EFFECT OF HARVESTING METHODS AND NPK FERTILIZER ON SOIL pH, SOIL AND LEAF MAJOR NUTRIENTS CONTENTS AND YIELD OF TEA IN TANZANIA

BY

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DECLARATION

Declaration by Student

I declare that this thesis is my original work and has not been presented for examination in any other University. No part of it may be reproduced without prior written permission from the author and/or the University of Eldoret

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DEDICATION

To my late parents; my father Joel Mvangila Makweta and my mother Anyamidze Fungamusamo Samanga they could not live long enough to see this!

ABSTRACT

Tea (*Camellia sinensis*, (L), O. Kuntze crop in Tanzania has been traditionally harvested by hand. In recent years, high cost and shortage of labour have compelled tea growers to opt for mechanical harvesting. Mechanical harvesting is becoming very important and is considered vital for survival of the tea industry. However tea growers have reported decline in yield after some years of mechanical harvesting and there is a notion that nutrients lost through the harvested crop differ from hand harvested tea. Thus there is need to replenish nutrients lost through harvested crop which is different from hand harvested tea, however to replenish soil nutrients in mechanical harvested tea, growers are applying the same fertilizer rates as in hand harvesting method. The objective was to determine the effect of tea harvesting methods (hand and mechanical) and NPK fertilizer on soil pH, major nutrients (NPK) uptake, tea yield components (shoot weight, shoot type composition) and yield. The study had two parts. First a survey was conducted on tea estates (Ngwazi, Itona and Itambo) where both hand and mechanical harvesting had been practiced for more than three years. Soil and leaf samples were collected for soil pH, soil and leaf major nutrients (NPK) analysis. Yield data were used to compare yield trend in hand and mechanical harvesting. In the second part, two experiments were set at the Tea Research Institute of Tanzania stations (Marikitanda and Ngwazi) using randomized complete block design (RCBD) with split-plot arrangement. Experiments were conducted for 10 and 8 months at Marikitanda and Ngwazi respectively. Hand and mechanical (shear) harvesting formed the main plots and the six fertilizer rates (0, 50, 100, 150, 200, 250 kg N/ha) the sub-plots. NPK 25:5:5 fertilizer was applied once. Soil and leaf samples were analyzed for soil pH, soil and leaf major nutrients (NPK) contents. Yield, shoot count and shoot weight data were recorded. Results showed that, tea in mechanical method had higher soil pH and K uptake by tea plants. Tea plants in hand method had higher uptake of N and P. Mechanical method had significantly ($p<0.05$) lower shoot weight and had higher proportions of mature leaf and broken leaf (low quality greenleaf). Yield was significantly ($p<0.05$) higher in mechanical than hand method. The interaction between harvesting methods and fertilizer rates on shoot weight was not significant. Effects of fertilizer rates showed that, soil pH decreased with fertilizer rates, soil nutrients uptake increased with fertilizer rates but declined at high rates: At Marikitanda Tea Research Station, nitrogen declined at 250 kg N/ha, phosphorus at 250 kg N/ha and potassium at 150 kg N/ha. At Ngwazi Tea Research Station, nitrogen declined at 250 kg N/ha, phosphorus at 200 kg N/ha and potassium at 200 kg N/ha. Shoot weight increased with fertilizer rates but not significantly. At both experimental sites, shoot weight declined at 250 kg N/ha. Yield increased with fertilizer rates but declined at high rates: At Marikitanda Research Station, the yield declined at 200 kg N/ha, at Ngwazi Tea Research Station it declined at 250 kg N/ha. Only at Marikitanda did fertilizer rates showed significant ($p<0.05$) difference. There was no significant difference in fertilizer rates between hand and mechanical harvesting. The interaction between harvesting methods and fertilizer rates on yield was not significant. It is recommended that during the first few years (≤ 3) same rate of fertilizer should be applied in both hand and mechanical harvesting, this study should be continued in order to further assess the effects of harvesting methods on soil pH, nutrients uptake and yield.

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ABBREVIATIONS AND ACRONYMS

^0C	Degree Celsius
ANOVA	Analysis of variance
BS	Base saturation
CEC	Cation exchange capacity
FAO	Food and Agriculture Organization
HCl	Hydrochloric acid
LSD	Least significant difference
m	Meter
M	Molar
mm	millimeter
MTC	Mufindi Tea Company
MTRS	Marikitanda Tea Research Station
NPK	Nitrogen phosphorus Potassium
NTRS	Ngwazi Tea Research Station
TRFK	Tea Research Foundation of Kenya
TRIT	Tea Research Institute of Tanzania
UNESCO	United Nations Education, Science and Culture Organization
UTTL	Unilever Tanzania Tea Limited
WATCO	Wakulima Tea Company

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My family; Upendo my wife, Obadia my son, Wende and Atwawe my daughters their patience during my absence and moral support are highly acknowledged.

CHAPTER ONE

INTRODUCTION

1.1 General introduction

In Tanzania, tea (*Camellia sinensis* (L), O. Kuntze) plant is grown for the purpose of getting a beverage. The tea beverage is made from harvested tender shoots commonly two leaves and a bud. Tea beverage is a popular drink in many parts of the world, rated as the second most popular drink after water (Martin, 2007). Depending on the method of preparation, different types of teas are produced. Collins (2012) discussed the types and their methods of preparation: Green tea is prepared from plant's youngest leaves whereby a natural oxidation (fermentation) process is stopped soon after harvesting. Black tea is also produced from youngest leaves but leaves are left to ferment completely before rolling and dried. Oolong tea is semi-fermented after harvesting. White tea is made from unopened buds which are dried in sun or steamed. To get buds alone requires very high level of selectivity during harvesting. Owour (1997) reported that, East Africa mainly produces black tea.

Under natural environment tea plant can grow to a height of 17 m depending on the type (Plate 1.1a). However under cultivation, it is maintained at a height of between 0.6 to 1.0 m (Stephens, 1991) (Plate1.1b). This is a convenient height for harvesting. The spacing between plants ranges from 0.60 to 0.90 m depending on the clone and between rows it is 1.2 m. In both young and mature plants a special way of cutting the stem (pruning) to the desired height is done. Pruning in young plants (formative pruning) is done to enhance spreading of the branches which is important for good plucking table establishment (Tea Research Foundation of Kenya, Growers Handbook, 1986).

Regular pruning in mature tea (normal pruning) rejuvenates the tea plant and helps to maintain the required plant height (Tea Research Foundation of Kenya, Tea Growers Handbook, 1986). The interval between two pruning is called pruning cycle and it varies with clone, location and field management level, but in Tanzania the pruning cycle is generally four years.

Plate 1.1a: Tea plant left to grow

Plate 1.1b: Tea plants (bushes) under field management.

(*Source:* Author, 2013)

1.2: Fertilizer for tea

Othieno (1980) reported nitrogen, phosphorus and potassium as the major nutrients required by the tea plant. The nutrients are commonly applied as NPK (25:5:5) fertilizer. In Tanzania an economic rate of 150 kg N/ha as NPK for hand harvesting is recommended (adapted in 1996 from East Africa Tea Research Foundation). The rate 150 kg N/ha is also recommended in Kenya but higher rates (200-250 kg N/ha) are applied for high yielding cultivars (Owour, 1997).

1.3: Tea harvesting

Tea harvesting techniques have been evolving with time. The Chinese history indicates that, in early days people climbed tea plants and chopped the branches (Martin, 2007). In Tanzania hand harvesting has been regarded as the traditional way but it is labour intensive. In recent years the problem of labour shortage has been growing. Partly this is due to smallholder tea farmers tending their own tea farms thus increasing labour shortage in estates, diversification of crops and unwillingness of majority of young people to be involved in tea farming (TRIT, 2006/07). Apart from labour shortage cost associated with hand harvesting has been increasing (TRIT, 2010/11).

Labour shortage is affecting both large estates and smallholder farmers thus, companies (Wakulima Tea Company (WATCO), Unilever Tanzania Tea Limited (UTTL), Mufindi Tea Company (MTC)) started looking for alternative ways of harvesting as well as facilitating smallholder tea farmers to use alternative way of tea harvesting. Therefore the companies in Tanzania opted for mechanical harvesting. Mechanical tea harvesting is the use of harvesting aid ranging from simple tools like a shear to hand held and wheeled machines. Smallholder farmers have also started using shears in tea harvesting. Since the commencement of mechanical tea harvesting in Tanzania, scientific investigations were mainly focused on the productivity of the harvesting method and their effects on greenleaf quality. For example, Burges *et al*., (2006), reported an increase of broken leaves of between 7 % and 9 % due to mechanical harvesting. Harvesting rounds were extended by between 2 to 2.5 phyllocron when compared with hand harvesting. Smallholder farmers are however replenishing soil nutrients based on a fertilizer rate (150 kg N/ha) which was recommended for hand harvesting. Companies also use the same rate of fertilizer in both hand and mechanical tea harvesting. Plates 1.2a, 1.2b and 1.2c show the two methods of tea harvesting.

(a) Hand harvesting method

(b) Mechanical (shear) harvesting method

(c) Mechanical (hand held machine) harvesting method

Plate 1.2: Tea harvesting methods. *(Source:* Author, 2013)

1.4: Problem statement

Willson (1992) reported that, in estates up to 80% of the labour force consists of pluckers but, there is shortage of labour and the cost of hand harvesting has been increasing. Awasthi and Sakar (1983) noted that 60 % of total cost in tea field operations is due to hand harvesting. Bore (2009) noted that in Kenya 30-40% of all field cost is due to hand harvesting. These two problems have compelled tea growers to mechanize tea harvesting. However mechanical harvesting is also associated with challenges. The damage to the plant is thought to be higher in mechanical than hand harvesting and the healing of wounds uses the stored photosynthates. It has been reported that, mechanical tea harvesting causes decline in yield after some years (Madamombe, *et al*., 2011; Bore, 2009). It is therefore possible that tea in mechanical harvesting requires different rates of fertilizer to replenish nutrients lost through the harvested crop.

Although mechanical tea harvesting is taking root in Tanzania, no previous work has been carried out to find out if the nutrients required to replenish nutrients lost from mechanized tea harvesting is different from hand harvested.

1.5: Justification

In order for soil to continuously supply the required nutrients to tea plants, the lost nutrients including loss through the harvested crop must be replenished in the form of fertilizer. It is possible that tea fields in mechanical harvesting lose more nutrients, Thus not replenishing nutrients removed from tea fields in the form of fertilizer will lead to soil nutrients depletion leading to low yields. The study was necessary to assess the soil nutrients depletion due to mechanical harvesting.

This work is part of the programme in TRIT to determine fertilizer rate for mechanically harvested tea.

1.6: Objectives

The main objective was to determine the effects of harvesting methods and NPK fertilizer rates on soil pH, major nutrients (NPK) uptake and yield of tea.

Specific objectives were:

1. To determine the effect of hand and shear (mechanical) tea harvesting on the soil pH, soil and tea leaf major nutrients (N,P,K) contents
2. To determine the effect of NPK fertilizer rates on soil pH, soil and leaf major nutrients (N,P,K) contents
3. To determine the effects of harvesting methods (hand and shear) and NPK fertilizer rates on tea yield and yield components (shoot weight and shoot type composition)

1.7: Research questions

1. Hand and mechanical methods of harvesting have the same effect on soil nutrients uptake?

2. NPK fertilizer rates have the same effect on soil pH, soil and leaf nutrients contents?

3. NPK fertilizer rates have the same effect on yield and yield components of tea?

CHAPTER TWO

LITERATURE REVIEW

2.1: Origin and botanical description of tea

The history of tea (*Camellia sinensis,* (L), O. Kuntze) is long and complex (Yee, 1996). It was discovered in China in 2737 B.C. The word tea was derived from the Chinese word *tchai*. Tea belongs to the family of Theaceae (flowering plants) (Yee, 1996). It is an indigenous plant throughout South-East Asia. The area stretches from Assam land in the West to China in the East and down to Vietnam in the South (Weatherstone, 1992). According to Stephens (1991), tea genotypes are in two major groups: China type originated from China, a tea plant with small upright leaves. The second is Assam type originated from Assam, India a tea plant with larger horizontal leaves. According to Taylor's Dictionary for Gardeners (*en.wikpedia.org/wiki/History of Tea*), the term *sinensis* is a Latin word meaning from China. Seurei (1997) noted that taxonomic importance is macro morphological features of leaves (such as color) and reproductive structures. The latter are more important in differentiating tea types. Tea is highly self-incompatible as such it is heterogeneous (Banerjee, 1992). Breeding and selection have produced numerous seedlings and clonal tea types which vary from original plants (Kigalu, 1997). It is thus difficult to find tea plants under cultivation which exactly resemble the original form. In early days tea was used for medicinal purposes only. By 300 B.C. tea became daily drink in China. From the centers of origin, tea spread to other parts of the world such as in Japan 900 A.D. and England 1669. The Genus Camellia has

82 species. It is only *Camellia sinensis,* (L.), O. Kuntze, whose harvested tender leaf is consumed as a beverage (Yee, 1996).

2.2: Agro ecological requirements for tea

2.2.1: Rainfall and temperature

Tea requires a minimum annual rainfall of 1200 mm which is well distributed (Tea Research Foundation of Kenya, Tea Growers Handbook (1986). It was further noted that, a well-covered field of mature tea has an evapotranspiration varying from 120 to 150 mm/month. It requires air mean temperature of 25 ^{o}C. The upper limit of temperature is 35 ^{o}C and the lower limit is 10 ^{o}C. Tanton (1982) noted that rainfall, temperature, solar radiation and vapor pressure deficit are the major weather variables affecting the growth and yield of tea.

2.2.2: Altitude

Although tea is greatly affected by altitude due to orographic lift, it is highly adaptable, thus it is grown at altitude ranging from sea level as in Japan to altitude above 2700 m in some parts of Africa (Willson, 2012). It was also pointed out that, production declines with an increase with altitude due to slow growth resulting from low temperatures but the quality is superior. In Tanzania, tea is grown in areas with altitude ranging from 1000 to 2000 m (TRIT, 2010/11). In Kenya tea performs well from 1500 to 2600 m (Tea Research Foundation of Kenya, Tea Growers Handbook, 1986).

2.3: Appropriate soils for growth of tea

2.3.1: Physical characteristics and soil types

Othieno (1992), noted that tea demands precise soil characteristics for economic yield although it grows in a wide range of soils. The important physical characteristics are soil depth (at least 2 m) and good drainage. A study in rooting depth in Tanzania showed that roots of mature tea went as deep as 6 m. Similar depth was found at Kericho, Kenya for a 17 year old seedling tea and in Malawi roots of mature tea were found at 5.5 m deep (Carr, 2012). As noted by Othieno (1992), it is difficult to have soils fit in a specific definition due to diversity of soils on which tea grows successfully. Floor and Magoggo (1992), who carried out soil fertility appraisal of tea fields in some tea estates in Amani area in Tanzania, reported the type of soil to be Haplic Ferralsol (FAO-UNESCO). Othieno (1992) noted that, in Kenya and some parts of Tanzania and Uganda tea soils are Nitisols (FAO-UNESCO). Boul, *et al*., (1997), referred to Nitisol as having the following basic diagnostic features: Presence of argillic or kandic horizon, base saturation of less than 35 % at 1.25 m below the upper boundary of the argillic or kandic horizon or 1.8 m below the surface whichever is deeper. Ferralsols (FAO-UNESCO), which is Oxisols in the USDA system) was described as having oxic horizon or kandic horizon as the main diagnostic feature.

2.3.2: Soil chemical characteristics suitable for tea

According to Othieno (1992), important chemical characteristic for growing tea is soil pH. Soil pH is a measure of acidity or alkalinity of the soil and is defined as the negative logarithm to base 10 of the activity of hydrogen ions [H^+] (Perry, 2012). Othieno (1992) noted that, the optimum pH range for tea is between 5.0 and 5.6.

Generally, aluminium has a toxic effect to roots of other plants but not to some plants including tea. Ghanati e*t al.,* (2005) showed that aluminum maintains the activity of antioxidants enzymes. This results in increased membrane integrity and delayed aging. This is the reason for the stimulatory effects of aluminum on growth of tea plants.

Soil pH affects nutrients availability to plants. Whiting *et al*., (2011), summarized the nutrients availability according to soil pH level (Figure 2.1). The thickness of the bars is proportional to nutrients availability.

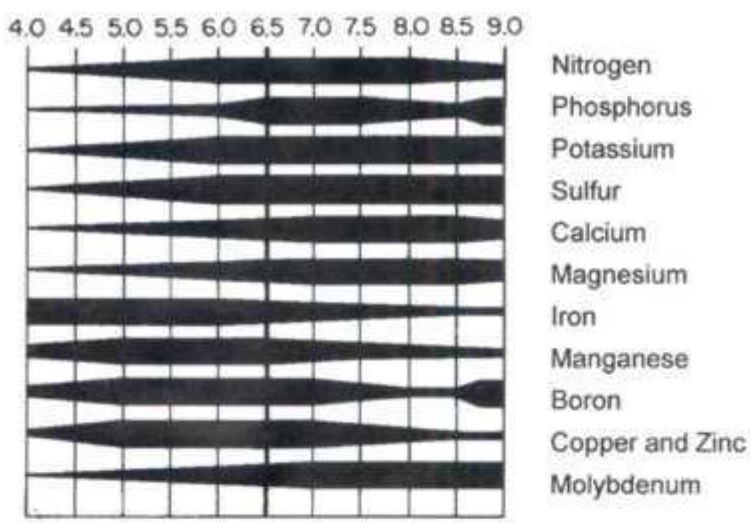


Figure 2.1: Effect of soil pH on nutrients availability. **(*Source*: Whiting *et al*., 2011)**

2.4: Fertilizers for tea

The use of NPKS compound fertilizer was recommended by the Tea Research Foundation of Kenya (Tea Growers Handbook, 1986). According to Wanyoko (1997), the most common formulation is 25:5:5:5. The author further noted that, the use of NPK 20:10:10 also gave good results in Kenya and the introduction of compound fertilizer was a result of general declining yield in East African tea due to the use of straight N fertilizer such as sulphate of ammonia (SA) alone. It was noted that the decline was due to deficiency of potassium. In Kenya, NPKS fertilizer increased yield from 1000 to 2000 kg made tea/ha/year. No difference in yield response was observed between NPK 25:5:5 and 20:10:10 (Wanyoko, 1997).

