}}{\text{Quantity of fertilizer nutrient applied (kg/ha)}}$$

Nutrient uptake=Nutrient concentration*dry matter

Dry matter-Kg of made tea/ha

Partial factor productivity (P_fP)

$$P_fP = \frac{\text{Yield of made tea (kg/ha)}}{\text{Amount of fertilizer nutrients applied (kg/ha)}}$$

Determination of the economic benefits of the treatments

The total estimated cost and the estimated revenue of each fertilizer regime were calculated so as to establish the profit from each fertilizer regime. The total cost comprised the cost of fertilizer used, cost of applying the fertilizer and the cost of plucking/harvesting. The total revenue included the farm gate price that is paid on a monthly basis for the green leaf delivered and the annual payment that varies from factory to factory. One kilogram was valued at Ksh. 14/= as the farm gate price per kilogram of the total green delivered to the factory in a month, which is the price paid to small scale farmers affiliated to KTDA for the green leaf delivered in a month. The annual payment was 35.05/= of the cumulative green leaf in the financial year equivalent to the payment made to farmers who delivered green leaf to Mungania tea factory in the financial year 2014/2015 where the experiment was laid. Hence the green leaf was valued at Ksh. 49.05/kg. The total cost included the labor cost of applying the fertilizer (Ksh /ha), the purchasing cost of the fertilizers (Ksh/ha) and the cost of plucking (Ksh /ha) hectare. The labor cost of harvesting was calculated at Ksh. 10/ = per kilogram of harvested green leaf while the labor cost of applying fertilizer was estimated at Ksh. 50 per 50 kg bag of fertilizer. A 50 kg bag of NPK 26.5.5 and rutuba fertilizer was valued at the market price of Ksh. 2250 and Ksh. 3000 respectively. The total revenue was calculated by multiplying the cumulative green leaf with the total paid per kilogram to the farmers.

The total cost= the purchasing cost of fertilizer applied + the cost of harvesting + cost of applying fertilizer.

Total revenue =cumulative green leaf (kg/ha)* Ksh. 49.05

Net revenue=Total Revenue-total cost

3.4 Data analysis

All data collected were subjected to analysis of variance (ANOVA) using GENSTAT discovery edition 14 software and means were separated using the least significant difference (LSD) at p=0.05.

CHAPTER FOUR: RESULTS

4.1 Effects of varying inorganic NPK and organic Rutuba fertilizer regimes on soil nutrients, pH, total carbon and exchangeable acidity in a clonal tea field at the end of the experiment.

Fertilizer application regimes had a significant effect ($p \leq 0.05$) on the soil pH, exchangeable acidity, total carbon, manganese, copper, iron and zinc contents (Table 4.1). Application of 1875 kg Rutuba/ha had significantly higher pH than all the fertilizer rates except application of 625 kg Rutuba/ha + 625 kg NPK/ha which was not significantly different from 937.5 kg Rutuba/ha, 625 kg Rutuba/ha and the no-fertilizer control. All the sole NPK rates were not significantly different. The soil pH ranged from 3.94 (1875 kg NPK/ha) to 5.36 (1875 kg Rutuba/ha). Application of 1875 kg NPK /ha had significantly higher exchangeable acidity than all the other application rates. Application of 625 kg Rutuba/ha + 625 kg NPK/ha, 625 kg NPK/ha, 937.5 kg NPK/ha, 625 kg Rutuba/ha and the no-fertilizer control were not significantly different in the soil exchangeable acidity. There was no significant difference in the soil exchangeable acidity between the application of 1875 kg Rutuba/ha and 937.5 kg Rutuba/ha. The soil exchangangeable acidity ranged from 0.3 Me % (1875 kg Rutuba/ha) to 0.57 Me% (1875 kg NPK/ha). Application of 1875 kg Rutuba /ha had significantly higher content of total carbon than all the other fertilizer rates except application of 937.5 kg Rutuba/ha. There was no significant difference in the total carbon content between the application of 937.5 kg Rutuba/ha, 625 kg Rutuba/ha, 625 kg NPK/ha and the application of 625 kg Rutuba/ha + 625 NPK/ha. Application of 1875 kg NPK /ha, 937.5 kg NPK/ha and the no-fertilizer control were not significantly different in the total carbon content. The total carbon ranged from 2.96 % (no-fertilizer control) to 4.32% (1875 kg Rutuba/ha). Application of 1875 kg Rutuba/ha had significantly higher content of Mn than all the other fertilizer regimes except 937.5 kg Rutuba/ha which was not significantly different from 625 kg Rutuba/ha. There was no significant difference in the Mn content among all the NPK rates and the no-fertilizer control. The Mn content ranged from 0.18 Me% (all NPK fertilizer rates) to 0.33 Me % (1875 kg Rutuba/ha). The three sole Rutuba application rates and 625 kg Rutuba/ha + 625 kg NPK/ha had significantly higher content of Cu than all the sole NPK rates and the no-fertilizer control. The no-fertilizer control had significantly higher Cu content than all the sole NPK application regimes. Copper content ranged from 2.28 ppm (1875 kg NPK/ha) to 4.37 ppm (1875 kg Rutuba/ha). Application of 1875 kg Rutuba/ha had significantly the highest content of Fe compared to all the other treatments while 937.5 kg Rutuba/ha and 625 kg Rutuba/ha had significantly higher Fe content than all the NPK treatments and the no-fertilizer control. The sole NPK applications had lower Fe content than the no-fertilizer control. The Fe content ranged from 45.83 ppm (1875 kg NPK/ha) to 94.5 ppm (1875 kg Rutuba/ha). Application of 1875 kg Rutuba/ha had significantly higher Zn content than all other fertilizer rates except 937.5 kg Rutuba/ha. There was no significant difference between applications of 937.5 kg Rutuba/ha and 625 kg Rutuba/ha but these two treatments had higher Zn content than all the NPK treatments, no-fertilizer control and the application of 625 kg Rutuba/ha + 625 kg NPK/ha. The application of 625 kg Rutuba/ha + 625 kg NPK /ha had significantly higher Zn soil content than all the sole NPK application rates. All the NPK rates and the no-fertilizer control were not significantly different in the zinc soil content. Zinc content ranged from 2.45 ppm (625 kg NPK /ha) to 7.99 ppm (1875 kg Rutuba/ha).