The author however, noted that high production in Kenya has been maintained even when fertilizers without P and K are used after continuous usage of NPK compound formulations fertilizers. The fertilizer rate of 150kg N/ha for seedling and low yielding clonal tea was recommended. Owuor (1997) gave the range of N for cultivars with good response as from 200 to 250 kg N/ha. Tea Research Institute of Tanzania adapted recommendation by Tea Research Foundation of East Africa. The economic application rate of 150 kg N/ha is used. The amount of fertilizer applied in tea fields vary greatly among countries. The use of 40 kg N/ha and 800-1200 kg N/ha in Vietnam and Japan respectively are reported. Some tea growers in India apply 10 kg N/100 kg of made tea for yields between 2000 and 3000 kg (Owuor, 1997). There is limited information which relates fertilizer rates and mechanical tea harvesting.

2.5: Effect of fertilizer rates on the quality of black tea

East and Central Africa mainly produce black tea. Black tea quality is affected by high nitrogenous fertilizer rates (Owour, 1997). It was reported that, high rates such as 1200 kg N/ha applied in Japan reduce catechins levels which in turn lead to low level of theaflavins. Undesirable aroma may arise due to increased levels of unsaturated fatty acids (Owour, 1997). High levels of unsaturated fats and amino acids are beneficial to green tea. It was noted that the high levels of N used in Japan are meant to improve the quality of green tea and not to increase production. Owour (1997) also reported that in Kenya, the quality of black tea was affected when fertilizer rate was higher than 300 kg N/ha. Lelyveld e*t al*., (1990), also reported that high levels of N caused grassy taste of black tea. Reduction in theaflavins and total color of infusion was also noted.

2.6: Sources, deficiency symptoms and functions of major nutrients (NPK) in tea plant

2.6.1: Sources of nitrogen

The ultimate source of nitrogen is atmosphere which makes up about 78% (Tisdale and Nelson, 1975). However, plants cannot utilize N in its elemental form. Natural ways which add nitrogen into the soil are; fixation by bacteria, action of lightning, small amount of ammonia in the air arising from industries (Davies *et al.*, 1982).

Decomposition of organic matter particularly leaf fall and prunings left *in situ* plays important role in tea production. Natural ways of adding nitrogen into the soil cannot meet plants requirements. Ford (2005) noted that, nitrogen from natural ways of fixing has been exceeded by human activity by 1.5 times. Therefore it must be added as fertilizer. Owuor (1997) noted that, nitrogen is the major nutrient for tea. Davies *et al.*, (1982) reported tha,t nitrogen is the most difficult to apply in the correct quantity. Bonheure and Willson (1992) noted that, tea plant demand for nitrogen is high because the crop harvested is leaf.

2.6.2: Ways of nitrogen addition and removal in tea fields

Under the natural environment there is a cycle of nutrients. Ford (2005) defined nitrogen cycle as the process by which nitrogen is converted into its various chemical forms. Pidwirny (2006) stated that plants take up N in NH_4^+ and NO_3^- forms. It was further noted that NH_4^+ in high concentrations is toxic and most plants obtain nitrogen in the form of nitrate (NO_3^-). Ishigaki (1978) however, reported that, tea plants absorb ammonium (NH_4^+) more effectively than nitrate. Apart from industrial fertilizer application and mineralization, biological nitrogen fixation (BNF) is important. BNF occurs at soil pH of between 5.5 and 10 and it is optimum at 7 (Pidwirny, 2006). This implies that in soil pH of less than 5.5, NH_4^+ form dominates. It is an advantage to tea since it does well in acidic soils. Nitrogen loss through leaching is also reduced since NH_4^+ is held on soil colloids surface (micelle fixation) because soil colloids are negatively charged. Loss through denitrification is also reduced due to reduced rate of converting nitrogen to nitrate. Figure 2.2 summarizes the ways of nitrogen addition and removal in tea field.

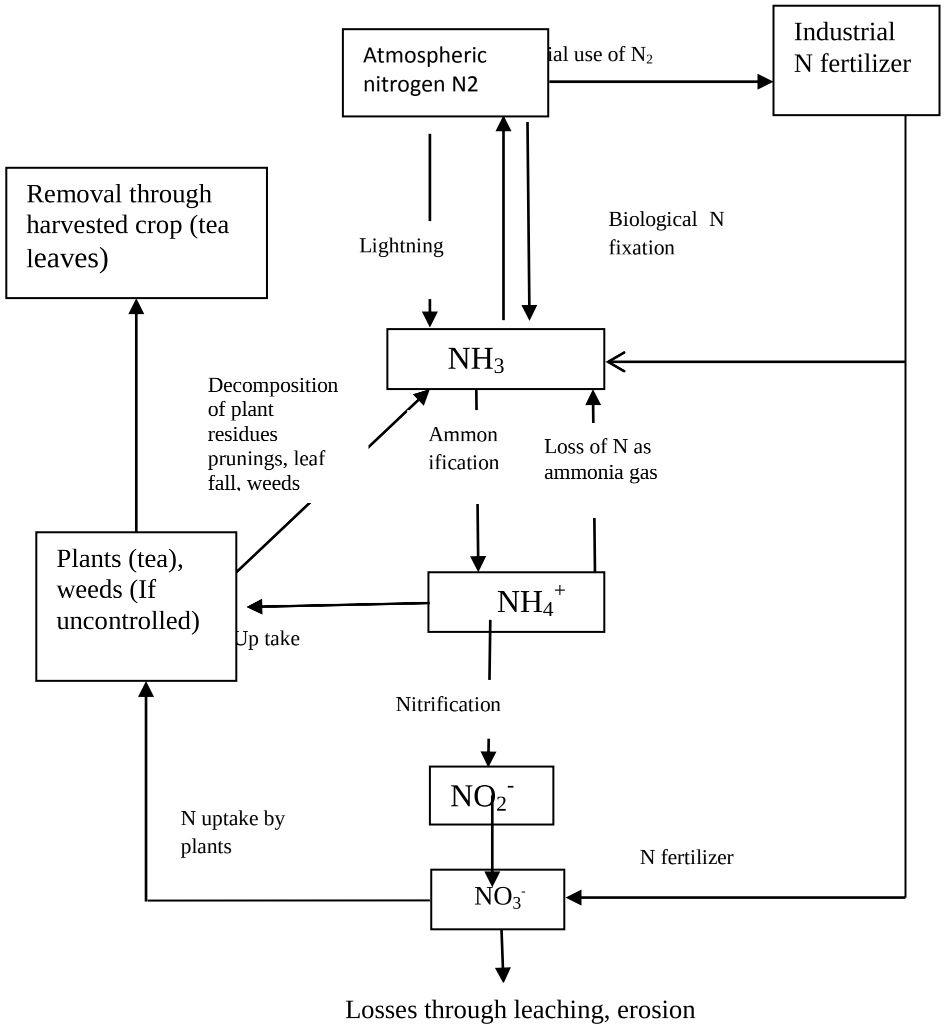


Figure 2.2: Suggested ways of nitrogen addition and removal in tea field.

***(Source*: Modified by author from *htt://www.en.wikipedia.org/wiki/file*: The nitrogen cycle)**.

In tea fields loss of nutrients through harvested crop is very important. This does not occur in natural environment. When weeds are controlled, tea is the only plant that takes nutrients from the soil. Unlike in natural environment or grazing fields, there is limited direct droppings from animals thus it is not shown in the diagram. In tea fields nutrients are returned to the soil by leaf and stems parts droppings and prunings. Pruning does not occur in natural environment. These explanations apply to general maintenance of soil fertility under tea.

2.6.3: Functions and deficiency symptoms of nitrogen in plants

Wickremasinghe and Krishnapillai (2008) listed the functions of nitrogen: It is an important constituent of chlorophyll, nucleic acid, protoplasm and plays important role in the physiology of the plant. Davies *et al.*,(1982) pointed out that nitrogen controls the rate of plant growth, controls the amount of leaf produced and the stage of maturity. Deficiency symptoms of nitrogen are yellowing of young leaves and stunted growth. There are cases where deficiency symptoms vary with clone. Wickremasinghe and Krishnapillai (2008) reported the symptoms in Sri Lanka for clones TRI 2024 and 2023 as plants show pinkish yellow. In Tanzania yellowing is common in smallholders' tea fields especially in the Northern part of the country. In this part of the country farmers have not applied fertilizer for many years (TRIT, 2007//2008)

2.6.4: Sources of phosphorus

The study by McClellan *et al.*, (2007) showed that orthophosphates ($H_2PO^-_4$ and HPO^{-2}_4) which are the primary forms of phosphorus taken by plants originate largely from primary and secondary minerals from the weathering phosphate rocks, organic matter decomposition and application of phosphate industrial fertilizers. Rehm *et al*., (2002) listed the following organic materials: animal manure, composts and sewage sludge. In tea fields leaf fall and prunings are the most important. The author further noted that, in the soil it ranges between 0.001mg/l to 1 mg/l. Phosphorus availability is soil pH dependent (Figure 2.1). Orthophosphates react with aluminium and iron in low soil pH and with calcium in high and neutral pH to form insoluble complex compounds. The case with low pH is common in tropical soils. The formation of complexes causes phosphorus unavailability. If the pH in tea fields is not managed, phosphorus deficiency may occur. Phosphorus is commonly added in tea fields in form of phosphatic fertilizer as Triple Super Phosphate (TSP), Single Super Phosphate (SSP), compound fertilizer of Nitrogen, Phosphorus and Potassium (NPK) and Diammonium Phosphate (DAP). McClellan *et al*., (2007) showed that, availability of phosphorus from organic form is determined by carbon: phosphorus (C: P) ratio. When the C: P ratio is less than 200:1 net mineralization takes place. When C: P ratio is between 200:1 and 300:1 mineralization equals immobilization. Net immobilization occurs when C:P ratio is greater than 300:1

2.6.5: Ways of phosphorus addition and removal in tea fields

. Figure 2.3 summarizes the sources and ways through which soil phosphorus is lost or made unavailable to plants. Loss through leaching is very little because soil phosphorus is immobile.

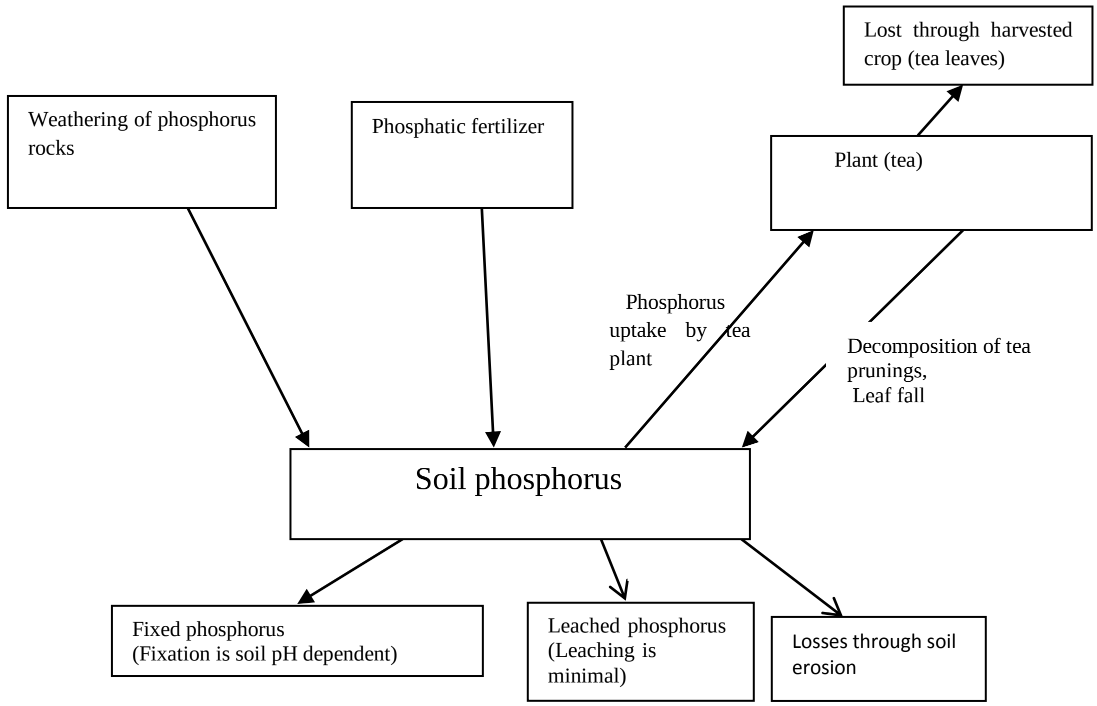


Figure 2.3: Suggested ways of phosphorus addition and removal in tea field.

***(Source*: Modified by author from McClellan e*t al*., 2007).**

2.6.6: Functions and deficiency symptoms of phosphorus in tea plant

Bonheure and Willson (1992) listed the functions of phosphorus in plants: It plays important role in the formation of wood and roots, transportation of energy, metabolism of fats in the process of respiration, it is a constituent of nucleic acid, phospholipids and enzymes and also it is involved in the utilization of nitrogen.

The Tea Research Foundation of Kenya Growers Hand Book (1986) described the symptoms of phosphorus deficiency as loss of glossiness (shiny surface) of mature tea leaves and excessive die back of young and old stems especially the die back from the ends which have been cut during pruning.

2.6.7: Sources of potassium

Othieno (1992) noted that potassium is derived from minerals (e.g. feldspars, micas, and muscovite) and from the decomposition of organic matter. Rehm and Schmitt (2002) noted that, about 90-98% of potassium is in minerals and is not available for plants use. The release of potassium from the minerals is too slow to meet crop demand. To meet crop demand, supplying potassium as fertilizer is important. Potassium in the soil is in dynamics of adsorption, fixation and release (Othieno, 1992). Rehm and Schmitt (2002) referred to those distinctive forms as unavailable, slowly available and readily available potassium. Unavailable potassium is what exists in minerals, slowly available is trapped between layers of clay minerals (montimorillonite and illite). These authors noted that, montimorillonite cracks when it dries and traps the potassium. The trapped potassium is released when it gets wet. Illite does not release all potassium even when it gets wet. Apart from fixation, potassium availability is also affected by soil pH (Figure 2.1). Willson and Bonheur (1992) noted that availability levels of potassium fall as acidity increases. They reported that tea response to potassium in East Africa occurs when soil pH is below 5.2. This implies that potassium application as a fertilizer is important since tea is grown in acidic soils.

2.6.8: Ways of potassium addition and removal in tea fields

The sources and dynamics of potassium in tea fields are summarized in the figure 2.4

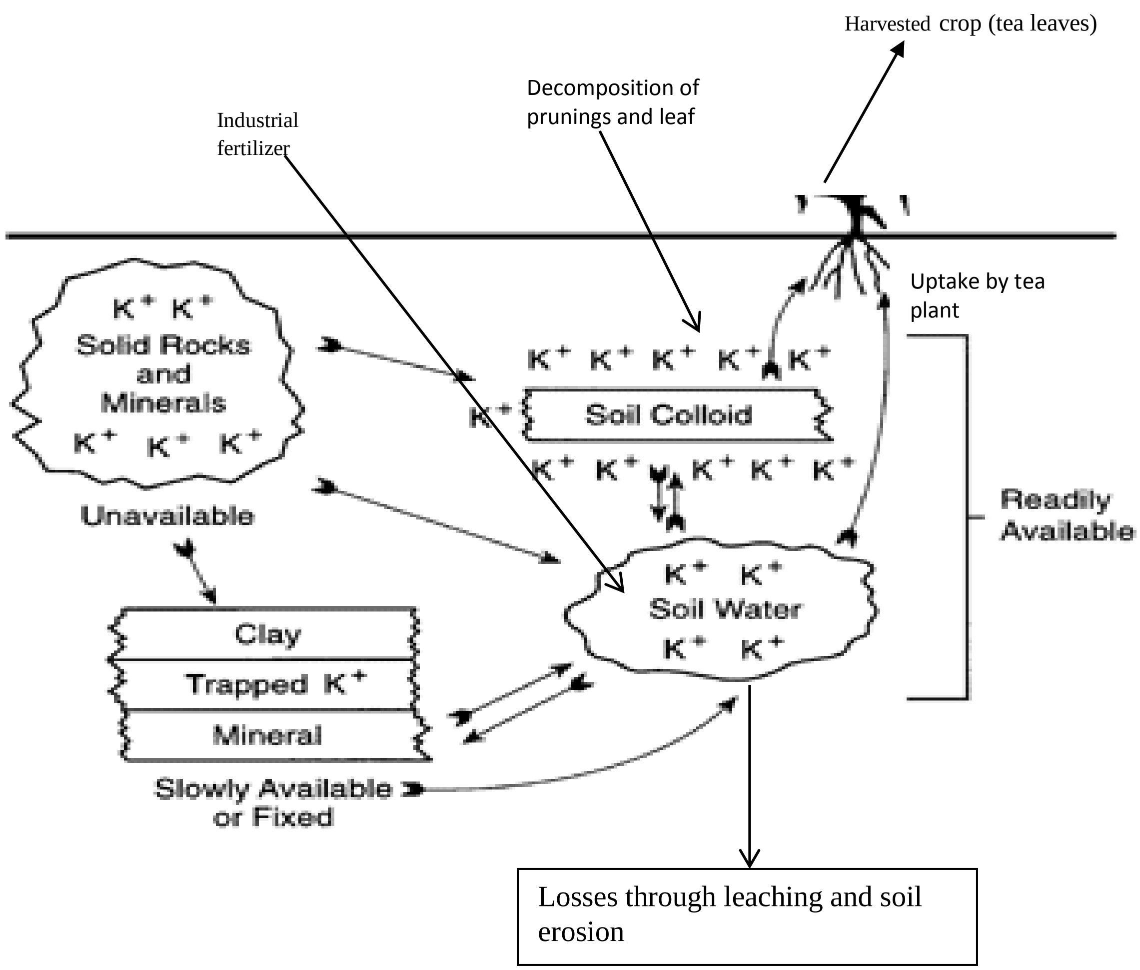


Figure 2.4: Suggested ways of potassium addition and removal in tea field.