Table 4. 1: Effect of different fertilizer regimes on soil pH, Exchangeable acidity, total carbon and micronutrients in a tea clonal field at Kianjokoma at the end of the experimental period.

Treatments	pH	Ea (Me %)	TC (%)	Mn (Me%)	Cu (ppm)	Fe (ppm)	Zn (ppm)
1875 kg NPK/ha	3.94[c]	0.57[a]	3.03[d]	0.18[c]	2.28[d]	45.83e	2.70[d]
625 kg Rutuba/ha +625 kg NPK/ha	4.83[ab]	0.47[b]	3.60[bc]	0.23b[c]	4.06[a]	61.27[c]	3.74[c]
937.5 kg NPK/ha	3.98[c]	0.47[b]	3.05[cd]	0.18[c]	2.66[cd]	47.47[e]	2.71[d]
625 kg NPK/ha	4.06[c]	0.43[b]	3.47[bc]	0.18[c]	2.89[c]	49.63[de]	2.45[d]
1875 kg Rutuba/ha	5.36[a]	0.30[d]	4.32[a]	0.33[a]	4.37[a]	94.50[a]	7.99[a]
937.5 kg Rutuba/ha	4.41[bc]	0.33[cd]	3.92[ab]	0.28[ab]	4.34[a]	76.40[b]	7.43[ab]
625 kg Rutuba/ha	4.27[bc]	0.43[b]	3.63[bc]	0.26[b]	4.01[a]	69.43[b]	6.75[b]
Control	4.71[b]	0.43[b]	2.96[d]	0.19[c]	3.44[b]	54.67[cd]	3.05[cd]
P-value	0.003	0.002	<.001	<.001	<.001	<.001	<.001
LSD p≤ 0.05	0.63	0.10	0.52	0.06	0.46	7.04	0.99
CV%	9	17	8.6	15.5	7.4	6.4	12.3

Treatments with different letters in the same column are significantly different according to LSD at p≤ 0.05; CV=coefficient of variation; Ea=Exchangeable acidity; TC=Total carbon

Application regimes had no significant effect on the TN and Na content but significantly (p≤ 0.05) affected P, K, Ca and Mg content (Table 4.2). Application of 1875 kg NPK/ha had significantly the highest P content compared to all the other fertilizer regimes. Application 937.5 kg NPK/ha and 625 kg NPK/ha were not significantly different in P content. Application of 625 kg Rutuba /ha + NPK 625 kg NPK/ha, 625 kg NPK/ha, 1875 kg Rutuba/ha and 937.5 kg Rutuba/ha were not significantly different in the P content. Application of 937.5 kg Rutuba/ha and 625 kg Rutuba/ha were not significantly different in P content. The no-fertilizer control had the lowest P content compared to all treatments except 625 kg Rutuba/ha. The P content ranged from 23.33 ppm (control) to 65 ppm (1875 kg Rutuba/ha). The three NPK sole applications and the application of 625 kg Rutuba/ha + 625 kg NPK/ha had significantly higher K content than all the other application rates. There was no significant difference in K content among applications 625 kg Rutuba/ha + 625 kg NPK/ha, 937.5 kg NPK/ha, 625 kg NPK/ha and 625 kg Rutuba/ha. There was no significant difference in the K content between 625 kg Rutuba/ha +625 kg NPK/ha and all the sole Rutuba application rates which were in turn not significantly different from the no-fertilizer control. K content ranged from 0.75 Me % (non-fertilized control) to 1.5 (1875 kg NPK/ha). All the sole Rutuba applications, application of 625 kg Rutuba/ha + 625 kg NPK/ha and 625 kg NPK/ha had significantly the highest Ca content compared to the other treatments. All the sole NPK rates, 625 kg Rutuba/ha+ 625 kg NPK/ha and the no-fertilizer control were not significantly different in the Ca content. Ca content ranged from 4.47 Me% (control) to 8.13 Me % (1875 kg Rutuba/ha).

Application of 1875 kg Rutuba/ha had significantly higher Mg content than 937.5 kg Rutuba/ha which in turn had higher Mg content than all the other treatments. The no-fertilizer control had no significantly different Mg content in compared to 625 kg NPK/ha but had significantly higher Mg content than 937.5 kg NPK/ha and 1875 kg NPK/ha. The three sole NPK fertilizer application rates were not significantly different in the Mg content The Mg content ranged from 0.21 ppm (1875 kg NPK/ha and 937.5 kg NPK/ha) to 0.55 ppm (1875 kg Rutuba/ha).

Table 4. 2: Effects of different fertilizer regimes on total nitrogen, phosphorus, potassium, calcium, magnesium and sodium in a clonal tea field at Kianjokoma from June 2014 to June 2015

Treatments	TN (%)	P (PPM)	K (Me %)	Ca (Me %)	Mg (Me %)	Na (Me %)
1875 kg NPK/ha	0.35[a]	65.00[a]	1.50[a]	4.57[b]	0.21[f]	0.25[a]
625 kg Rutuba/ha + 625 kg NPK/ha	0.33[a]	43.33[c]	1.26[abc]	6.73[ab]	0.34[c]	0.35[a]
937.5 kg NPK/ha	0.31[a]	53.33[b]	1.40[ab]	4.80[b]	0.21[f]	0.23[a]
625 kg NPK/ha	0.33[a]	45.00[bc]	1.40[ab]	5.90[ab]	0.23[ef]	0.28[a]
1875 kg Rutuba/ha	0.38[a]	43.33[c]	0.94[cd]	8.13[a]	0.55[a]	0.40[a]
937.5 kg Rutuba/ha	0.35[a]	36.67[cd]	0.96[cd]	7.90[a]	0.45[b]	0.40[a]
625 kg Rutuba/ha	0.33[a]	30.00[de]	1.02[bcd]	7.57[a]	0.28[d]	0.32[a]
Control	0.32[a]	23.33[e]	0.75[d]	4.47[b]	0.25[de]	0.25[a]
p value	0.20	<.001	0.01	0.04	<.001	0.31
LSD p≤ 0.05	NS	9.16	0.38	2.67	0.04	NS
CV%	18	12.3	12.8	24.4	7	23

Treatments with different letter(s) in the same column are significantly different according to LSD at p≤ 0.05; CV=coefficient of variation; TN=total nitrogen; LSD=least significant difference

4.2 Effects of varying organic rutuba and inorganic NPK fertilizer regimes on the average width and length of the second leaf of the harvestable shoot.