***(Source*: Modified by author from potassium cycle by Rehm and Schmitt, 2002).**

2.6.9: Functions of potassium in plants

Othieno (1992) listed the functions of potassium: It is used in the production and translocation of carbohydrate and is related to nitrogen metabolism. Wickremasinghe and

Krishnapillai (2008) also listed the functions as activator of enzymes involved in carbohydrate and protein metabolism, membrane permeability, water balance (osmoregulation) and stomatal opening. Bonheure and Willson (1992) also discussed the functions of potassium: Potassium accumulates in the parts of the plant where cell division and growth are concentrated. It is therefore important for young plants. It stimulates their growth and formation of strong frame. However Willson and Freeman (1970) pointed out that, the ratio of K: N is very important than the ratio of N to other bases. This is because K is present in high concentration. The higher the K: N the higher the yield. They showed N uptake by plants is affected by excess calcium.

2.7: Losses of nutrients from tea fields

Losses of nutrients from tea fields occur in many ways. Bonheure and Willson (1992) discussed them: Lost in crop, soil erosion, drainage of excess water containing nutrients, decomposition to gases (for nitrogen) and uncontrolled weeds. In well managed mature tea farms erosion is not a big problem due to good tea canopy. Drainage of excess water (leaching) is a problem to nitrate N because unlike (NH_4^+), nitrate (NO_3^-) is negatively charged and thus it can easily be leached. NH_4^+ is lost by volatilizing as ammonia gas (NH_3) (McKenzie, 2003). It was also noted that, ammonium in the soil exists in equilibrium with ammonia gas. The equilibrium is highly soil pH dependent. At soil pH near neutral (pH 7) the nitrification is rapid and so it appears this limits volatilization. In acidic condition ($pH < 6$), nitrification is slow, and this appears to favor volatilization.

In tea fields soils are usually acidic; it appears therefore that volatilization of ammonia takes place. According to McKenzie (2003), there is significant unavailability of potassium due to fixation onto clay mineral interlayers and phosphorus due to precipitation by aluminum and iron in acidic soil condition. Thomason (1997), showed the influence of soil pH on the distribution of orthophosphate in the soil solution:

$$H_3PO_4 \longleftrightarrow H_2PO^-_4 \longleftrightarrow HPO_4^{-2} \longleftrightarrow PO^-_4$$

H_3PO_4	$H_2PO^-_4$	HPO_4^{-2}	PO^-_4
pH < 2	pH > 2, p H < 7	p H > 7, p H < 12	p H > 12
	P fixed by Al and Fe	P fixed by Ca	

The nutrients lost through harvested crop is proportional to crop removed. It is therefore related to the method of harvesting. Mechanical tea harvesting does not harvest selectively thus, more nutrients are probably lost. Eden (1952) investigated the nutrients lost per 1000 kg of made tea in hand harvesting method as given in Table 2.1.

Table 2.1: Nutrients lost through harvested crop per 1000 kg made tea under hand harvesting

	NUTRIENTS LOSS (kg/1000 kg made tea)		
Plant part	**N**	**P_2O_5**	**K_2O**
Young shoots	40.2	8.5	16.0
Stems	23.6	7.0	18.7
Old leaves	27.2	4.6	13.0
Total	**91.0**	**20.1**	**47.7**

***(Source*: Eden, 1952)**

Othieno (1979) also reported nutrients lost in hand harvested in 1000 kg of made tea for clone TRFK 6/8: 40kg N, 4 kg P_2O_5 and 19 kg K_2O. The differences in nutrients lost shown by the two authors imply that nutrients lost through harvested crop is clonal specific and not general as given by Eden (1952) who did not specify the clone he used to conduct the study.

2.8: Nutrients deficiency diagnostic methods

Deficiency symptom is one of the diagnostic methods for nutrient deficiency. Tiwari *et al*., (2010) noted that a symptom may be associated with more than one mineral deficiency and therefore is seldom sufficient. The combination of soil and plant analyses is considered sufficient.

2.8.1: Soil analysis

Barker *et al*., (1997), referred to soil analysis as the process used to determine the level of nutrients in a soil sample. He also listed the objectives of soil analysis: To provide an index of nutrient availability, to predict the probability of obtaining a profitable response to fertilizer application, to provide a basis for fertilizer recommendations for a given crop and to evaluate the fertility status of the soil and plant nutrient management program. Schulte and Kelling (2013) pointed out that, presence of adequate nutrients in the soil does not guarantee that the nutrients will be taken up by plants due to other factors like temperature, humidity, soil moisture and plant health. Therefore soil analysis alone may not be sufficient without plant analysis. Table 2.2 summarizes soil nutrients elements ratings. The ratings refer to soil nutrient status at the time of sampling. The ratings are not specific to tea but are applicable.

Table 2.2: Soil nutrients elements content ratings

Nutrient element	Very low	low	Medium	high	Very high
Total N (%)	< 0.10	0.10-0.20	0.21-0.50	> 0.50	
Available P (Kurtz-Bray 1)- mg/kg		< 7	7-20	>20	
Exchangeable K- clay loam soils (cmolc/k g	< 0.20	0.20-0.40	0.41-1.2	1.21-2.00	> 2.00
Exchangeable K – loamy soils	< 0.13	0.13	0.26-0.80	0.81-1.35	> 1.35
Exchangeable K – sandy soils	< 0.05	0.05-0.10	0.11-0.40	0.41-0.70	> 0.70
Exchangeable calcium (Ca) for soils rich in 2:1 clays (cmolc/kg)	<2.0	2.0-5.0	5.1-10.0	10.1-20.0	>20.0
Ca for loamy soils (cmolc/kg	<0.5	0.5-2.0	2.1-4.0	4.1-6.0	>6.0
Ca for Kaolinitic soils (cmolc/kg)	<0.2	0.2-0.5	0.6-2.5	2.6-5.0	>5.0
Exchangeable Mg clayey soils (cmolc/kg	<0.3	0.3-1.0	1.1-3.0	3.1-6.0	>6.0
Exchangeable Na cmolc/kg	<0.10	0.10-0.30	0.31-0.70	0.71-2.00	>2.00

(*Source*: Westerhout and Ikera, 1992)

2.8.2: Plant analysis

Plant analysis was defined by Schulte and Kelling (2013) as the quantitative determination of the elements in plant tissue. Plant analysis mainly refers to the analysis of N, P, K, Ca, Mg, S, Fe, Mn, Mo, Cu, Zn, and B. There are cases where Al and Na are included in the analysis. C, H and O are not limiting and as such they are not routinely analyzed.

According to Tiwari *et al.,* (2010), plant analysis reflects the actual nutritional status of the plant. This is the advantage of plant analysis over soil analysis. The use of leaf analysis as a diagnostic method is based on the principle that leaf is the principal part of plant metabolism. The first mature leaf is used for tea leaf analysis in Kenya (Kamau *et al*., 2005). In Tanzania third leaf is used (TRIT). The counting of leaves is from the bud downwards. The ratings for leaf nutrients content are given in Table 2.3

Table 2.3: Nutrient levels in tea plant tissues based on analysis of the third leaf

Element	Deficient	Low	Adequate	High
Nitrogen %	< 2.80	< 3.00	3.00-3.50	> 3.50
Phosphorus %	< 0.12	< 0.15	0.16-0.20	> 0.20
Potassium %	< 1.0	< 1.2	1.2-1.8	> 1.8
Calcium %		< 0.8	0.8-1.6	> 1.8
Magnesium	< 0.1	0.1-1.5	0.15-0.25	> 0.25
Sulphur %			0.08-0.20	
Manganese (ppm)			3,000-5,000	
Copper (ppm)		< 10	>10	> 50
Zinc (ppm)	< 7	7-10	> 10	> 50
Iron (ppm)		< 150	>150	

(*Source*: Tea Research Institute of Tanzania adapted from Broke Bond Kenya)

2.9: The history and development of tea in Tanzania

History of tea in Tanzania dates back to 1902 when the first tea plant was planted at Marikitanda, Amani area in Tanga region and in 1904 planted at Kyimbila, in Mbeya region (Carr *et al.*, 1994). From these two areas tea spread to other parts of the country. Commercial tea production in Tanzania started in 1926. By 1960 the production reached 3,700 tons of made tea (Assenga, *personal communication*). Tea is now grown in seven districts; Njombe (Njombe region), Mufindi and Kilolo (Iringa region), Muheza, Korogwe and Lushoto (Tanga region), Tarime (Mara region) and Bukoba (Kagera region), (TRIT, 2009/2010).

Before Tanzania mainland independence 1961, tea growing was restricted to estates. People living around the estates were the source of labour. Some people from southern part of Tanzania were going to northern part to work in tea plantations. After independence smallholder tea farmers were encouraged. Since then small scale farming has been increasing.

2.10: Economic importance of tea in Tanzania

Tanzania produces 32,000 tons of made tea annually which is about 1% of the world production (Assenga, *personal communication*). Area under tea is 22,739 ha of which estate is 11,272 and that under smallholder is 11,485 ha (TRIT, 2010/2011). Tea is an important source of employment. In 2006 there were about 31000 households directly engaged in tea production and about 10,000 people were employed in factories (Simbua, 2006). Tea is the third important cash crop after cotton and coffee (Kigalu, 1997; Assenga, *personal communication*), it earns foreign currency of about US$45 million annually (Simbua, 2006).

2.11: Why mechanizing tea harvesting?

Although harvesting tea by hand is regarded as traditional way, attempts to use harvesting aids started many years ago. Nyasulu (2000) reported that *swinburn cropper* was used in Assam in 1887 and shear in Japan in early1900s. It is not clear why they wanted to mechanize tea harvesting in those days, it was probably intended to improve plucking efficiency which reflects the difficulty associated with hand harvesting. In East and Central Africa mechanized tea harvesting is due to labour shortage and high cost associated with hand harvesting (Bore, 2009, Nyirenda, 1999, TRIT, 2008/09). It appears that labour shortage is more important than cost. In Kenya mechanized harvesting is intended to lower the cost (Bore, 2009). But since labour is available mechanizing tea harvesting is not well accepted by workers and Central Organization of Trade Union (COTU), (press statement October, 21st 2010). Martin (2000) reported that, there was a time in Malawi when mechanical tea harvesting was more expensive than hand harvesting, but mechanizing tea harvesting was still an option due to unavailability of labour. The author further noted that, South Africa and Zimbabwe mechanized tea harvesting in response to labour shortage in 1980s and 1990s respectively.

Tanzania started mechanizing tea harvesting in 1980s. The use of shears in harvesting is reported to have increased the harvesting productivity in Tanzania by up to 50 % (Mhagama *personal communication*). Bore (2009) reported an increase in efficiency by 20 % in Kenya compared to hand harvesting.

2.12: Effect of mechanical tea harvesting

2.12.1: Effect on yield and quality

Willson (1992) who discussed mechanical tea harvesting pointed out that there is no selectivity in mechanical harvesting. A study by Burges *et al*., (2006), showed that following shear plucking broken leaves increased from between 40 and 48 %, coarse material to between 7 and 9 % which imply reduction in green leaf quality and weight was reduced by 13%. Ravichandran and Parthiban (1998), found that hand harvested teas were richer in green leaf biochemical precursors than shear harvested. Mechanical injury and non-selectivity of leaf were found to be the causes of quality deterioration of shear harvested tea. The study also showed that, plucking rounds were extended from 2 to 2.5 phyllocron when compared to hand harvesting. He also noted a reduction of leaf area index to below 5.

Yield fall was noted due to mechanized tea harvesting (Willson 1992, Sharma and Satyanarayana, 1994, Ravichandran and Parthiban 1998). Bore (2009) noted reduction in the maintenance foliage. Reduction in maintenance foliage means reduced photosynthesis but Willson (1992), reported that, less than 5 % of the incident light penetrated lower than 15 cm below the plucking table. The author recommended the thickness of maintenance foliage to be 25 cm at which there is no reduction in photosynthesis.

Nutritional value of tea to consumers is another important aspect of tea quality. Studies have shown that, the value of mechanically harvested tea is different from hand harvested tea. Ravichandran and Parthiban (1998) noted that chemical quality parameters and sensory evaluation of black tea varied with the method of harvesting. Amarakoon (2008) showed that quality tea had very little amount of aluminium and thus there is no effect to the consumer. However, the study showed that mature leaves have higher concentration of aluminium than young leaves. A study by Robur Tea Co. Ltd (*http://en.wikipedia.org/wiki/Health*) in Australia also found that aluminiun and fluoride contents were higher in mature leaves than young ones. Mature leaves were found to contain between 10 to 20 times more aluminium than young leaves. Due to non-selectivity, mechanically harvested tea has more of this element than hand harvested tea. It was therefore concluded that, mechanically harvested tea has higher risk of causing osteofluorosis and fracture due to fluoride and aluminium toxicity to consumers.

2.12.2: Effect on mechanical injury to plant

Both hand and mechanical harvesting impart mechanical injury to plants, but the extent of damage is higher in mechanical harvesting. Plants respond to wounds by various ways including mechanism of repairing the wound, adjusting metabolism to the imposed nutritional demands and release of stored materials (León *et.al*, 2001, Takahashi, 2011). This shows that different methods of harvesting may impose different nutritional requirements for tea plant.

2.12.3: Efforts to mitigate undesirable effects of mechanical tea harvesting

In Tanzania a shear with a step was tried. The shear step is a height at which the shear cutting blades are raised (Plates 2.1a, 2.1b). The step reduces the chance of harvesting young shoots shorter than the step. Burges *et.al*.,(2006) noted that for every 1 mm of step added the yield was reduced by 40-50 kg made tea/ha.

Reduction in yield due to step could be due to the effectiveness of step to enhance selective plucking. In Russia, the Russian rubber finger harvester was developed (Willson 1992). Nyirenda (1999) in Malawi proposed that clones suitable for mechanical harvesting are those with horizontal leaf pose. Similar recommendation was made by Bore (2009) in Kenya. In Tanzania alternating mechanical with hand harvesting is being tried (Ngwala, *personal communication*, Karumbaiah, *personal communication*). Also the use of large wheeled machine was abandoned (Ngwala, *personal communication)*. This was due to soil compaction. A study by Ng'etich and Bore (2000) in Kenya also showed that wheeled harvesters caused soil compaction. There has been no study done in Tanzania which relates mechanical harvesting and nutrients uptake by the tea plant.

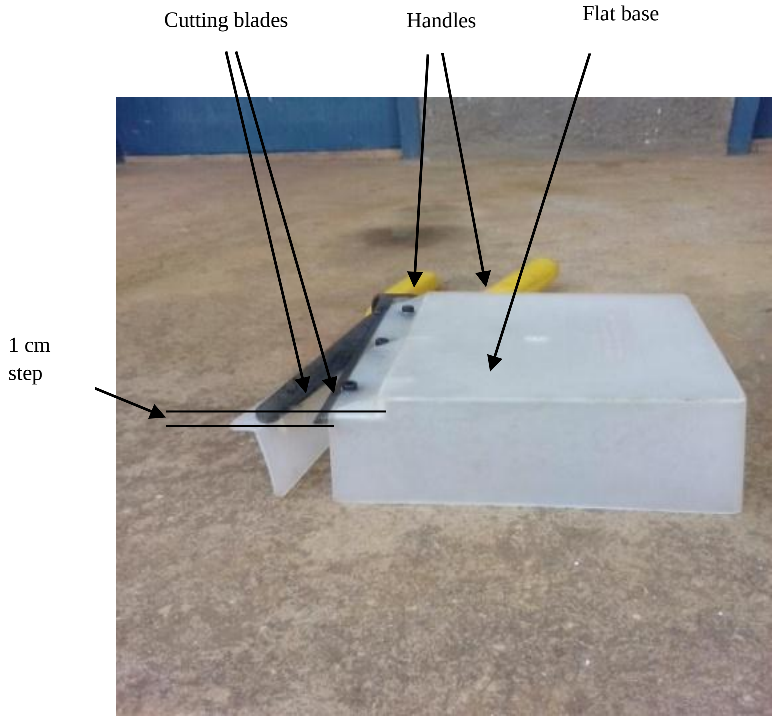


Plate 2.1a: A shear turned upside down showing a 1 cm step between the flat base and the cutters

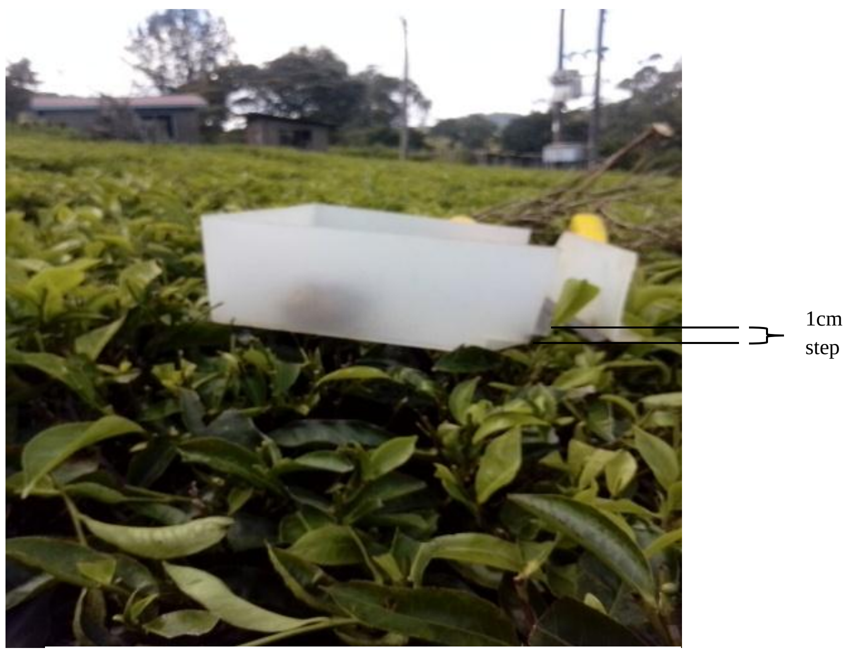


Plate 2.1b: A shear on its flat base showing how the step enhances selective harvesting.

(*Source*: Author)

CHAPTER THREE

MATERIALS AND METHODS

3.1: Study sites locations

The study had two parts. First a survey was conducted in estates which had used mechanical and hand harvesting for three or more years. Secondly, two experiments were set. Figure 3.1 shows the locations of all study sites (surveyed and experimental sites). Surveyed sites were Itona and Itambo tea estates in Mufindi district and Itambo estate in Njombe district. Experiments sites were set at Marikitanda and Ngwazi Tea Research Stations. Marikitanda Tea Research Station is in Muheza district, North-East of Tanzania. Ngwazi Tea Research Station is in Mufindi district. Mufindi and Njombe districts are in the Southern part of Tanzania.

3.2: Survey study

3.2.1: Description of the surveyed estates

3.2.1.1: Ngwazi estate

The estate belongs to Unilever Tea Tanzania Limited (UTTL) and the fields are very close to Ngwazi Tea Research Station (8°32’S, 35°10’E), at an altitude of 1840 m above sea level. The meteorological station used by Ngwazi Tea Research Station is within the Estate. The monthly mean air temperature is 16 °C and the mean annual rainfall is 900 mm (TRIT, 2007/8)

3.2.1.2: Itona estate

The estate belongs to Mufindi Tea Company (MTC) (8°28’ S 35°45’E). The altitude is 2000 m above sea level. It is about 60 km East of Ngwazi Tea Research Station. The monthly mean air temperature is 18 °C the mean annual rainfall is 1100 mm

3.2.1.3: Itambo estate

Itambo estate (09°25’S,34°45’E, altitude 1860 m. above sea level) is also owned by MTC. The monthly mean air temperature is 16 °C and the annual mean rainfall is 1000 mm.

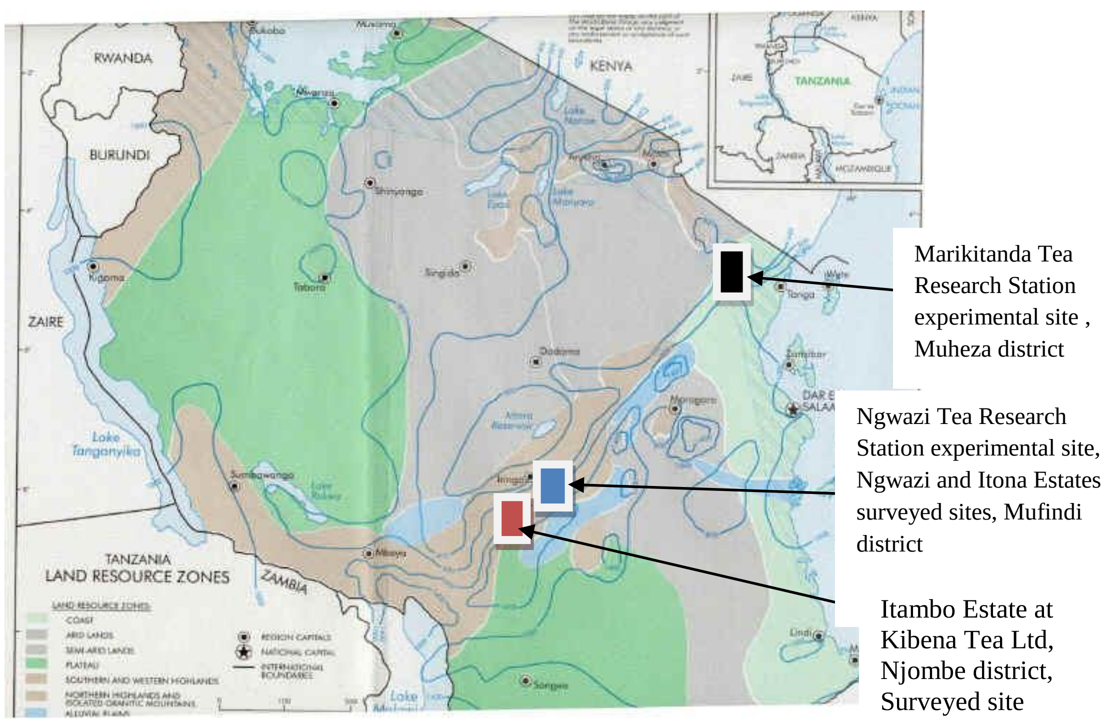


Figure 3.1: Tanzania map showing the locations of the study sites.

(*Source*: Author)

3.2.2: Survey data collection

3.2.2.1: Weather and yield data

Weather and yield data were obtained from the estates' data bases

3.2.2.2: Soil and leaf samples collection

Soil and leaf samples were collected from Ngwazi estate only. Other estates had already abandoned hand harvesting method. The collection was on quarterly basis according to climatic variation within the year as shown on Table 3.1.

Table 3.1: Months for samples collection in survey

Quarter of the year	Months within the quarter	Season	Sampling month
1	September, October, November	Dry warm	November
2	December, January, February	Wet warm	February
3	March, April, May	Wet cool	May
4	June, July, August	Dry, cool	July*

***(Source*: Tea Research Institute of Tanzania (TRIT), 2006/2007)**

Key: * In the 4th quarter sampling was done in July instead of August for convenience of the project timetable.

3.2.2.3: Sampling design

Fields with similar field managements were selected. Field managements considered were fertilizer application, pruning and weeding. Each sampling area within the selected field had 300 tea bushes. Composite soil samples were made from 5 zig-zag auger holes in each sampling area. Soil samples were collected at a depth of 0- 20 cm. This is the depth at which tea feeder roots are concentrated (Carr, 2012). Third leaf was collected randomly from the 300 bushes. 50 to 100 leaves were collected per sample. Field layout for Ngwazi estate is shown on Figure 3.2.

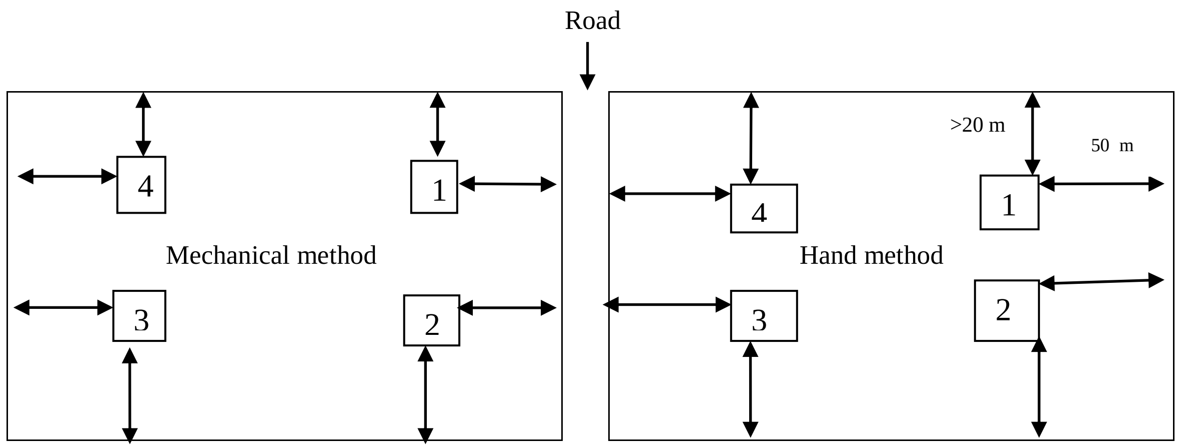


Figure 3.2: Ngwazi estate field layout
1, 2, 3 and 4 are sampling areas with 300 bushes each. All sampling areas were at the same distances as shown area 1 (hand method)

3.2.4: Samples analysis

Samples were analyzed at Tea Research Institute of Tanzania's soil and leaf laboratory according to Tanzania National Soil Service Laboratory Procedures for Routine Analysis outlined by Westerhout and Ikerra (1992). Samples were analyzed for soil pH, soil and leaf major nutrients (NPK) contents. The details of the analysis are given under experiments samples analysis section 3.3.6

3.2.5: Survey data analysis

Data were analyzed using descriptive statistics (means, percentages). Other methods of analysis could not be used due to disconformities with the existing fields' arrangement.

3.3: Field Experiments

Usually estates operations are not controlled to the same extent as in experiment although operations have been done for a long time. Experiments therefore were meant to compliment findings from the survey.

3.3.1: Marikitanda Tea Research station site description

Marikitanda Tea Research Station (MTRS) is located at 5^{o}08'S, 38^{o}35' E at an elevation of 970 m. Tea (clone TRFK 6/8) was planted in 1967 at a spacing of 1.2 m between lines and 0.9 m between plants. The monthly mean air temperature was 20 ^{o}C and the mean annual rainfall of 1500 mm. The site is rain fed i.e. there is no supplemental irrigation.

3.3.2: Ngwazi Tea Research Station site description

Ngwazi Tea Research Station (NTRS) is located at 8^{o}32'S, 35^{o} 10'E at an of elevation of 1840 m. Tea (clone BBK7) was planted in 2003 at a spacing of 1.20 m between lines and 0.6 m between plants. The monthly mean air temperature was 16 ^{0}C and mean annual rainfall of 900 mm. In dry season it is irrigated using sprinklers.

3.3.3: Study of the soils at sites (Marikitanda and Ngwazi Tea Research Stations)

The soils were studied by digging of profile pits. Morphological study was done on site. Soil texture was estimated by hand feel method. Soil samples were collected for characterization (determination of physical and chemical characteristics in the laboratory).

3.3.4: Experimental design

At both experimental sites, the experiments were set up using a randomized complete block design (RCBD) with split-plot arrangement replicated three times (Mead, *et al*., 1993). Shear and hand harvesting methods formed the main plots, fertilizer levels the sub plots. The fertilizer NPK (25:5:5) was applied at six levels of nitrogen (0, 50,100,150,200 and 250 kg N/ha). Fertilizer was applied in October, 2012 and December, 2013 at Marikitanda and Ngwazi respectively. The month to apply fertilizer depended on the onset of rainfall. The field layout is presented in Figure 3.3 given below.

	BLOCK 1			BLOCK 2			BLOCK3		
Main plots	1 SN0	2 SN100	3 SN200	13 HN150	14 HN50	15 HN250	25 SN200	26 SN250	27 SN0
	4 SN50	5 SN150	6 SN250	16 HN0	17 HN200	18 HN100	28 SN150	29 SN50	30 SN100
Main plots	7 HN150	8 HN200	9 HN250	19 SN200	20 SN100	21 SN150	31 HN100	32 HN250	33 HN50
	10 HN50	11 HN0	12 HN100	22 SN250	23 SN0	24 SN50	34 HN0	35 HN200	36 HN150

Figure 3.3 Experiments field layout

Key: S= Shear harvesting and H= hand harvesting (Main plots),

N= Nitrogen rates (0, 50, 100, 150, 200 and 250 kg N/ha) as NPK 25:5:5

Plots 1-36 (split plots)

3.3.5: Data collection

3.3.5.1: Temperature and rainfall data

Weather data from TRIT data bases were used to indicate the temperature and rainfall trends in the year of study and of the previous years.

3.3.5.2: Soil samples from the profiles

Soil samples were collected from each soil horizon for physical and chemical characterization. The soil physical characteristic measured was bulk density which was determined using core ring method according to Westerhout and Ikerra (1992).

3.3.5.3: Soil and leaf samples collection from experimental plots

Soil samples were collected at 0- 20 cm from 5 zig zag auger holes. Polythene bags were used to carry the soil. Leaf samples were collected randomly from the six bushes within the plot. Samples were taken from each treatment, in each block. Due to financial constraints, samples were bulked on treatment basis. From each treatment, one soil sample (1 kg) and one leaf sample (between 50 and 100 leaves) were obtained. Soil samples were put in polythene bags and leaf samples in the paper bags. Samples were dully labeled to indicate the treatments.

3.3.5.4: Yield and yield components data collection

The following data were collected:

Fresh leaf weight: Fresh leaf harvested from each experimental plot was kept in a well labeled polythene bag. The weight of the bag was tared. Fresh leaf weight was converted to yield per hectare by multiplying by 0.22 (22% of the fresh weight) (TRIT)

Shoot count and weight: This involved counting the number and taking weight of all types of shoots (bud, 1leaf + bud, 2leaves + bud), broken leaves (weight only), maintenance foliage (weight only), non-leaf materials such as woody materials (weight only) and weight of unclassified materials. Some materials could not be placed in any class because they had combined features such as wood and leaf parts.

Mean fresh weight of a shoot grade-sample was calculated according to Templer (1978) using the following formula:

Mean fresh weight (mg) = (1000 *g) /n

where g = weight (in grams) of the fresh shoot grade-sample

n = the number of shoots in the sample

3.3.6: Laboratory analysis

Samples were sent to Tea Research Institute of Tanzania's soil and leaf laboratory for analysis.

3.3.6.1: Preparation of soil samples for analysis

Sample registration: Samples arriving at the laboratory were registered in the laboratory register and given laboratory code numbers

Drying of samples: Soil samples were taken to a special drying room, and while maintaining the labels, samples were air dried by spreading on clean polythene trays for about two weeks. Large fragments and stones were removed.

Crushing and sieving: Dry samples were crushed in a motor and sieved through 2 mm sieve and stored in well labeled plastic bottles.

3.3.6.2: Analysis of soil samples

Samples were analyzed using the Tanzania National Soil Services, laboratory procedures outlined by Westerhout and Ikerra (1992).

Soil pH (1: 2.5 soil-water) determination

A suspension of 1: 2.5 soil-water was prepared. The soil pH –water was then measured potentiometrically using a glass-calomel combination electrode pH meter which was calibrated at pH 4

(b) Analysis for soil nitrogen (N)

The total soil N was analyzed using semi-micro Kjeldahl method. Concentrated sulphuric acid was used to digest the soil in the presence of selenium catalyst. This process converts organic nitrogen into ammonium sulphate, ammonia is liberated after making the solution alkaline. The ammonia was trapped in boric acid which was then titrated with standardized 0.02 N sulphuric acid. The method determines all soil N except that in nitrate and nitrite forms.

(c) Analysis for available soil phosphorus (P)

Soil P was analyzed using Bray and Kurtz No.1 method. The method is used for soil with pH<7. The extraction of easy-soluble forms of P was done by using 0.025 M hydrochloric acid (HCl) and 0.03 M ammonium fluoride (NH_4F). In this process, the blue coloured complex forms during the coloration process of P which is then reduced to molybdenum salts (phosphorus- molybdenum). From the molybdenum salts, P was measured by spectrometer

(d) Analysis of exchangeable cations

Sodium (Na) and potassium (K) were determined using flame photometer. Calcium (Ca) and magnesium (Mg) were determined using atomic absorption spectrophotometer (AAS). A 1.0 M neutral ammonium acetate filtrate was prepared from which exchangeable sodium, calcium, potassium and magnesium were determined directly.

(e) Cation exchange capacity (CEC)

CEC was determined using ammonium acetate method at pH 7. The method is used for soil filtrate of pH < 7.5.