Fertilizer application regimes significantly ($p \leq 0.05$) affected the average width of the second leaf in both seasons (Table 4.3). In the first season, the three sole NPK application rates and the application of 625 kg Rutuba/ha + 625 kg NPK/ha had significantly higher average width than all the other treatments. The three sole Rutuba application rates were not significantly different. Application of 625 kg Rutuba/ha, 937.5 kg Rutuba/ha and the no-fertilizer control were not significantly different in the average width of the second leaf. The average width of the second leaf in season one ranged from 1.8 cm (no-fertilizer control) to 2.8 cm (625 kg Rutuba/ha + 625 kg NPK /ha). In season two application of 625 kg Rutuba/ha+ 625 kg NPK/ha, 1875 kg

Rutuba/ha and the three sole NPK fertilizer application rates had significantly higher average width than all other treatments. There was no significant difference in the average width of the second leaf between application of 1875 kg Rutuba/ha and 937.5 kg Rutuba/ha. Application of 937.5 kg Rutuba/ha and 625 kg Rutuba/ha had no significant difference in the average width of the second leaf. In the second season the average width of the second leaf ranged from 1.8 cm (no-fertilizer control) to 2.9 cm (625 kg NPK/ha and 625 kg Rutuba/ha + 625 kg NPK/ha.

The fertilizer application regimes had a significant ($p \leq 0.05$) effect on the length of the second leaf in both seasons (Table 4.3). Application of 625 kg Rutuba/ ha + 625 kg NPK/ha and the three NPK application rates had significantly higher average length of the second leaf than all the three sole Rutuba treatments and the no-fertilizer control. Application of 1875 kg Rutuba/ha had a significantly higher average length than all the other Rutuba application rates and the no-fertilizer control. There was no significant difference in the average length of the second leaf among application of 937.5 kg Rutuba/ha, 625 kg Rutuba/ha and the no-fertilizer control. In season one, the average length of the second leaf ranged from 4.1 cm (control) to 7.4 cm (1875 kg NPK/ha and 625 kg Rutuba/ha+ 625 kg NPK/ha). In both seasons application of 625 kg Rutuba/ha rutuba did not significantly increase the average length of the second leaf relative to the no-fertilizer control. There was no significant difference in the length of the second leaf among the Rutuba application rates. All sole Rutuba treatments except 625 kg Rutuba/ha had significantly higher average leaf length than the no-fertilizer control. The average length of the second leaf ranged from 4.4 cm (no-fertilizer control) to 7.6 cm (1875 kg NPK/ha).

Table 4. 3: Length and width (cm) of the second leaf of the harvestable shoot for different fertilizer regimes in first and second seasons at Kianjokoma from June 2014 to June 2015

Treatments	Season 1		Season 2	
	Average width (cm)	Average length (cm)	Average width (cm)	Average length (cm)
1875 kg NPK /ha	2.7[a]	7.4[a]	2.7[a]	7.0[a]
625 kg Rutuba/ha +625 kg NPK/ha	2.8[a]	7.4[a]	2.9[a]	7.1[a]
937.5 kg NPK/ha	2.7[a]	6.9[a]	2.7[a]	7.1[a]
625 kg NPK/ha	2.7[a]	6.9[a]	2.9[a]	7.2[a]
1875 kg Rutuba/ha	2.3[b]	5.7[b]	2.6[ab]	5.6[b]
937.5 kg Rutuba/ha	2.0[bc]	4.6[c]	2.2[bc]	5.2[b]
625 kg Rutuba/ha	2.1b[c]	4.5[c]	2.2[c]	4.9[bc]
Control	1.8[c]	4.1[c]	1.8[d]	4.4[c]
p-value	<.001	<.001	<.001	<.001
$LSD_{(p\leq 0.05)}$	0.3	0.5	0.4	0.7
CV%	8	4.9	8.5	6.2

Treatments with different letters in the same column are significantly different at according to the least significant difference test ($p\leq 0.05$)

4.3 Effects of varying organic rutuba and inorganic NPK fertilizer regimes on the green leaf and made tea yields

Green leaf and made tea yields varied significantly ($p \leq 0.05$) with the fertilizer application regime in both seasons (Table 4.4). In the first season, fertilizer application, irrespective of the regime and type significantly increased green leaf and made tea yields. Application of 625 kg Rutuba/ha + 625 kg NPK /ha had significantly the highest yield in green leaf and made tea compared to all the other fertilizer application regimes. The three sole NPK fertilizer rates were not significantly different in green leaf and made tea yields but they had higher green leaf and made tea yields than all the three Rutuba application rates. Application of 1875 kg Rutuba/ha of and 937.5 kg Rutuba/ha had significantly higher green leaf and made tea yields than application of 625 kg Rutuba/ha which was not significantly different from the no-fertilizer control. Season one green leaf yield ranged from 1521 kg/ha (no-fertilizer control) to 6587 kg/ha (625 kg Rutuba/ha + 625 kg NPK/ha) while made tea ranged from 342 kg/ha (no-fertilizer control) to 1482 kg/ha (625 kg Rutuba/ha+ 625 kg NPK/ha).

In season two, 625 kg Rutuba/ha + 625 kg NPK had significantly the highest green leaf and made tea yields compared to all other fertilizer regimes (Table 4.4). The three sole NPK rates were not significantly different in green leaf and made tea yields. There were no significant differences in the green leaf and made tea yields amongst applications of 1875 kg NPK/ha, 625 kg NPK/ha and 1875 kg Rutuba/ha. The three Rutuba application rates were not significantly different in green leaf and made tea yields but they had significantly higher green leaf and made tea yields than the no-fertilizer control. Season two leaf yield ranged from 2621 kg /ha (no-fertilizer control) to 6444 kg/ha (625 kg Rutuba/ha+ 625 kg NPK/ha) while the made tea ranged from 588 kg/ha (no-fertilizer control) to 1450 kg/ha (625 kg Rutuba /ha + 625 kg NPK /ha).