Soil colloidal complex was saturated with ammonium by treating with excess of 1 M neutral ammonium acetate. Alcohol was used to wash the excess of ammonium ions. Acidified 1 M potassium chloride was used to replace adsorbed ammonium by potassium. Distillation was used to determine ammonium in the extract in an alkaline medium. The ammonium was absorbed in boric acid. The CEC was then calculated after titrating the distilled ammonium with sulphuric acid.

3.3.6.3: Preparation of leaf samples

Registration: Samples were registered in the laboratory register and coded (giving laboratory number)

Drying: Samples were dried in a well-ventilated oven at 70 ^{o}C for 48 hours

Grinding: The dried samples were ground to obtain fine powder and homogenous sample using stainless still mill. Stainless still mill was used in order to avoid contamination of samples with trace elements

Storage: The samples were kept in well labeled paper bags and stored in a cool and dry place.

3.3.6.4: Analysis of leaf samples

The analysis was done according to Tanzania National Soil Service Laboratory procedures outlined by Westerhout and Ikerra (1992).

(a) Analysis for total leaf nitrogen (N)

The digestion of the sample was done using a mixture of sulphuric acid, selenium and salicylic acid. The aliquot of the digest was made alkaline by adding alkaline reagents and ammonia was liberated and trapped in boric acid. The distillate in boric acid was titrated with 0.02 N sulphuric acid until colour changed from green to light red. Total % N was then calculated.

Analysis of leaf phosphorus (P)

The sample was digested with a mixture of sulphuric acid, selenium and salicylic acid. Coloring reagents were added in the digest. A blue coloured complex of reduced molybdenum salt was formed. The phosphorus molybdenum was determined using spectrometer.

Analysis of leaf potassium (K)

The digestion of the sample was done using a mixture of sulphuric acid, selenium, hydrogen peroxide and salicylic acid. Potassium was then determined in the digest using flame photometer

3.3.7: Statistical analysis of yield and mean shoot weight

Yield and shoot weight data were analyzed using analysis of variance (ANOVA) (Mead et.al.1993). SAS version 9.1 statistical package was used. Means were separated by least significant difference (LSD) at 5% significant level

3.3.7.1: Statistical model

The following statistical model was used:

$$y_{ijk} = \mu + b_i + h_j + e_{ij} + f_k + (hf)_{jk} + e_{ijk}$$

Where μ is the general mean, y is a yield or shoot weight as a function of blocking effect (b_i), harvesting method (h_j), main plot error (e_{ij}), fertilizer levels (f_k), interaction between harvesting methods and fertilizer levels $(hf)_{jk}$ and the split plot error (e_{ijk}). The analysis of variance skeleton is given in Table 3.2.

Table 3. 2: Analysis of variance (ANOVA) skeleton

Source of variation (SV)	Degree of freedom (DF)	Sums of squares (SS)	Means of sum of squares (MS)	F_{value}	F_{Table}
Blocking effect (3)	(b-1) = 2	$\sum_{i=1}^{3}(B^2)$ /hf - cf	$\frac{SS}{df}$		
Harvesting methods (2)	(h-1) = 1	$\sum_{1}^{2}(H^2)/f$- cf	$\frac{SS}{df}$		
Main plots error	(b-1)(h-1) = 2	By subtraction			
Fertilizer rates, 6 rates	(f-1) = 5	$\sum_{1}^{6}(H^2)/bf$- cf	$\frac{SS}{df}$		
Interaction effect (2 harvesting methods * 6 levels of fertilizer)	(h-1)*(f-1) = 5	$\sum_{1}^{12}(F^2)/bh$- cf	$\frac{SS}{df}$		
Split plots error	(r-1)h(b-1) = 8	By subtraction			
Totals	(h*f)*r)-1 = 35	$\sum(F^2) - cf$			

h= Number of harvesting methods=2, H= Main plot yield, f= fertilizer levels= 6, F = experimental plot yield, b= r (replications) = number of blocks= 3

3.3.8: Data analysis for nutrients and shoot type composition

These were analyzed using descriptive statistics (i.e. averages, percentages,) due to sample bulking.

CHAPTER FOUR

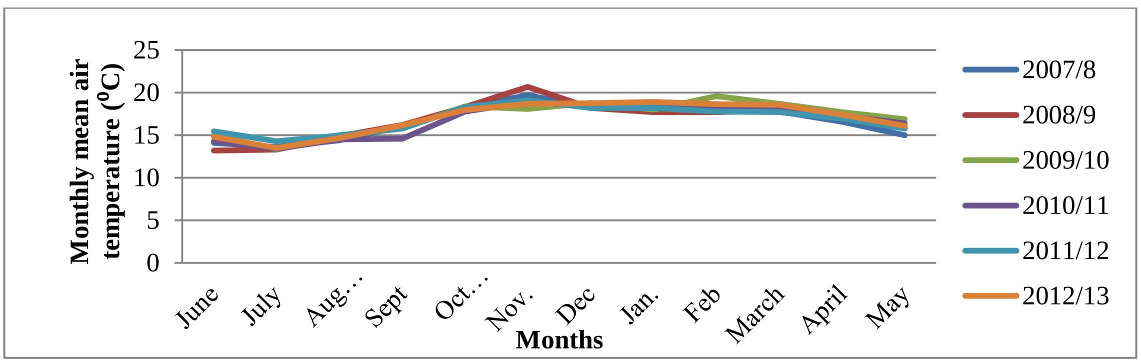
RESULTS AND DISCUSSION

The study had two parts; survey and experiments. Results are presented based on these parts.

4.1: Survey results

4.1.1: Temperature and rainfall trends

Figures 4.1, 4.2 and 4.3 show rainfall and temperature trends at Ngwazi, Itona and Itambo estates respectively. The figures show the trends in the period in which yield data were used.



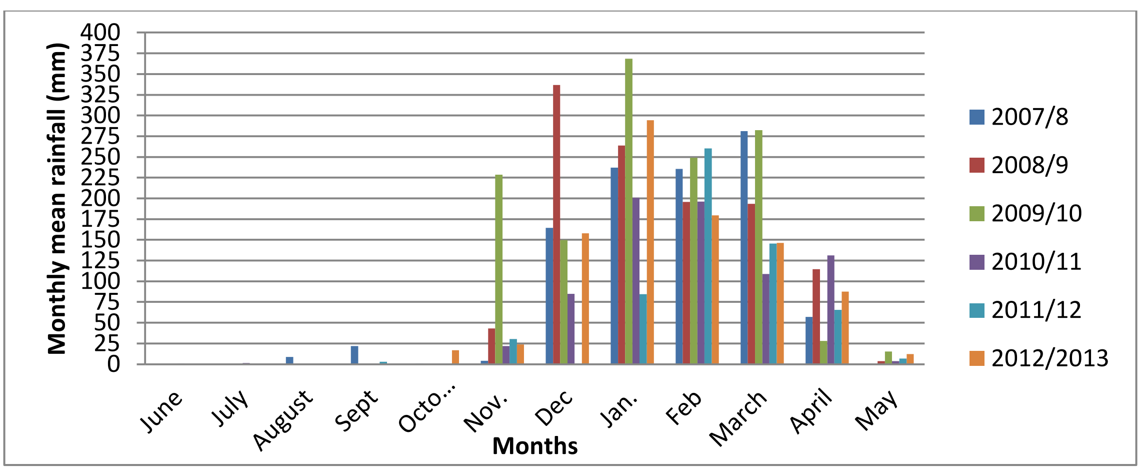
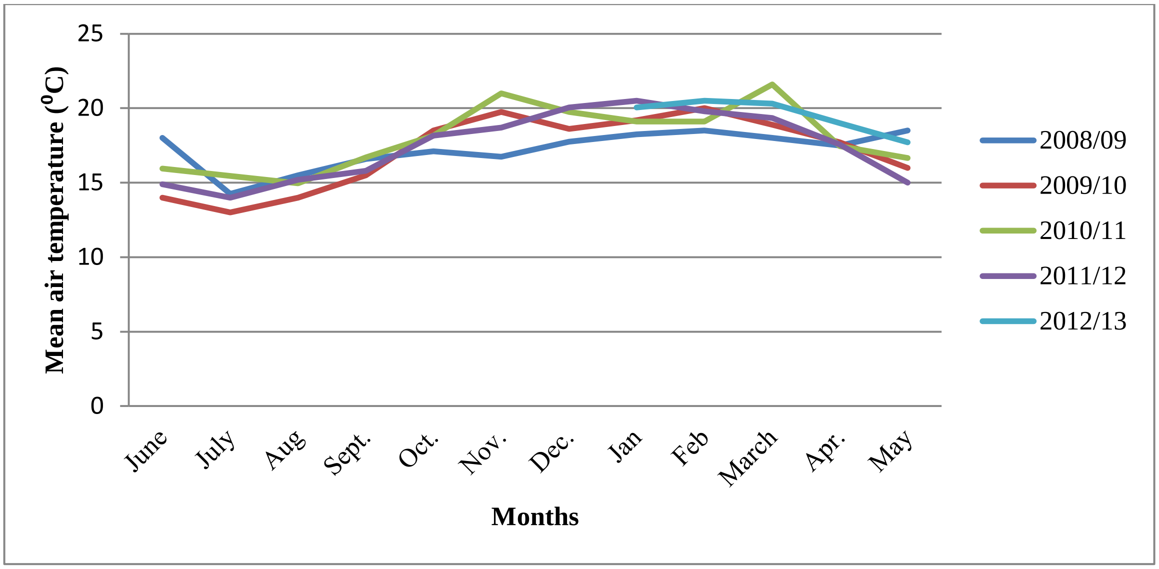


Figure 4.1: Ngwazi estate monthly mean air temperature and rainfall



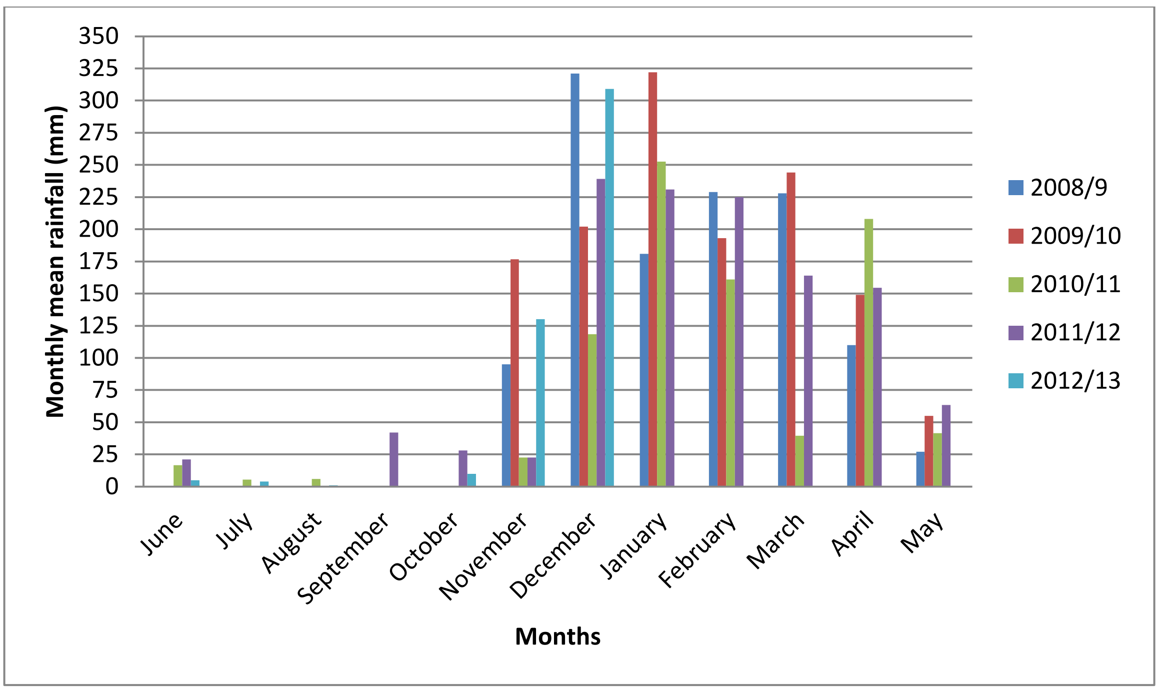
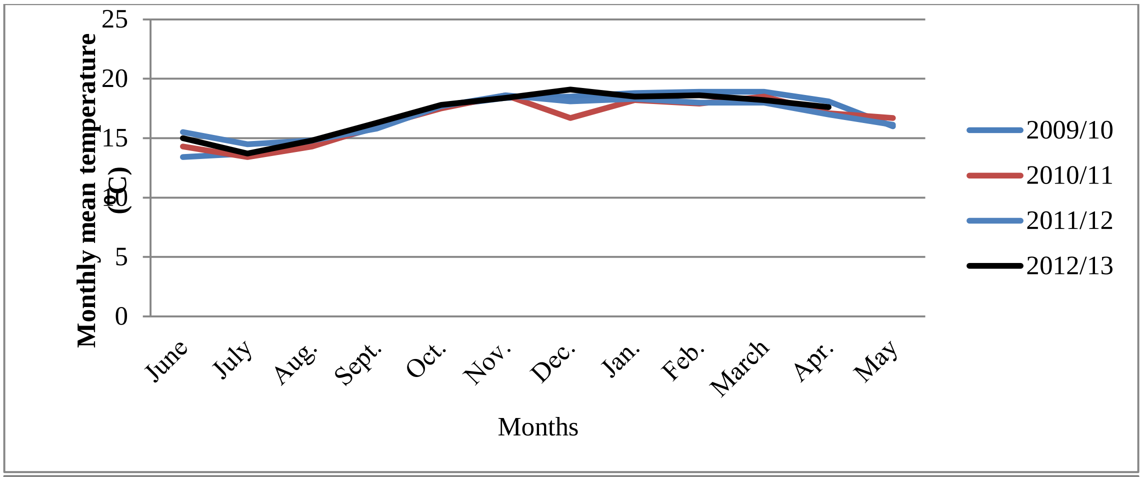


Figure 4.2: Itona estate monthly mean air temperature and rainfall



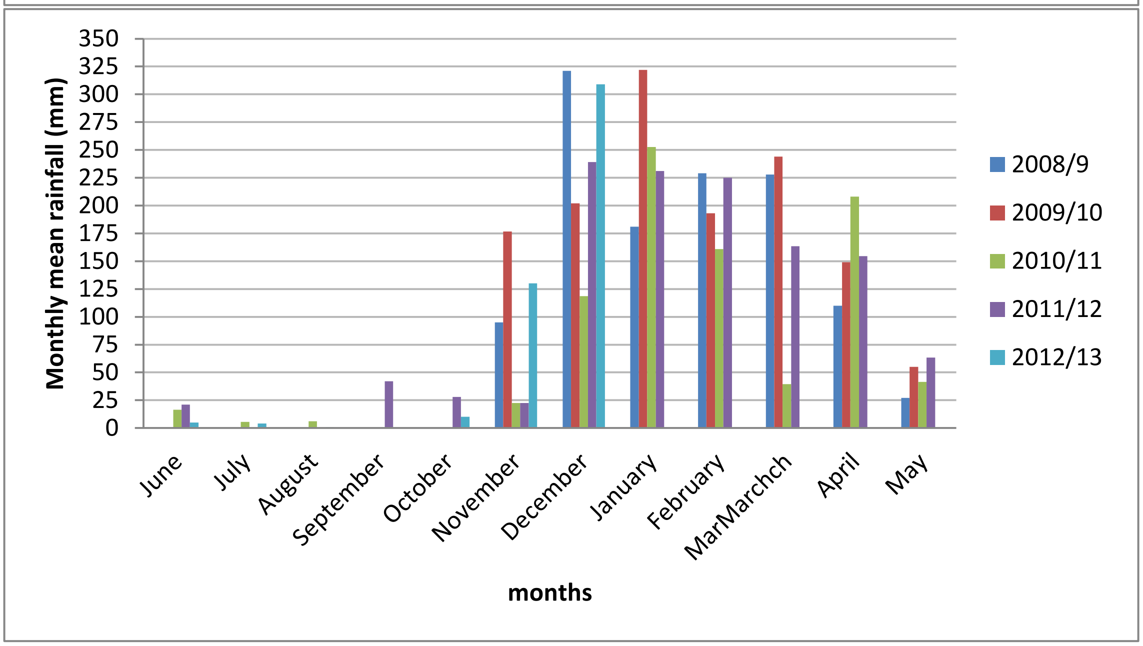


Figure 4.3: Itambo estate monthly mean air temperature and rainfall

Except at Itambo estate in which 2012/2013 rainfall was less than other years, in other estates, weather in 2013/2014 was similar to the previous years' trend. However, Itambo estate is irrigated during dry season or in the period of inadequate rainfall.

4.1.2: Effect harvesting methods on soil pH from the survey at Ngwazi estate

Figure 4.4 shows the variation of soil pH with harvesting methods at Ngwazi estate. The trend shows that machine (mechanical) harvesting was associated with lower soil pH (mean 4.97) than the hand method (mean 5.05). Lowest soil pH was observed in November (warm dry season) and in February (wet warm season) and highest in wet cool season (May). The seasons are as shown on Table 3.1

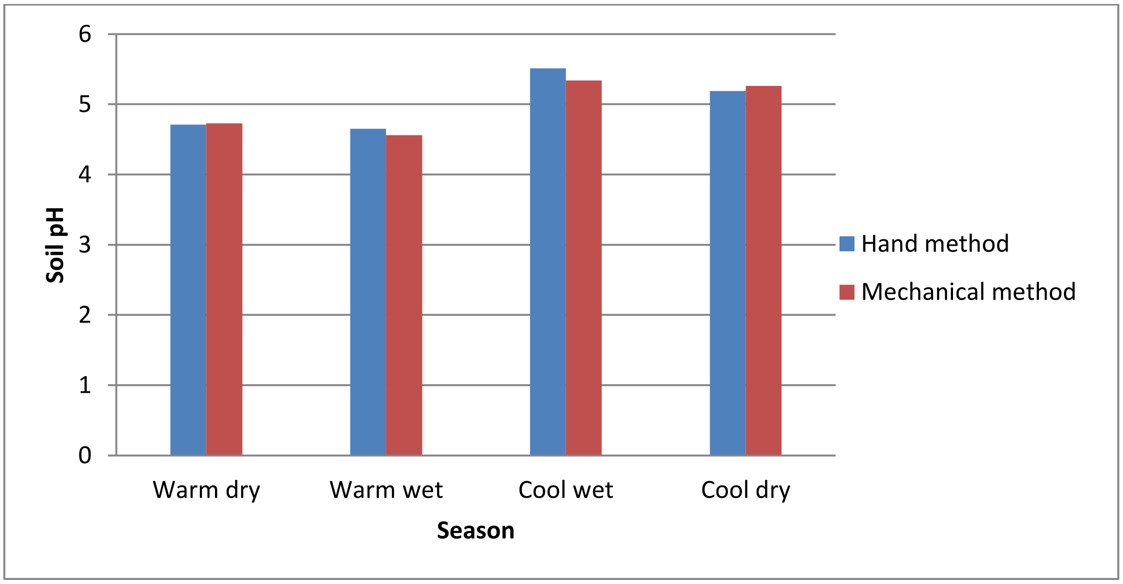


Figure 4.4: Effect of harvesting methods on soil pH at Ngwazi Estate

Mechanical method was associated with lower soil pH than hand method. Bonheure and Willson (1992) showed that, K is concentrated in young shoots. Mechanical harvesting being non-selective (Willson, 1992), it takes more young shoots and thus more K is lost. Possibly, the plant reacts by taking more K from the soil. The charge imbalance caused by the uptake of base cations is balanced by H^+ exudated by plant and thus lowering the soil pH.

Low soil pH in November (warm dry season) was thought to be due to increased uptake of K. The demand of K could have increased in order to control the loss of water. Wickremasighe and Krishnapillai (2008) reported that, one of the roles of K is to check plant's water balance (osmoregulation). The need to control loss of water is reduced in wet cool season (May) and thus demand for K is reduced. The reduced uptake of K reduces the amount of H^+ exudates from the plant. There is a possibility that there are some chemical reactions in the soil which cause combination of H^+ with other elements. With the reduced exudation of H^+, the soil pH increases. The lowest soil pH was observed in February (wet warm). This was thought to be due to leaching of base cations which enhanced more exudation of H^+.

4.1.3: Effect of harvesting methods on soil and leaf major nutrients (NPK) content at Ngwazi estate

Table 4.1 shows soil and leaf major nutrients (NPK) content. The trend shows that, mechanical method was associated with higher Soil N and P while K was lower than hand method. The trend in leaf showed that, mechanical method was associated with higher leaf N than hand harvesting method, while lower leaf P and K were associated with mechanical harvesting than hand method. Effect of fertilizer was not considered because the fields received fertilizer at the same rate.

Table 4.1: Soil and leaf nutrients contents from the survey at Ngwazi Estate

Harvesting methods	Soil			Leaf		
	% N	P (mg/kg)	K ($cmol_C$/kg)	%N	%P	%K
Hand	0.18*	8.90	0.31*	3.24	0.45	3.10
Machine	0.19*	11.52	0.29*	3.67	0.34	3.07

Key: * rated low. Others were rated adequate

High soil nutrients content could be due to low uptake by plants. The results imply that hand harvested tea plants could have higher uptake of N and P than mechanical tea harvesting while tea in mechanical harvesting appear to have higher uptake of K. This is similar to the observation made on soil pH on the uptake of K.

4.1.4: Effect of harvesting methods on tea yield

Tables 4.2, 4.3 and 4.4, give tea yield trends in hand and mechanical harvesting. At Itona and Itambo estates the yields are given in the last three years of hand harvesting, the first and second three years of mechanical harvesting and the means of yield in each harvesting method. The trend shows that, in the first three years of mechanical harvesting the yield was higher than in hand method. In the last three years of mechanical harvesting the yield declined slightly and was lower than in the hand method. In all estates the mean yields were higher in mechanical than hand method.

Table 4.2: Effect of harvesting methods on tea yield from survey at Itona estate

Harvesting method	Hand harvesting					Hand held Machine harvesting				
Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Yield Kg made tea/ha/year	5362	2800	3339	4065	4334	4462	4746	2989	3626	4766
Totals grouped in three year-periods			**11,738**			**12,197**				
			11,738					**11,381**		
Yield mean per harvesting method	**3,980**					**4,117**				

Table 4.3: Effect of harvesting methods on tea yield from the survey at Ngwazi estate

Harvesting methods	Hand method			Machine method		
Year	2007	2008	2009	2010	2011	2012
Yield (kg made tea/ha)	2572	2560	3192	2534	2960	4361
Mean (kg made tea/ha)	**2775**			**3285**		
Grand mean (kg made tea/ha)	**3030**					

Table 4.4: Effects of harvesting methods on tea yield at Itambo estate

Harvesting methods	Hand method				Machine method			
Year	2004	2005	2006	2007	2009	2010	2011	2012
Yield (kg made tea/ha/year)	3262	3283	3700	3435	4455	3394	2982	3112
Totals grouped in three year-periods		**10,418**			**10,831**			
		10,418				**9,488**		
Mean	**3,420**				**3,486**			
Grand mean = 3453								

Grouping the yield totals in three years was done in order to show the trend of yield in more than a year of mechanical harvesting. Yields trends might have been affected by other factors since comparison is based on different years. However results are consistent. They show that in the initial period of mechanical harvesting yield tended to increase. Beyond three years of mechanical harvesting at Itona and Itambo estates the yield trend declined and was lower than yield in hand method. The observed trend is similar with other findings which reported a decline in yield after some years of mechanical harvesting (Willson, 1992).

4.2: Experiments results

4.2.1: Temperature and rainfall trends

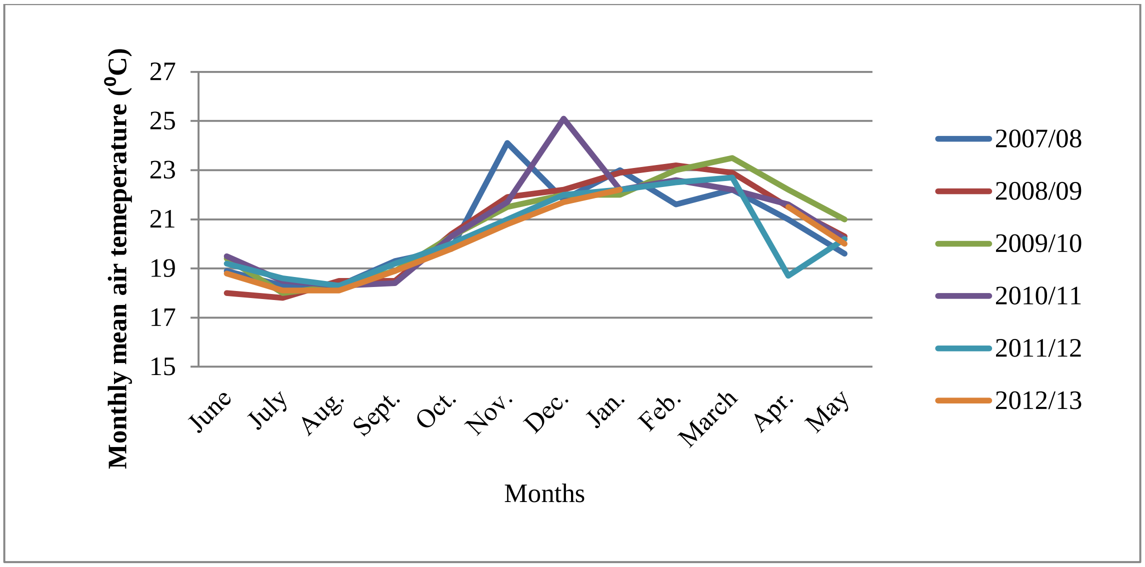
Weather was not a factor in the study but is related to factors of the study

4.2.1.1 Ngwazi Tea Research Station (NTRS)

This site uses the same meteorological station with Ngwazi Estate (surveyed). Weather data are presented in Ngwazi estate section.

4.2.1.2: Marikitanda Tea Research Station (MTRS)

Rainfall and temperatures trends are presented, Figure 4.5. Generally rainfall in 2012/2013 was similar to the previous years' trend except February which was drier. April had less rain but sufficient (> 150 mm). Temperature was similar to the previous years' trend.



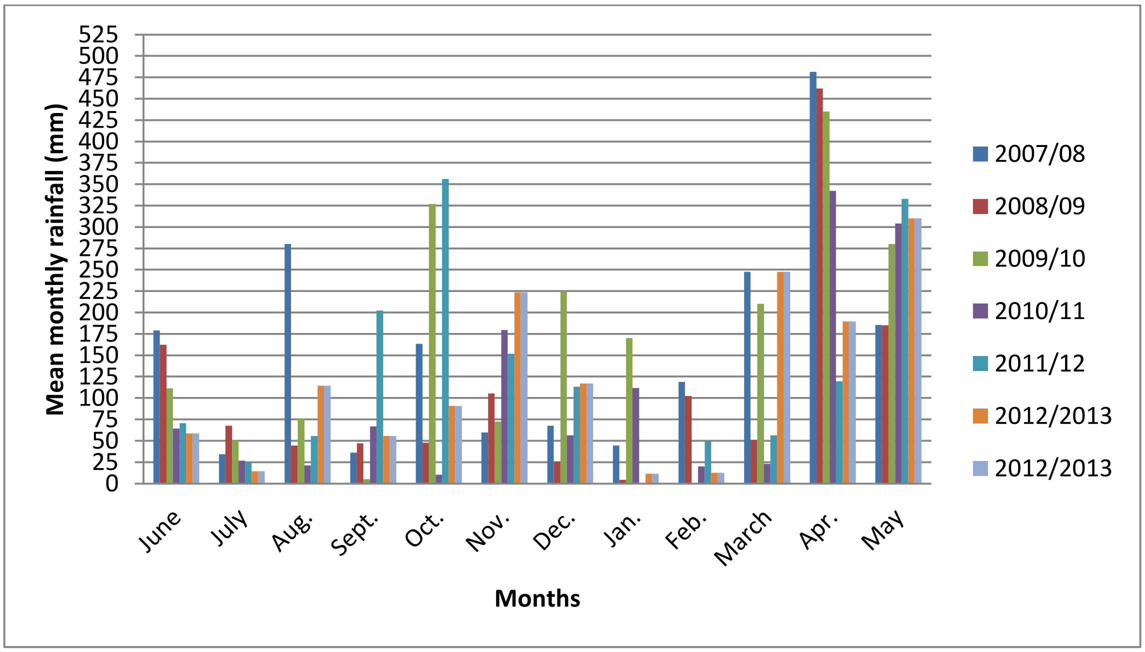


Figure 4.5: Marikitanda Tea Research Station monthly mean air mean temperature and rainfall

4.2.2: Study of the soils

4.2.2.1: Soil characterization at Marikitanda Tea Research Station

Tables 4.5 and 4.6 show soil physical and chemical characteristics respectively for Marikitanda site

Table 4.5: Marikitanda Tea Research Station soil physical characteristics

Horizon	Depth (cm)	Bulk density (g/cm^3)
A_p	20	1.08
Bt_1	70	1.49
Bt_2	145	1.44
BC	145+	Transition to C

There is transitional horizon at 42 cm between A_p and Bt_1

Table 4.6: Marikitanda Tea Research Station soil chemical characteristics

Horizon	pH (1:2.5) ($H_2$0)	K^+ ($cmol_c$/kg)	Ca^{+2} ($cmol_c$/kg)	Mg^{+2} ($cmol_c$/kg)	Na^+ ($cmol_c$/kg)	CEC ($cmol_c$/kg)	BS (%)
A_p	4.85	0.16	0.31	0.17	0.07	17.31	4.10
Bt_1	4.86	0.25	0.25	0.10	0.05	9.55	6.81
Bt_2	5.24	0.18	0.78	0.29	0.05	8.06	16.13

Plate 4.1: Soil profile at Marikitanda Tea Research Station. (*Source*: Author)

4.2.2.2: Soil description at Marikitanda Tea Research Station

Tables 4.5 and 4.6 give the physical and chemical characteristics of the soil respectively. Plate 4.1 shows the soil profile. The soil is old, moderately deep (< 2 m), with black surface horizon. The horizon has higher cation exchange capacity (CEC) than other horizons due to organic matter, red subsurface horizons indicate the presence of Fe^{+2}. The base saturation (BS < 17%) is low (acidic condition) and BS increases with depth implying pedogenic processes include leaching of bases. The reaction of hydrogen peroxide (appendix I) was low showing the absence of Fe^{+2} and Al^{+3} (sesquioxides) accumulation. The main diagnostic feature is the Bt horizons (argillic) and low BS. There is no other distinctive feature thus the soil is Haplic Nitisol (FAO-UNESCO, 1988). The leaching is due to high rainfall in this site.

4.2.2.3: Soil characterization at Ngwazi Tea Research Station

Table 4.7: Ngwazi station soil physical characteristics

Horizon	Depth (cm)	Bulk density (g/cm^3)
Ap	22	1.35
Bt_1	60	1.37
Bt_2	104	1.34
Bt_3	200+	1.33

There is transitional horizon at 40 cm between A_p and Bt_1

Table 4.8: Ngwazi station soil chemical characteristics

Horizon	Depth (cm)	pH (1:2.5) (H_2O)	K^+ ($cmol_c$ /kg)	Ca^{+2} ($cmol_c$ /kg)	Mg^{+2} ($cmol_c$ /kg)	Na^+ ($cmol_c$ /kg)	CEC ($cmol_c$ /kg)	BS (%)
Ap	22	5.00	0.32	0.26	0.59	0.07	17.81	7.00
AB	40	4.83	0.27	0.34	0.24	0.08	11.95	7.78
Bt_1	60	5.27	0.13	0.55	0.53	0.05	7.52	16.76
Bt_2	104	5.84	0.19	0.32	0.64	0.07	7.42	16.44
Bt_3	200+	5.72	0.17	0.23	0.64	0.08	8.51	13.16

Plate 4.2: Ngwazi Tea Research Station soil profile. (*Source*: Author)

4.2.2.4: Soil description at Ngwazi Tea Research Station

Tables 4.7 and 4.8 give the soil physical and chemical characteristics respectively of Ngwazi Tea Research Station and plate 4.2 shows the soil profile. The soil is very old, very deep (>2 m), with black surface horizon with higher cation exchange capacity (CEC) than other horizons due to soil organic matter and red subsurface horizons due to Fe^{+2}. Base saturation (BS) is low (< 17%) and increases with depth implying leaching of bases is taking place. Low BS implies acidic condition. The reaction of hydrogen peroxide (Appendix II) was low implying absence of Al^{+3} and Fe^{+2} accumulations (sesquioxides). The presence of Bt (argillic) horizons and low BS and having no any other distinct feature; The soil is Haplic Nitisol (FAO –UNESCO, 1988). The site is irrigated due to insufficient rainfall. Leaching may be caused by high rainfall in short periods due to poor distribution and or over irrigation.

At both sites results show that, soils have low exchangeable base cations. This was also reflected in the low base saturations. On both sites cation exchange capacity (CEC) was rated medium at surface horizons and low in the subsurface horizons. Higher CEC at the surface horizons was attributed to presence of organic matter coming from leaf fall and prunings which was also reflected by low bulk densities (Tables 4.5 and 4.7). Due to low K, applying it in the form of fertilizer is important. Othieno (1992) recommended the minimum soil depth of 2 m for tea and soil pH of 5.0-5.6. The depth at Marikitanda is less than 2 m which may be affecting the development of roots especially the tap root which can go deeper than 6 m (Carr, 2012). Based on soil depth, Ngwazi appears to be more suitable for tea growing than Marikitanda.

4.2.3: Effect of harvesting methods and fertilizer rates on Soil pH

Figures 4.6 and 4.7 show how soil pH varied with harvesting methods and fertilizer rates. In both methods of harvesting the trend showed that, the soil pH decreased with increase of fertilizer rates. The trend for harvesting methods effect showed that shear was associated with lower soil pH than hand method. Samples were bulked and thus, could not use statistical method other than descriptive for data analysis.