Table 4. 4: Green leaf (kg/ha) and made tea yields (kg/ha) under different fertilizer regimes at Kianjokoma from June 2014 to June 2015

Treatments	Season 1		Season 2		Cumulative yield	
	G L	MT	GL	MT	GL	MT
1875 kg NPK/ha	4162[b]	936 [b]	5339[bc]	1201[bc]	9501[b]	2137[b]
625 kg Rutuba/ha +625 kg NPK/ha	6587[a]	1482[a]	6444[a]	1450[a]	13031[a]	2932[a]
937.5 kg NPK/ha	4105[b]	924[b]	5382[b]	1211[b]	9486[b]	2135[b]
625 kg NPK/ha	4004[b]	900[b]	5296[bc]	1192[bc]	9300[b]	2093[b]
1875 kg Rutuba/ha	2856[c]	642[c]	4435[cd]	998[cd]	7291[c]	1641[c]
937.5 kg Rutuba/ha	2669[c]	600[c]	4004[d]	901[d]	6674[c]	1501[c]
625 kg Rutuba/ha	1708[d]	384[d]	3660[d]	823[d]	5368[d]	1207[d]
Control	1521[d]	342[d]	2612[e]	588[e]	4133[e]	930[e]
p-value	<.001	<.001	<.001	<.001	<.001	<.001
LSD $_{(p\leq 0.05)}$	362.8	73.53	920.5	207.1	1036	233.3
CV%	5.4	5.4	11.3	11.3	7.3	7.3

Treatments with different letters in the same column are significantly different at according to the least significant difference test ($p\leq 0.05$)

GL-Green leaf; MT-Made tea; CV=coefficient of variation; LSD=least significant difference

4.4 Effects of varying inorganic and organic fertilizer regimes on leaf nitrogen, potassium and phosphorus uptake

Fertilizer application had a significant ($p \leq 0.05$) effect on the N K and P leaf content (Table 4.5). Application of 625 kg Rutuba/ha + 625 kg NPK/ha had significantly the highest nitrogen content compared to no-fertilizer control and other fertilizer regimes. There were no significant differences in the leaf N content between application of 937.5 kg NPK/ha and 625 kg NPK/ha and between 1875 kg NPK/ha and 1875 kg Rutuba/ha. The latter treatment was not significantly different from the application of 937.5 kg rutuba/ha. Applications of 937.5 kg Rutuba/ha and 625 kg Rutuba/ha were not significantly different in the leaf N content. The N leaf content ranged from 2.1 % (no –fertilizer control) to 4.5 % (625 kg Rutuba/ha+ 625 kg NPK/ha).

Application of 1875 kg Rutuba/ha had significantly the highest potassium content compared to the no-fertilizer control and other treatments except application of 937.5 kg Rutuba/ha which was not significantly different from 625 kg Rutuba/ha + 625 kg NPK/ha. All the three sole NPK application rates and the no-fertilizer control were not significantly different in the leaf K content. The leaf K content varied from 2.4 % (no-fertilizer control and 1875 kg NPK/ha) to 5.4 % (1875 kg Rutuba/ha). All the sole Rutuba fertilizer rates and application of 625 kg NPK/ha + 625 kg Rutuba/ha had significantly the highest leaf P content compared to other fertilizer regimes. There was no significant difference in the leaf P content among the sole NPK application rates and between application of 1875 kg NPK/ha and the no-fertilizer control. The P content varied from 0.3 % (no-fertilizer control and 1875 kg NPK/ha) to 0.5 % (all sole rutuba applications and 625 kg NPK/ha+ 625 kg Rutuba/ha).

Table 4. 5: Nitrogen, potassium and phosphorus leaf uptake under different fertilizer regimes at Kianjokoma from June 2014 to June 2015

	Nitrogen (%)	Potassium (%)	Phosphorus (%)
1875 kg/ha NPK	3.5[c]	2.4[d]	0.3[de]
625 kg Rutuba/ha + 625 kg NPK/ha	4.5[a]	4.4[b]	0.5[a]
937.5 kg NPK/ha	3.9[b]	2. 6[d]	0.4[cd]
625 kg NPK/ha	4.1[b]	2.7[cd]	0.4[bcd]
1875 kg Rutuba /ha	3.2[cd]	5.4[a]	0.5[a]
937.5 kg rutuba/ha	3.1[de]	4.8[ab]	0.5[a]
625 kg Rutuba/ha	2.9[e]	3.5[c]	0.5[a]
Control	2.1[f]	2.4[d]	0.3[e]
p value	<.001	<.001	<.001
LSD p≤ 0.05	0.3	0.9	0.1
CV%	4.6	14.4	10.7

Treatments with different letters in the same column are significantly different according to LSD at p≤ 0.05; CV=coefficient of variation

4.5 Effects of varying inorganic and organic fertilizer regimes on apparent nutrient recovery, partial factor productivity and agronomic efficiencies of nitrogen, potassium and phosphorus in clonal tea.