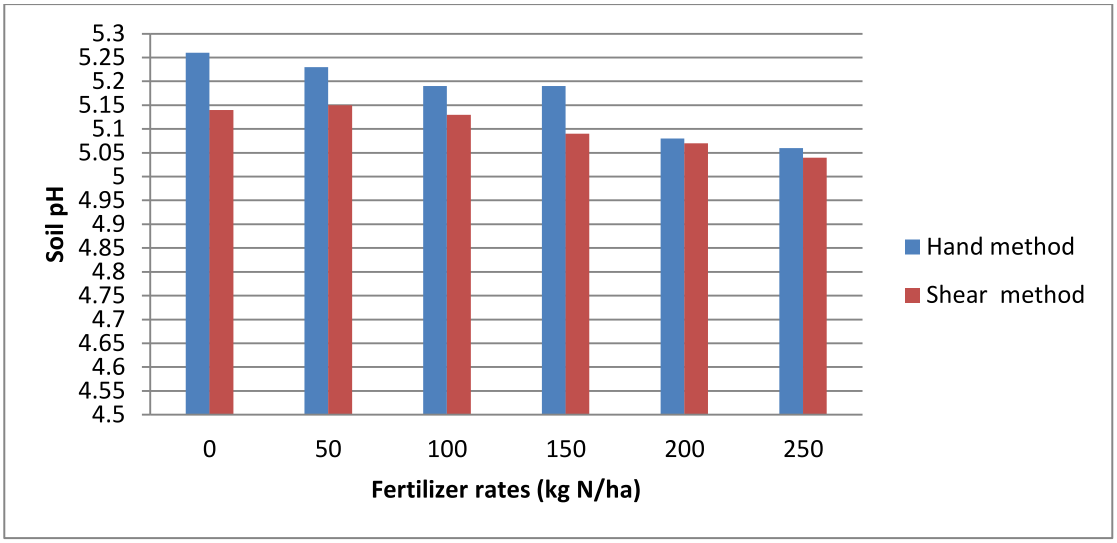


Figure 4.6: Effect of harvesting methods and fertilizer rates on soil pH at Marikitanda Tea Research Station

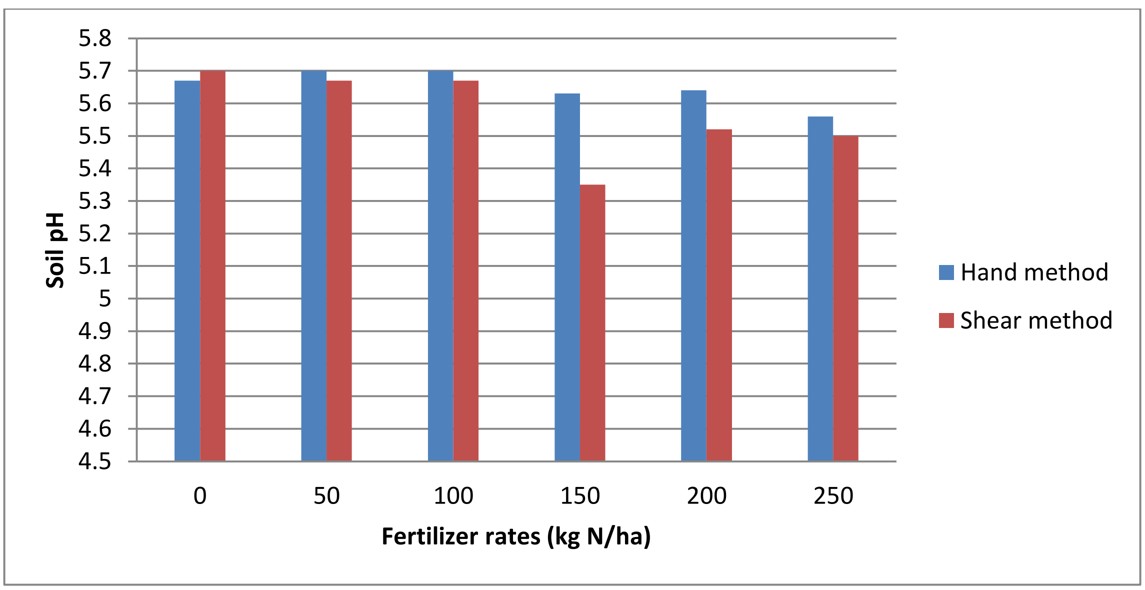


Fig.4.7: Effect of harvesting methods and fertilizer rates on soil pH at Ngwazi Tea Research Station

The soil pH in both surveyed (Ngwazi estate) and experimental sites was lower in mechanical harvesting plots. This trend suggests that mechanical harvesting could be causing higher uptake of base cations particularly K. Higher uptake of base cations implies more exudation of H^+ by plants in order to restore soil solution charge balance. This causes the soil pH to decrease. This is also discussed under survey results (section 4.1.2).

The effects of fertilizer rates on soil pH showed decreasing trend. The trend was thought to be due to the release of H^+ as a result of oxidation of NH^+_4. Kamau (2002) noted similar trend. It was further pointed out that with an increase of N rate, bases are leached. The leaching of bases is attributed to competition for exchange sites between base cations and ammonium ion. Although tea performs well in acidic soil, care should be taken not to allow the pH to go below 5.0 which according to Othieno, (1992) is the minimum for optimal tea growth. From this observation, it implies that the risk of causing soil pH to go below the range is high in tea clones which require high rates of N fertilizer application. Also closer monitoring of soil pH in mechanical harvesting is required.

4.2.4: Effect of harvesting methods and fertilizer rates on soil major nutrients (NPK) contents

Tables 4.9 and 4.10 give the effects of harvesting methods and fertilizer rates on soil major nutrients (NPK) at Marikitanda and Ngwazi Tea Research Stations respectively. Samples were bulked and thus, could not use statistical methods other than descriptive for data analysis.

Table 4.9: Effect of harvesting methods and fertilizer rates on soil major nutrients (NPK) contents at Marikitanda Tea Research Station

Fertilizer rates (kg N/ha)	% N			P (mg/kg)			*K (cmol$_c$/kg)		
	Hand method	Shear method	Mean	Hand method	Shear method	Mean	Hand method	Shear method	Mean
0	0.24	0.24	**0.24**	9.39	18.85	**14.12**	0.23	0.25	**0.24**
50	0.25	0.24	**0.25**	17.62	20.42	**19.02**	0.25	0.27	**0.26**
100	0.26	0.26	**0.26**	17.62	20.50	**19.06**	0.21	0.27	**0.24**
150	0.27	0.26	**0.27**	18.28	19.11	**18.70**	0.18	0.25	**0.22**
200	0.26	0.28	**0.27**	16.63	20.58	**18.61**	0.19	0.24	**0.22**
250	0.25	0.25	**0.25**	15.27	18.10	**16.69**	0.17	0.22	**0.20**
Mean	**0.26**	**0.26**		**15.80**	**19.59**		**0.21**	**0.25**	

Key: * low. K was low in all rates of fertilizer

Table 4.10: Effect of harvesting methods and fertilizer rates on soil major nutrients (NPK) contents at Ngwazi Tea Research Station

Fertilizer rates (kg N/ha)	%N			P (mg/kg)			K (cmol$_c$/kg)		
	Hand method	Shear method	**Mean**	Hand method	Shear method	**Mean**	Hand method	Shear method	**Mean**
0	0.20*	0.20*	**0.20**	9.47	10.95	**10.21**	0.42	0.20*	**0.31**
50	0.20*	0.20*	**0.20**	8.65	12.02	**10.35**	0.45	0.31*	**0.38**
100	0.21	0.21	**0.21**	9.96	14.08	**12.02**	0.45	0.24*	**0.35**
150	0.21	0.22	**0.22**	12.19	13.67	**12.93**	0.43	0.46	**0.45**
200	0.21	0.21	**0.21**	9.88	11.28	**10.58**	0.39*	0.43	**0.41**
250	0.18*	0.21	**0.20**	7.82	9.88	**8.85**	0.36*	0.33*	**0.35**
Mean	**0.20**	**0.21**		**9.67**	**11.98**		**0.42**	**0.33**	

Key: * low

4.2.4.1: Soil N

At the Marikitanda Tea Research Station (Table 4.9), both harvesting methods effect on soil N was equal. The trend of effect of fertilizer rates on soil N increased with fertilizer rates up to 150 kg N/ha as NPK fertilizer and then declined. In hand method the soil N showed increasing trend up to 150 kg N/ha while in shear method increased up to 200 kg N /ha.

At the Ngwazi Tea Research Station (Table 4.10) shear harvesting method was associated with higher soil N than hand method. The effect of fertilizer rates on soil N showed increasing trend with fertilizer rates. Highest value was observed at 150 kg N/ha and then declined. In both harvesting methods, fertilizer rates did not show a clear trend but high fertilizer rates caused low values of soil N.

The observed increasing trend of soil N content with fertilizer rates especially at Marikitanda is consistent with other findings (Kebeney, 2010; Kamau, *et al.,* 2005). The low values of soil N observed at high fertilizer rates could be due to low soil pH in which N was lost through volatilization as ammonia as pointed out by McKenzie (2003). Across the sites only at Marikitanda where the harvesting means were the same. At Ngwazi estate (surveyed) and Ngwazi Tea research Station the soil N means were higher in mechanical harvesting. This trend implies that hand harvested tea has probably higher uptake of the soil N than mechanically harvested tea.

4.2.4.2: Soil P

At the Marikitanda Tea Research Station, the trend showed that shear harvesting method had higher soil P than hand method. Fertilizer rates effect on soil P showed increasing trend from the control to 100 kg N/ha and then there was a decline. In both harvesting methods soil P did not show clear trend. In hand method highest value of soil P was observed at 150 kg N/ha while in shear method the highest value was at 200 kg N/ha. Similarly at Ngwazi Tea Research Station shear method was associated with higher soil P than hand method. Fertilizer rates effect on soil P showed increasing trend with fertilizer rates up to 100 kg N/ha and then declined. The lowest value was observed at 250 kg N/ha. In both methods of harvesting soil P showed increasing trend but declined at high fertilizer rates.

The increasing trend of soil P with fertilizer rates is similar with Kebeney, (2010) who found that soil P increased with fertilizer rates but declined at high rates. The decline in soil P at high rates of fertilizer was attributed to fixation by Fe^{+2} and Al^{+3} due to increased acidity as pointed out by Othieno (1992). Opala, *et.al.*, (2006) reported that application of high amounts of P will exhaust the P fixing capacity of the soil and more P will be available. In this study, low soil P availability was observed at high rates of NPK fertilizer which appears to be a contrary to the report. This was attributed to the acidifying effect of NPK fertilizer. P was added to the soil and at the same time soil pH was lowered. It appears therefore that, more favourable condition (low pH) for P fixation occurred at high fertilizer rates. In all the study sites including surveyed estate, Low soil P was associated with hand harvested plots. This suggests that hand harvested tea could have higher uptake of soil P than mechanically harvested tea.

4.2.4.3: Soil K

At Marikitanda Tea Research Station, shear harvested plots were associated with higher soil K than hand method. Effects of fertilizer rates on soil K increased from the control to 50 kg N/ha at which the highest value was observed and lowest was observed at 250 kg

N/ha. Low soil K at higher rates of fertilizer was observed in both harvesting methods. At Ngwazi Tea Research Station, higher soil K was associated with hand harvesting method. Effects of fertilizer rates on soil K did not show clear trend but, lowest value was observed at 250 kg N/ha.

The observed trend of low soil K at high fertilizer rates was probably due to increased soil acidity. Bonheure and Willson (1992) noted that soil K in acidic soil was low. This observation was attributed to leaching out of base cations at low soil pH as noted by Kamau (2002). Except at Marikitanda, in all other sites soil K was lower in the mechanically harvested tea. This trend implies that tea in mechanical harvesting could have higher uptake of K than tea in hand harvesting method. This observation is similar to the observation made in soil pH where tea in mechanical harvesting was thought to have higher uptake of base cations.

4.2.5: Effect of harvesting methods and fertilizer rates on leaf major nutrients (NPK) contents

Tables 4.11 (Marikitanda Tea Research Station) and 4.12 (Ngwazi Tea Research Station) give the effect of harvesting methods and fertilizer rates on leaf NPK contents. Samples were bulked and thus, statistical methods other than descriptive could not be used for data analysis.

Table 4.11: **Effect of harvesting methods and fertilizer rates on leaf major nutrients (NPK) contents at Marikitanda Tea Research Station**

Fertilizer rates (kgN/ha)	% N			%P			% K		
	Hand method	Shear method	Mean	Hand method	Shear meth od	Mean	Hand method	Shear method	Mean
0	3.23	3.22	**3.23**	0.53	0.55	**0.54**	1.42	2.49	**1.96**
50	3.84	3.92	**3.88**	0.54	0.58	**0.56**	1.54	3.67	**2.61**
100	3.85	3.45	**3.65**	0.76	0.65	**0.71**	2.84	4.97	**3.91**
150	3.22	3.11	**3.17**	0.67	0.44	**0.56**	2.61	1.90	**2.26**
200	3.10	3.01	**3.06**	0.41	0.59	**0.50**	2.13	2.13	**2.13**
250	3.09	3.00	**3.05**	0.56	0.49	**0.53**	2.01	0.95*	**1.48**
Mean	**3.39**	**3.30**		**0.58**	**0.55**		**2.09**	**2.69**	

Key: * low

Table 4.12: Effect of harvesting methods and fertilizer rates on leaf major nutrients (NPK) contents at Ngwazi Tea Research Station

Fertilizer rates (kg N/ha)	**%N**			**%P**			**%K**		
	Hand method	Shear method	Mean	Hand method	Shear method	Mean	Hand method	Shear method	Mean
0	3.01	3.13	**3.07**	0.32	0.29	**0.31**	1.90	0.95*	**1.43**
50	3.20	3.38	**3.76**	0.42	0.20	**0.31**	1.66	3.08	**2.37**
100	3.50	3.64	**3.57**	0.45	0.38	**0.42**	2.96	2.99	**2.98**
150	4.13	3.31	**3.72**	0.44	0.40	**0.42**	2.49	2.46	**2.48**
200	3.42	3.18	**3.3**	0.39	0.32	**0.36**	1.66	2.13	**1.90**
250	2.77*	2.77*	**2.77**	0.25	0.21	**0.23**	2.01	1.78	**1.90**
Mean	**3.34**	**3.24**		**0.38**	**0.30**		**2.11**	**2.23**	

Key: * low

4.2.5.1: Leaf N

At the Marikitanda Tea Research Station higher leaf N was associated with hand than shear method. The leaf N increased at 50 kg N/ha and then declined. In both harvesting methods the lowest leaf N was observed at 250 kg N/ha. Similarly at the Ngwazi Tea Research Station, hand method had higher leaf N than shear. Leaf N increased with fertilizer rates up to 150 kg N/ha and then declined. In both harvesting methods the lowest leaf N was observed at 250 kg N/ha

The increasing trend of leaf N with nitrogenous fertilizer rates was also observed by Kamau *et al.*, (2005). The observed decline in leaf N at high rates of fertilizer is similar with the trend observed in soil N. The decreased soil N at high fertilizer rates could have reduced the N uptake by tea plants. Ranganathan (1973) made similar observation. Except at Ngwazi estate (surveyed) in the two experimental sites, higher leaf N was associated with hand harvested tea. This indicates that, hand harvested tea could be taking more N than tea in mechanical method. This observation is similar to the observation made on the soil N.

4.2.5.2: Leaf P

At Marikitanda Tea Research Station, higher leaf P was associated with hand than shear harvested tea. Effect of fertilizer rates on leaf P showed increasing trend with fertilizer rates up to 100 kg N/ha and then declined. Generally in both harvesting methods leaf P showed increasing trend at low fertilizer rates and declined at high rates. At Ngwazi Tea Research Station hand method had was also associated with higher leaf P than shear method. Effects of fertilizer rates on leaf P showed increasing trend with fertilizer rates up to 150 k N/ha and then declined. A similar trend of leaf P decline at high fertilizer rates was observed in each method of harvesting.

The increasing trend of leaf P and then a decline at higher rates of fertilizer was similar to soil P trend. Thus decline in leaf P at high fertilizer rates could be due to reduced soil P availability. As noted by Othieno (1992), soil P availability decreases with decreasing soil pH. Across all sites, leaf P was higher in hand harvesting method. The trend implies that hand harvested tea could have higher P uptake than tea in mechanical method.

4.2.5.3: Leaf K

At the Marikitanda Tea Research Station, shear harvested tea was associated with higher leaf K than hand harvested. Effects of fertilizer rates on leaf K showed increasing trend with fertilizer rates up to 100 kg N/ha and then declined at high rates. The same trend was observed in both harvesting methods. Similarly at the Ngwazi Tea Research Station shear harvested tea was associated with higher leaf K than hand harvested. Effects of fertilizer rates on leaf K showed increasing trend up to 100 kg N/ha and then declined. In shear harvested tea leaf K showed decreasing trend from 50 kg N/ha. There was no clear trend in hand method but high fertilizer rates lead to lower leaf K.

The decreasing trend of leaf K at high fertilizer rates is similar to trend observed in soil K. Decreasing trend in leaf K was also observed by Owour *et al.*,(1992). Kamau *et al.*, (2005) reported that the uptake of soil K was depressed at high levels of soil N. According to Wanyoko (1997), depression of K uptake is due to the presence of ammonium ion which the tea plant prefers to take. According to McKenzie, (2003), ammonium ions dominate at low pH. These could be the reasons for decreasing trend of leaf K. Kamau, *et al.*, (2005) noted that K deficiency cannot be corrected by applying NPK, but should be applied as remedial K. This note supports the observed decreasing trend. Only at Ngwazi estate (surveyed) where the leaf K was higher in hand harvested tea. In all experiments leaf K was higher in shear harvested tea. This trend suggests that, mechanically harvested tea could have higher uptake of K than hand harvested. This is similar to the observation made on soil K.