The fertilizer application regimes had significant effects (p ≤0.05) on the apparent nutrient recovery (ANR) of nitrogen, potassium and phosphorus (Table 4.6). Application of 625 kg Rutuba/ha and 937.5 kg Rutuba/ha had significantly the highest apparent nutrient recovery of nitrogen (ANR_N) compared to all the other treatments. Application of 1875 kg Rutuba/ha had a significantly higher ANR_N than all the sole NPK application rates and application of 625 kg Rutuba/ha + 625 kg NPK/ha. The ANR_N of 625 kg NPK/ha and 625 kg Rutuba/ha + 625 kg NPK/ha were not significantly different but significantly higher than 1875 kg NPK/ha and 937.5 kg NPK/ha which were not significantly different. The ANR_N ranged from 0.11 (1875 kg NPK/ha) to 1.69 (937.5 kg Rutuba/ha). All the sole Rutuba applications had significantly higher apparent nutrient recovery of potassium (ANR_K) than all the other fertilizer rates. There was no significant difference in ANR_K between application of 625 kg NPK/ha and 625 kg Rutuba/ha +625 kg NPK/ha. All the sole NPK applications rates were not significantly different in ANR_K. The ANR_K ranged from 0.32 (1875 kg NPK/ha) to 4.01 (1875 kg Rutuba/ha). Application of 937.5 kg Rutuba/ha and 625 kg Rutuba/ha had significantly higher apparent nutrient recovery of phosphorus ($ANR_{P)}$ than all the other fertilizer régimes. Application of 1875 kg Rutuba/ha had a significantly higher ANR_P than all the sole NPK fertilizer rates but was not significantly different from application of 625 kg Rutuba/ha + 625 kg NPK/ha which was not significantly different from application of 625 kg NPK/ha. Application of 937.5 kg/ha NPK and 1875 kg/ha NPK were not significantly different and had the lowest ANR_P. The ANR_P ranged from 0.05 (1875 kg NPK/ha) to 0.52 (937.5 kg Rutuba/ha). The fertilizer regimes had significant effects on the partial factor productivity (PfP) of nitrogen, potassium and phosphorus (Table 4.6). Application of 625 kg Rutuba/ha and 937.5 kg Rutuba/ha had significantly higher PfP_N than all the other treatments. Application of 1875 kg Rutuba/ha had significantly higher partial factor productivity of nitrogen ($PfP_{N)}$ than all the sole NPK treatments and application of 625 kg Rutuba/ha + 625 kg NPK/ha whose PfP_N were not significantly different. The PfP_N ranged from 4.38 (1875 kg NPK/ha) to 92.04 (625 kg Rutuba/ha). Application of 625 kg Rutuba/ha had significantly higher partial factor productivity of potassium (PfP_K) than all the other treatments. There were no significant differences in the PfP_k among applications 625 kg Rutuba/ha+ 625 kg/ha NPK, 625 kg NPK/ha, 1875 kg Rutuba/ha and 937.5 kg Rutuba/ha. Application of 625 kg Rutuba/ha +625 kg NPK/ha and application of 937.5 kg NPK/ha were not significantly different from application of 625 kg NPK/ha which was not significantly different from application of 1875 kg NPK/ha. The PfP_K ranged from 22.8 (1875 kg NPK/ha) to 158.39 (625 kg Rutuba/ha). Application of 625 kg Rutuba/ha and 937.5 kg Rutuba/ha had significantly higher partial factor productivity of phosphorus (PfP_P) than all the other treatments. Application of 1875 kg Rutuba/ha, 625 kg NPK/ha, 937.5 kg NPK/ha and 625 kg Rutuba/ha + NPK 625 kg NPK /ha were not significantly different in PfP_P. Applications of 937.5 kg Rutuba/ha NPK and 1875 kg NPK/ha were not significantly different in partial PfP_P. The PfP_P ranged from 22.8 (1875 kg NPK/ha) to 195.18 (625 kg Rutuba/ha).

Table 4. 6: Effects of varying inorganic and organic fertilizer regimes on the apparent nutrient recovery and the partial factor productivity of nitrogen, potassium and phosphorus in clonal tea at Kianjokoma from June 2014 to June 2015.

Treatment	ANR_N	ANR_K	ANR_p	PfP_N	PfP_K	PfP_P
1875 kg NPK/ha	0.11^{d}	0.32^{d}	0.05^{e}	4.38^{c}	22.80^{d}	22.80^{c}
625 kg Rutuba/ha+ 625 kg NPK/ha	0.64^{bc}	2.77^{abc}	0.31^{bc}	16.69^{c}	75.43^{bc}	78.31^{b}
937.5 kg NPK/ha	0.26^{d}	0.74^{cd}	0.12^{de}	8.76^{c}	45.53^{c}	45.53^{bc}
625 kg NPK/ha	0.41^{c}	$1.08b^{cd}$	0.19^{cd}	12.88^{c}	66.96^{bcd}	66.96^{b}
1875 kg Rutuba/ha	0.84^{b}	4.01^{a}	0.32^{b}	41.66^{b}	101.07^{b}	88.37^{b}
937.5 kg Rutuba/ha	1.69^{a}	3.41^{a}	0.52^{a}	76.26^{a}	102.34^{b}	161.78^{a}
625 kg Rutuba/ha	1.35^{a}	2.96^{ab}	0.46^{a}	92.04^{a}	158.39^{a}	195.18^{a}
P Value	<.001	0.01	<.001	<.001	0.003	<.001
L.S.D $_{p\leq 0.05}$	0.33	2.09	0.13	21.52	52.3	43.87
CV%	27.2	31.1	26.2	33.5	21.2	26.2

Treatments with different letters in the same column are significantly different according to least significant difference at $p\leq 0.05$; ANR_N=Apparent nutrient recovery of nitrogen; P_fP_N =Partial factor productivity of nitrogen ANR_K=Apparent nutrient recovery of potassium; PfP_K=Partial factor productivity of potassium; ANR_P=Apparent nutrient recovery of phosphorus; P_fP_P =Partial factor productivity of phosphorus. CV=coefficient of variation; LSD=least significant difference

The fertilizer application regimes had significant ($p \leq 0.05$) effects on the agronomic efficiencies of nitrogen, potassium and phosphorus (Table 4.7). Applications of 937.5 kg Rutuba/ha and 625 kg Rutuba/ha had significantly the highest agronomic efficiency of nitrogen (AE_N) compared to all other fertilizer regimes. The AE_N of 625 kg Rutuba/ha was not significantly different from 1875 kg Rutuba/ha whose AE_N was not significantly different from 625 kg Rutuba/ha + 625 kg NPK/ha. All the sole NPK fertilizer rates and 625 kg Rutuba/ha + 625 kg NPK/ha were not significantly different in AE_N. The agronomic efficiency of nitrogen (AE_N) ranged from 2.48 (1875 kg NPK/ha) to 29.03 (937.5 kg Rutuba/ha). Application of 625 kg Rutuba/ha + 625 kg NPK /ha, 625 kg NPK/ha and sole Rutuba applications had significantly the highest agronomic efficiency of potassium (AE_K). There were no significant differences in AE_K among sole Rutuba application rates, 625 kg NPK/ha and 937.5 kg NPK/ha which was not significantly different from 1875 kg NPK /ha. The AE_K ranged from 12.88 (1875 kg NPK/ha) to 51.51 kg (625 kg Rutuba/ha + 625 kg NPK/ha). Application of 937.5 kg Rutuba/ha and 625 kg Rutuba/ha+ 625 kg NPK/ha had significantly higher agronomic efficiency of phosphorus (AE_P) than all the other fertilizer regimes. Application of 1875 kg Rutuba/ha, 625 kg Rutuba/ha, 625 kg NPK/ha and 625 kg Rutuba/ha+ 625 kg NPK/ha were not significantly different in AE_P. The AE_P from the application of 1875 kg NPK/ha was not significantly from that of the application of 937.5 kg NPK/ha whose AE_P was not significantly different from application of 625 kg NPK/ha, 1875 kg Rutuba/ha and 625 kg Rutuba/ha. The AE_P ranged from 12.88 (1875 kg NPK/ha) to 61.58 (937.5 kg Rutuba/ha).

Table 4. 7: Effects of varying inorganic and organic fertilizer regimes on the agronomic efficiencies of nitrogen, potassium and phosphorus in clonal tea at Kianjokoma from June 2014 to June 2015

Treatment	AE_N	AE_K	AE_P
1875 kg NPK/ha	2.48^{d}	12.88^{c}	12.88^{d}
625 kg Rutuba/ha+ 625 kg NPK/ha	11.04^{cd}	51.51^{a}	53.46^{ab}
937.5 kg NPK/ha	4.94^{d}	25.70^{bc}	25.7^{cd}
625 kg NPK/ha	7.15^{d}	37.20^{ab}	37.2^{bc}
1875 kg Rutuba/ha	18.04^{bc}	43.90^{ab}	38.27^{bc}
937.5 kg Rutuba/ha	29.03^{a}	37.55^{ab}	61.58^{a}
625 kg Rutuba/ha	21.17^{ab}	36.42^{ab}	44.89^{abc}
P Value	<.001	0.04	0.005
L.S.D. ≤0.05	9.51	21.72	21.03
CV%	39.7	15.5	30.2

Treatments with different letters in the same column are significantly different according to LSD at p≤ 0.05; CV=coefficient of variation; AE_N=Agronomic efficiency of nitrogen; AE_K=Agronomic efficiency of potassium; AE_P=Agronomic efficiency of phosphorus;

4.6 Effects of fertilizer regimes on the cost of production and profitability in tea production

The fertilizer application regimes had significant (p ≤0.05) effects on the total estimated cost of production and the estimated total revenue (Table 4.8). Application of 625 kg Rutuba/ha + 625 kg NPK/ha had significantly the highest estimated total cost but was not significantly different from the application of 1875 kg Rutuba/ha. Application of 1875 kg NPK/ha had a significantly higher estimated total cost than other sole NPK rates, 937.5 kg Rutuba/ha and 625 kg Rutuba/ha but was not significantly different from 1875 kg Rutuba/ha. Application of 625 kg NPK/ha had significantly higher estimated total cost than 625 kg Rutuba/ha but was not significantly different from 937.5 kg Rutuba/ha. The estimated total cost per/ha ranged from Ksh. 41,333 (control) to Ksh. 196, 557 (625 kg Rutuba /ha + 625 kg NPK/ha). Total cost for the farmers' practice (625 kg NPK/ha) was 61.45% lower than application of 625 kg Rutuba/ha + 625 kg NPK/ha. Application of 625 kg Rutuba/ha + 625 kg NPK/ha had significantly higher estimated total revenue than all the other fertilizer regimes. It had 40% and 215% higher total revenue than farmers' practice and the no-fertilizer control respectively. The total estimated revenue from the sole NPK fertilizer application regimes was not significantly different but they had higher estimated total revenue than all the sole Rutuba application rates. The estimated total revenue from the application of 1875 kg rutuba/ha was not significantly different application of 937.5 kg rutuba/ha but both regimes had significantly higher estimated revenue than application of 625 kg Rutuba/ha. The no –fertilizer control had significantly the lowest revenue compared to other treatments. The total estimated revenue ranged from Ksh. 144, 871 (no- fertilizer control) to Ksh. 456, 748 (625 kg NPK/ha+ 625 kg Rutuba/ha).

The fertilizer application regimes had significant effects on the net returns. Application of 625 Rutuba kg/ha + 625 kg NPK/ha had significantly higher net revenue than all the other treatments (Table 4.8) while application of 1875 kg Rutuba/ha had significantly the lowest net revenue. There was no significant difference in the estimated net revenue between an application of 937.5 kg NPK/ha and 625 kg NPK/ha but these applications had significantly higher net revenue than 1875 kg NPK/ha, all the sole Rutuba and the no-fertilizer control. Application of 1875 kg NPK/ha had significantly higher estimated net return than all the sole Rutuba rates and the no-fertilizer control. Application regimes of 937.5 kg Rutuba/ha, 625 kg Rutuba/ha and the no-fertilizer control were not significantly different in net return. The estimated net revenue ranged from Ksh. 68, 256 (1875 kg Rutuba/ha) to Ksh. 260, 191 (625 kg Rutuba/ha + NPK 625 kg NPK/ha). Application of 625 kg Rutuba/ha + 625 kg NPK/ha had 27.4% and 151.3% higher returns than the farmers' practice and the no-fertilizer control respectively. Increase in fertilizer rates from 625 kg NPK/ha (farmers' practice) to 937.5 kg NPK/ha and 1875 kg NPK/ha reduced the net returns by 4.7% and 25.7% respectively.

Table 4. 8: Cost of each fertilizer regime and the net revenue at Kianjokoma from June 2014 to June 2015

Fertilizer regime	CoF (Ksh/ha)	CoP (Ksh/ha)	CoAF (Ksh/ha)	TC (Ksh/ha)	TR (Ksh/ha)	NR (Ksh/ha)
1875 kg NPK/ha	84356	95008^{b}	1875	181239b	333003^{b}	151764^{c}
625 kg Rutuba/ha+ 625 kg NPK/ha	65619	130313^{a}	625	196557^{a}	456748^{a}	260191^{a}
937.5 kg NPK/ha	42178	94865^{b}	937.5	137980^{c}	332500^{b}	194520^{b}
625 kg NPK/ha	28119	92999^{b}	625	121743^{d}	325961^{b}	204218^{b}
1875 kg Rutuba/ha	112500	72906^{c}	1875	187281^{ab}	255537^{c}	68256^{e}
937.5 kg Rutuba/ha	56250	66735^{c}	937.5	123923^{d}	233907^{c}	109984^{d}
625 kg Rutuba/ha	37500	53675^{d}	625	91800^{e}	188132^{d}	96331^{d}
Control	_	41333^{e}	_	41333^{f}	144871^{e}	103539^{d}
p-value		<.001		<.001	<.001	<.001
LSD $p \leq 0.05$		10358		10358	36305	25947
CV%		7.3		4.4	7.3	10

CoF-Cost of fertilizer; Cop-Cost of plucking; CoAF-Cost of applying fertilizer; NR-Net revenue; TC-Total cost; TR-Total revenue

CHAPTER FIVE: DISCUSSION

Application of organic Rutuba led to higher soil pH than all NPK fertilizer rates. Similar results have been reported by Chong et al. (2008). The current observations could be attributed to the high pH in organic Rutuba (pH= 8.2). Therefore, the use of organic Rutuba has the potential of increasing the pH of a normally acidic tea field. Application of organic Rutuba led to increased total carbon compared to NPK fertilizer rates and the no-fertilizer control. This implies that continuous use of organic Rutuba fertilizer will lead to build up of total organic carbon thus improving soil fertility. The soil concentration of Mn, Cu, Fe and zinc were increased by the application of Rutuba fertilizer. This could be attributed to the high Mn, Cu, Fe and Zn content in the Rutuba fertilizer as compared to the NPK (26.5.5) fertilizer. The high pH from the application of Rutuba fertilizer could also have led to improved availability of nutrients. Nath (2013b), in a study on the status of micronutrients in tea plantations, reported that pH of the soil was positively correlated with micronutrients Mn, Fe, Cu and Zn. This implies that continuous use of Rutuba fertilizer will increase the micronutrient status in the soil hence lead to improved yield and quality of tea (Sedaghathoor et al., 2009).

There was no significant difference in the total nitrogen content among Rutuba and NPK fertilizer regimes probably because of leaching, denitrification and plant uptake of the nitrogen (Chong et al., 2008) and the low levels of nitrogen in the organic fertilizer. Similar results were noted by Chong et al. (2008). The NPK fertilizer regimes had higher soil P content than all Rutuba rates and the no-fertilizer control. Generally P content in the soil increased with increase in the rates of NPK and Rutuba fertilizers. This could be attributed to the low mobility of phosphorus in soil and the increase in P content with increasing rates of Rutuba and NPK fertilizer. Similar results have been noted by Nath (2013b) and Kekana et al. (2012) in which soil P increased with increase in fertilizer rates. The organic Rutuba treatments resulted to increased soil Ca and Mg content compared to NPK fertilizer regimes and no-fertilizer control. This could be attributed to the higher Ca and Mg levels, which were 3.1% and 0.4% respectively, in the organic Rutuba than in NPK fertilizer. This implies that continuous use of Rutuba fertilizer by farmers has the potential to increase Ca and Mg content in the soils while repeated use of NPK fertilizer alone will result in depletion of Ca and Mg in the soil.

Fertilizer application increased the width and length of the second leaf. Similar findings were reported by Chong et al. (2008). Increase in the NPK fertilizer rates from 625 kg NPK/ha to 1875 NPK/ha did not significantly increase the average width and length of the second leaf. This suggests that 625 kg NPK/ha had adequate levels of N P and K for leaf growth. Sole Rutuba rates did not significantly increase the average length of the second leaf compared to the no-fertilizer control but increased it in the second season. This could be attributed to the fact that the organic fertilizer needed longer time to release nutrients; hence in the second season the nutrients were probably more available to the plant (Hazra, 2016).

Application of fertilizer significantly improved green leaf and made tea yields. The highest green leaf and black made tea yields were realized from the application of 625 kg Rutuba /ha + 625 kg NPK/ha. The integrated system had the highest yield probably because the organic fertilizer improved the availability of nutrients. Similar results were noted by Tabu et al. (2015) who found that enriching cattle manure with inorganic fertilizer improved the yield of tea. There were increases in made tea and green leaf yields as the rates of Rutuba fertilizer increased from 625 kg Rutuba/ha to 1875 kg Rutuba/ha. This suggests that higher rates of Rutuba may be required to increase tea yields. In contrast, there were no significant ($p \leq 0.05$) increases in the green leaf and made tea yields as the rates of NPK fertilizer increased from 625 kg NPK/ha to 1875 kg NPK/ha. This could be attributed to the fact that application of 625 kg NPK/ha provided adequate N, P and K for the tea plants. In regard to N, Hamid et al. (2002) indicated that application of over 225 kg N/ha did not significantly increase yield of tea. In the current study 937.5 kg NPK/ha and 1875 kg NPK/ha provided 243.75 kg N/ha and 487.5 kg N/ha, respectively, which were above 225 kg N/ha. Green leaf and made tea yields were lower in plots with sole Rutuba compared to plots with NPK fertilizers. This could be attributed to low levels of mineralizable N in Rutuba.

As the rates of NPK fertilizer increased from 625 kg NPK/ha to 1875 kg NPK/ha the leaf nitrogen content did not increase significantly. This could be because of leaching and denitrification of the inorganic nitrogen. This implies that use of rates higher than 625 kg NPK/ha will lead to loss of N as it is not utilized by the plant. On the contrary, as the Rutuba fertilizer increased from 625 kg Rutuba/ha to 1875 kg Rutuba/ha the leaf nitrogen content increased implying that organic Rutuba may not be lost through leaching as fast as inorganic NPK fertilizer. Application of 625 kg Rutuba/ha+ 625 kg NPK/ha had the highest leaf nitrogen content compared to the other fertilizer rates implying that combination of NPK with Rutuba enhanced N uptake. Tabu et al. (2015) noted that enriching NPKS with organic manure led to increased leaf N content. Sole Rutuba application had lower N leaf content than sole NPK fertilizer application. This is likely due to the low N content in Rutuba fertilizer. Increase of NPK fertilizer from 625 kg NPK/ha to 1875 kg NPK/ha had no effect on the potassium leaf content while increase of Rutuba fertilizers rates increased the potassium leaf content. This could be attributed to increase in availability of micronutrients. Rutuba fertilizer and the application of

625 kg Rutuba/ha + 625 kg NPK/ha rates led to the higher leaf phosphorus content than NPK fertilizer rates and the no-fertilizer control. This could be due to the fact that the organic P in the Rutuba fertilizer was less fixed in the soil, hence more available to the plant due to higher pH (Sultana et al., 2014). This implies that organic Rutuba fertilizer can be used as a source of phosphorus for sustainable tea production.

Increasing Rutuba rates from 625 kg Rutuba/ha to 937.5 kg Rutuba/ha increased the apparent nutrient recovery (ANR) of N, K and P but further increase of the Rutuba rates to 1875 kg Rutuba/ha decreased the ANR_N and ANR_P but increased the $ANR_{K.}$ This suggests that moderate application of Rutuba enhance the apparent nutrient recovery of N, K and P. Increasing NPK fertilizer application rates from 625 kg NPK/ha to 937.5 kg NPK/ha decreased the ANR_N, ANR_K and $ANR_{P.}$ This suggests that low levels of NPK enhance N, P and K recovery.

Increase of rates from 625 kg /ha to 1875 kg/ha for both NPK and organic Rutuba fertilizers led to a decrease in the partial factor productivity (PfP) of N, K and P. Calvin et al. (2013) noted that increasing nitrogen rates from 100 kg N/ha to 200 kg N/ha decreased the partial factor productivity of nitrogen (PfP_N) and the partial factor productivity of potassium (PfP_K) with an increase in potassium from 40 K_20/ha to 80 K_20/ha. In the current study, nitrogen rates increased from 162.5 kg N/ha (625 kg NPK/ha) to 487.5 kg N/ha (1875 NPK/ha) for NPK fertilizer and 13.13 kg N/ha (625 kg Rutuba/ha) to 39.38 kg N/ha (1875 kg Rutuba/ha) for Rutuba fertilizer. Jagadeeswaran et al. (2005) noted that the partial factor productivity of NPK declined with increasing levels of NPK.

Increasing Rutuba levels from 625 kg Rutuba/ha to 937.5 kg Rutuba/ha increased the agronomic efficiency of nitrogen (AE_N) but further increase to 1875 kg Rutuba/ha reduced the AE_N while increasing NPK fertilizer from 625 kg NPK/ha 1875 kg NPK/ha reduced $AE_{N.}$ Increasing rates of Rutuba fertilizer from 625 kg Rutuba/ha to 1875 kg Rutuba/ha increased the agronomic efficiency of potassium (AE_K) while increasing rates of NPK fertilizer from 625 kg NPK/ha to 1875 kg NPK/ha reduced the $AE_{K.}$ Calvin et al. (2013) found out that increasing rates of potassium from 40 kg/ha to 80 kg/ha increased the AE_K from -0.59 to 0.04. Increase of Rutuba fertilizer rates from 625 kg Rutuba/ha to 937.5 kg Rutuba /ha increased the $AE_{P,}$ but increase to 1875 kg Rutuba /ha led to decline of AE_p while increase of NPK fertilizer rates from 625 kg NPK/ha to 1875 kg NPK/ha reduced the AE_P. This implies that use of moderate doses of Rutuba fertilizer increase the N, P and K efficiencies, thereby reducing pollution effects. Higher rates of NPK fertilizer reduce the N, P and K efficiencies, thus may lead to pollution effects in tea fields in the long term.

Application of 625 kg Rutuba/ha + 625 kg NPK/ha had the highest net returns compared to the farmers' practice and other fertilizer regimes. This implies that it is advisable for farmers in Kianjokoma (experimental site) to use this fertilizer regime rather than the current one. In addition, this fertilizer regime has the potential benefit of enhancing soil fertility compared to the farmers' practice. Application of 625 kg Rutuba/ha and 937.5 kg Rutuba/ha is not profitable enough as the net returns were not significantly higher than the no-fertilizer control.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The study has demonstrated that organic Rutuba has an effect of increasing the soil pH, total organic carbon, Mn, Cu, Fe, Zn, Ca and Mg relative to the no-fertilizer control and NPK fertilizer. Sole application of NPK (26.5.5) reduced soil pH. Co-application of 625 kg Rutuba/ha and 625 kg NPK/ha increased soil pH, Cu, Fe, Zn, and Mg contents compared to the sole NPK application rates. Increasing rates of NPK fertilizer from 625 kg NPK/ha to 1875 kg NPK/ha did not increase leaf growth and yield. Application of 625 kg Rutuba/ha + 625 kg NPK/ha had significantly the highest cumulative green leaf and made tea yields compared to the sole Rutuba and NPK. Rutuba fertilizer resulted to lower N leaf content than NPK fertilizer but increased the leaf P content. NPK fertilizer rates resulted to low K leaf content compared to the Rutuba fertilizer rates.

The ANR_N increased with increase of the Rutuba fertilizer rates from 625 kg Rutuba/ha to 937.5 kg Rutuba/ha, but reduced with further increase in Rutuba. Application of 625 kg Rutuba/ha + 625 kg NPK/ha improved the N, P and K use efficiencies compared to the sole NPK fertilizer rates. However, the sole rutuba application rates had higher nutrient use efficiencies of N, P and K than sole NPK fertilizer rates. Co-application of 625 kg Rutuba/ha and 625 kg NPK/ha produced higher net returns than the farmers' practice.

6.2 Recommendations

As a result of the findings in this study, it is recommended that:

1. Tea farmers in the study area could use 625 kg Rutuba/ha + 625 kg NPK/ha in tea production. There is however a need to conduct further trials to establish the optimum combination of Rutuba and NPK fertilizer.
2. Further trials should be done to determine the effect of the organic Rutuba fertilizer on the quality and biochemical composition of tea.
3. The current study was carried out in one site; there is a need for further studies to be conducted in different tea growing regions in Kenya.

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APPENDIX 1: COST AND NET REVENUE FROM EACH REGIME

Treatment	Cumulative Gl	No. of bags of 50 kg used	cost of fertilizer	cost of plucking	cost of applying fertilizer	Total cost	Total Revenue	Net revenue
1875 kg NPK/ha	9501	37.5	84356.25	95010	1875	181241.25	466024.05	284782.8
625 kg Rutuba/ha + 625 kg NPK/ha	13031	25	65618.75	130310	1250	197178.75	639170.55	441991.8
937.5 kg NPK/ha	9486	18.75	42178.125	94860	937.5	137975.625	465288.3	327312.675
625 kg NPK/ha	9300	12.5	28118.75	93000	625	121743.75	456165	334421.25
1875 kg Rutuba/ha	7291	37.5	112500	72910	1875	187285	357623.55	170338.55
937.5 kg Rutuba/ha	6674	18.75	56250	66740	937.5	123927.5	327359.7	203432.2
625 kg Rutuba /ha	5368	12.5	37500	53680	625	91805	263300.4	171495.4
Control	4133	0	0	41330	0	41330	144861.65	103531.65