High levels of leaf K observed at Ngwazi estate and Marikitanda Tea Research Station could have been caused by instrumental error. Apart from instrumental errors, nutrients recycling through leaf fall and prunings might have also contributed to the inconsistence of nutrients contents. The uptake of N and P by tea plants was higher in hand harvested plots. The elements take part in the formation of various compounds in the plant cells (Bonheure and Willson, 1992). In hand harvesting method photosynthesis is not much affected. This could be the reason for hand harvested tea to have higher uptake of these nutrient elements.

On the other hand K uptake was higher in mechanical harvested tea where photosynthesis is affected by the removal of young shoots and large proportion of mature leaves. The role of K is regulatory; it does not take part in the formation of organic constituents of the plant cells (Bonheure and Willson, 1992). It appears that the reduction in photosynthesis in mechanical harvesting does not affect the uptake of K. This could be the reason for higher uptake of K in the mechanical harvesting and during drought.

4.2.6: Effect of harvesting methods and different soil major nutrients levels on shoot weight

Tables 4.13 and 4.14 give the effect of harvesting methods and different soil major nutrients levels on shoot weight. At both sites harvesting methods had significant

($p<0.05$) effect on shoot weight with hand method having heavier shoots. Shoot weight increased with an increase in soil N, P and K applied as NPK fertilizer, but the effect was not significant. At the Marikitanda Tea Research Station, shoot weight in both method of harvesting reached a peak at 150 kg N/ha. At the Ngwazi Tea Research Station, the shoot weight for either harvesting methods reached a peak at 200 kg N/ha. The interaction between the harvesting methods and fertilizer rates was not significant.

Table 4.13: Effects of harvesting methods and fertilizer rates on mean shoot (g/shoot) weight at Marikitanda Tea Research Station

Fertilizer rates (kg N/ha)	**0**	**50**	**100**	**150**	**200**	**250**	**Mean shoot weight**
Mean shoot weight under hand method (g/shoot)	0.61	0.65	0.65	0.70	0.69	0.64	0.66a
Mean shoot weight under shear method (g/shoot)	0.50	0.50	0.52	0.57	0.55	0.55	0.53b
Average of mean shoot weight	0.56a	0.58a	0.59a	0.64a	0.62a	0.60a	0.59

LSD ($_{P=0.05}$) fertilizer rates= 0.140, harvesting methods =0.081

Fpr harvesting methods * fertilizer rates = 0.9984, % CV = 19.83

Table 4.14: Effects of harvesting methods and fertilizer rates on mean shoot (g/shoot) weight at Ngwazi Tea Research Station

Fertilizer rates (kg N/ha)	**0**	**50**	**100**	**150**	**200**	**250**	**Mean**
Mean shoot weight under hand method (g/shoot)	0.51	0.53	0.57	0.57	0.62	0.55	0.56a
Mean shoot weight under shear method (g/shoot)	0.44	0.45	0.47	0.49	0.53	0.50	0.48b
Average of mean shoot weight	0.48a	0.49a	0.52a	0.53a	0.58a	0.53a	0.52

LSD $_{(P=0.05)}$ for fertilizer rates= 0.1356 and for harvesting methods= 0.0783, Fpr harvesting methods * fertilizer rates = 0.9514, %CV =21.82

The trend observed is similar to how tea yield increases with fertilizer rates. It appears that yield trend is determined by shoot weight trend. Sitienei *et al*., (2013) reported that, nitrogen is the most important to determine the yield. It appears that low weight in mechanical harvesting is due to inefficient utilization of N. This is similar to the above results which show that tea in mechanical harvesting had less uptake of soil N. Although results show that tea in mechanical harvesting has uptake of soil K, still at high N levels K uptake is depressed (Kamau, et al., 2005). Depressed K uptake may affect the physiology of the plant thus contributing to low weight. Effect of harvesting methods on shoot weight is similar to the finding by Burgess, et al.,(2006) who reported that hand harvested shoots were heavier than mechanized harvesting by 13%. In this study the differences are higher (19.18% at Marikitanda and 14.3% at Ngwazi). This was attributed to difference in clones and environment.

Shoot weight is an important component of tea yield as shown by Carr, (2000):

$Y = NS * MSW * SRC$

Where: Y = Annual yield, NS = Number of harvested shoots, MSW = Mean shoot weight of the harvested shoots, SRC = Number of shoots replacement cycle per year

4.2.7: Effect of shoot type composition on nutrients loss

Tables 4.15 and 4.16 present the effect of harvesting methods on the composition (%) of shoot type by weight at Marikitanda and Ngwazi Tea Research Stations respectively. Samples were bulked and thus could not be analyzed using methods other than descriptive. Proportion (%) increased from buds to 3L +b. The 4L + b and buds constituted less than 1% in both methods. Banhji shoots had highest proportion in hand method while broken leaf was highest in shear method. Twigs and compound shoots were higher in shear method. Shoot types total percentages were less than 100 %, shear method with higher loss.

Table 4.15: Effect of harvesting methods on shoot type composition at Marikitanda Tea Research Station

Harvesting method	Bud	1L + b	2L + b	3L + b	4L + b	banhji	ML	BL	Twigs	CS	Total
Hand	0.20	1.63	14.86	11.93	0.87	55.32	0.53	6.60	0.06	0.003	92.0%
Shear	0.81	2.88	7.28	4.65	0.64	14.17	7.65	40.10	1.30	0.56	80.5%

Key: Bud- refers to unfurled leaf,

1L- first leaf, 2L- second leaf, 3L-third leaf, 4L- fourth leaf, Banhji-refers to dormant shoot, ML = maintenance leaf, BL= Broken leaf, CS = compound shoot, refers to shoot with more than one part e.g. leaf and stem, (Shoot types see appendix XIII)

Table 4.16: Effect of harvesting methods on shoot type composition at Ngwazi Tea Research Station

Harvesting method	Bud	1L + b	2L + b	3L+b	4L + b	banhji	ML	BL	Twigs	CS	Total
Hand	0.17	4.06	25.68	19.95	2.59	22.04	0.72	16.51	0.004	0.15	91.87%
Shear	0.81	3.39	10.35	10.86	4.42	13.47	9.07	31.83	2.01	2.45	88.66%

Key: Bud- refers to unfurled leaf, L- leaf, Banhji-refers to dormant shoot, ML = maintenance leaf, BL= Broken leaf, CS = compound shoot, refers to shoot with more than one part e.g. leaf and stem, Similar shoot distribution was observed by Othieno and Anyuka (1982). Willson (1992) showed that the amount of N,P and K lost through a crop depend on the shoot type. The results support that nutrients lost in hand are different from that in mechanical harvesting due to difference in shoot type composition. Since shear (mechanical) harvesting takes more shoot types than hand, it would appear that nutrients loss is higher in mechanical harvesting. However shoots in mechanical are lighter than those in hand harvesting (Tables 4.13 and 4.14). Verification by analyzing nutrients content in all shoot types from mechanical harvesting is required. Banhji shoots were higher in hand method. This was probably due to physiological changes in the tea plants.

4.2.8: Effect of harvesting methods and soil nutrients levels on yield

Tables 4.17 and 4.18 show how yield varied with harvesting methods and fertilizer rates. At both sites harvesting methods had significant ($p<0.05$) effect on tea yield, mechanical method having higher yield. At Marikitanda, yield increased significantly ($p<0.05$) with fertilizer rates and the yield in hand harvesting peaked at 200 kg N/ha and then declined while in shear harvesting it peaked at 150 kg N/ha and then declined.

At Ngwazi Tea Research Station, fertilizer rates had no significant ($p>0.05$) effect. In hand method yield peaked at 200 kg N/ha and in shear increased up to 250 kg N/ha. At both sites the interactions between harvesting methods and fertilizer rates (nutrients levels) were not significant.

Table 4.17: Effects of harvesting methods and fertilizer rates on tea yield at Marikitanda Tea Research Station experiment

Fertilizer rates (kg N/ha)	0	50	100	150	200	250	**Mean yield**
Hand method yield (kg made tea ha^{-1})	1762	2111	2127	2316	2338	2209	**2144a**
Shear method yield (kg made tea ha^{-1})	1749	2213	2368	2794	2659	2410	**2365b**
N rates mean yield	**1756a**	**2162b**	**2248b**	**2655c**	**2499b**	**2310**	**2254**
$LSD_{(P = 0.05)}$ for harvesting methods = 209, N rates = 361, Fpr harvesting methods * N rates = 0.7768, %CV = 13.38							

Table 4.18: Effects of harvesting methods and fertilizer rates on tea yield at Ngwazi Research Station

Fertilizer rates (kg N/ha)	0	50	100	150	200	250	**Mean yield**
Hand method yield (kg made tea ha^{-1})	464	524	533	497	574	498	**515a**
Shear method yield (kg made tea ha^{-1})	621	634	615	771	769	836	**708b**
N rates mean yield	**543a**	**579a**	**574a**	**634a**	**672a**	**667a**	**612**
$LSD_{(p=0.05)}$ for harvesting methods = 113 and for N rates = 195, Fpr harvesting methods * N rates = 0.7402, %CV 26.65							

Othieno, (1979) showed that nutrients lost in1000 kg made tea for clone TRFK 6/8 in hand harvesting was 40 kg N, 4 kg (1.75 kg P) and 19 kg K_2O (15.69 K). From this, N P K lost through the harvest at Marikitanda (clone TRFK 6/8) in hand method was: 85.76 kg N, 8.58 P and 33.64 kg K. Based on yield it appears as if more nutrients were lost from shear harvesting because the yield was higher. However considering the shoot weight (Tables 4.13 and 4.14) and shoot composition (Table 4.15 and 4.16), higher yield in shear does not necessarily imply higher nutrients loss. Low shoot weight in mechanical harvesting could be contributing to decline in yield as reported by others (Willson, 1992; Satyarayana, 1994). At Marikitanda Tea Research Station the yield in hand method peaked at 200 kg N/ha and in shear at 150 kg N/ha. The difference in yield between the two rates in hand method was not significant. Also at Ngwazi Tea Research Station the yield in hand method peaked at 200 kg N/ha and in shear increased up to 250 kg N/ha. The yield in shear method between 200 and 250 kg N/ha was not significant. Thus based on this yield trend, in practice 150 kg N/ha would be appropriate in both methods of harvesting at Marikitanda and 200 kg N/ha would be appropriate in both harvesting methods at Ngwazi Tea Research Station. This implies that under the short period of the study hand and mechanical tea harvesting, practically required the same rates of fertilizer.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1: Conclusion

Mechanically harvested tea had lower soil pH than hand method. Hand harvested tea had higher uptake of N and P while mechanically harvested tea had higher uptake of K. At Marikitanda Tea Research Station, soil N increased with fertilizer rates up to 200 kg N/ha, leaf N up to 100 kg N/ha. Soil P increased up 100 kg N/ha and leaf P up 150 kg N/ha. Soil K increased up to 50 kg N/ha, leaf K up to 100 kg N/ha. At Ngwazi Tea Research Station, soil N increased up to 150 kg N/ha, leaf N up to 100 kg N/ha, soil P increased up to 100 kg N/ha, leaf P up to 150 kg N/ha. Soil K increased up to 150kg N/ha, leaf K up to 100 kg N/ha.

Hand harvested tea had heavier shoots than mechanically harvested. Shoot weight increased with fertilizer rates up to 150 and 200 kg N/ha at Marikitanda and Ngwazi Tea Research Stations respectively. Mechanically harvested tea had higher proportion of mature and broken leaves (low quality greenleaf).

Mechanical harvesting method had higher yield than hand method. Yield increased with fertilizer rate up to 150 kg N/ha and 200 kg N/ha at Marikitanda and Ngwazi Tea Research Stations respectively. Practically, hand and mechanically harvested tea required the same rate of fertilizer.

5.2: Recommendations

1. In the first few years (≤ 3) of mechanical harvesting, the same rate of fertilizer should be applied in both hand and mechanically harvested tea.
2. This study should be continued for longer period (>3 years) in order to further assess the effects of mechanical harvesting on soil pH, nutrients uptake and tea yield.

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APPENDICES

Appendix I: Marikitanda Tea Research Stations soil profile description

Georeferencing **(**Profile location): S 05°07'7.85", E 038°35'8.18"

Elevation: 998 m above sea level.

Landform: Plateau

Drainage: Class 4, well drained

Slope gradient: Sloping (class 3), 6-13%

Slope type: Convex

Location along the slope: Near top the hill summit

Erosion: No signs of erosion

Natural fertility gradient: No observable fertility gradient

Master horizon	Horizon boundary width (cm)		Texture by hand feel method	Structure		Reaction with hydrogen peroxide (H_2O_2)
	From	To		Type	Grade	
Ap	0	20	Fine and sticky, formed ribbon but did not form ring	Blocky and small	Weak	Low
AB	20	42		Blocky and small	Weak	Low
Bt1	42	70	Finer and more sticky than above formed ribbon but a ring broke	Blocky and small	Weak	Low
Bt2	70	130	More sticky than above. Formed weak ribbon	Blocky and small	Weak	Low
BC	130	145				Low
C	145+		Gravel			Low

Appendix II: Ngwazi Tea Research Stations soil profile description

4.2.3.1: Ngwazi Tea Research Station profile description

Georeferencing**:** Profile Location: S 08º30'544''; E035º09'492"

Altitude: 2056 m above sea level

Land form: Plain

Slope gradient: Gentle sloping (class 2), 2-6%

Slope type: Convex

Location along the slope: Near hill top

Drainage: Well drained (Class 4)

Vegetation: Tea

Soil erosion: No sign of soil erosion

Fertility gradient: No observable fertility gradient

Master horizon designation	Horizon boundary width (cm)		Texture by hand feel method	STRUCTURE (Was slightly moist)		Reaction with hydrogen peroxide (H_2O_2)
	From	To		Type	Grade	
Ap	0	22	Slightly sticky	Blocky	Weak	moderate
AB	22	40	More sticky	Blocky	Weak	Low
Bt_1	40	60	Formed ribbon	Blocky	Weak	low
Bt_2	60	104	Formed weak ring	Blocky	Weak	Low
Bt_3	104	200	Formed weak ring	Blocky	Weak	Low

Appendix III: Itona estate monthly air temperature (^{0}C)

	Jan	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
2008	17.5	17.6	18	15.5	16.2	16	12.5	13.5	17.5	17.65	19	21.5
2009	18.25	18.5	18	17.5	18.5	18	14.25	15.5	16.6	17.1	16.75	17.75
2010	19.2	20	18.9	17.7	16	14	13	14	15.5	18.5	19.75	18.6
2011	19.1	19.1	21.6	17.45	16.65	15.95	15.45	14.95	16.7	18.15	21	19.75
2012	20.5	19.8	19.35	17.55	15	14.9	14	15.2	15.8	18.15	18.7	20.05
2013	20.05	20.5	20.3	19	17.7	16.15	NA					

NA= Not available

Appendix IV: Itona estate monthly rainfall (mm)

	June	July	Aug	Sept.	Oct.	Nov.	Dec.	Jan	Feb	March	Apr.	May	**Total**
2008/9	0	0	0	0	0	95	321	181	229	228	110	27	**1191**
2009/10	0	0	0	0	0	176.7	202	322	193	244	149	55	**1341.7**
2010/11	16.5	5.5	6	0	0	22.5	118.5	252.5	161	39.5	208	41.5	**871.5**
2011/12	21	0	0	42	28	22.5	239	231	225	164	154.5	63.5	**1190**
Average	**9.4**	**1.4**	**1.5**	**10.5**	**7**	**79.2**	**220.1**	**246.6**	**202**	**169**	**155.4**	**46.8**	**1148.6**
2012/13	**5**	**4**	**1**	**0**	**10**	**130**	**309**						

Appendix V: Ngwazi Tea Research Station monthly temperature (^{0}C)

Year / Month	June	July	Aug.	Sept	Oct.	Nov.	Dec	Jan.	Feb	March	Apr.	May
2007/8	14.1	13.6	14.4	16.1	18.3	19.7	18.2	18.2	17.8	17.8	16.6	15
2008/9	13.2	13.3	14.9	16.2	18.3	20.7	18.2	17.7	17.7	17.9	17.1	15.9
2009/10	15	13.3	15	15.8	18.4	18.1	18.8	18	19.6	18.7	17.7	16.9
2010/11	14.3	13.4	14.5	14.6	17.8	18.9	18.4	18.5	18.4	18.1	17.3	16.4
2011/12	15.44	14.31	14.95	15.81	18.3	19.1	18.21	18.22	17.79	17.7	16.97	15.8
2007/8-2011/12 average	**14.41**	**13.58**	**14.75**	**15.7**	**18.22**	**19.3**	**18.362**	**18.12**	**18.258**	**18.04**	**17.13**	**16**
2012/13	**14.81**	**13.5**	**14.67**	**16.17**	**17.96**	**18.7**	**18.75**	**18.93**	**18.64**	**18.57**	**17.41**	**16.1**

Appendix VI: Ngwazi Tea Research station monthly rainfall (mm)

Year / months	June	July	Aug.	Sept	Oct.	Nov.	Dec	Jan.	Feb	Mar.	Apr.	May	Total
2007/8	0	0.7	8.9	21.8	1.1	3.9	164.6	237.2	235.5	281.1	56.9	0.5	**1012.2**
2008/9	0	0	0.1	0	0.1	43	336.8	263.6	195.7	193.6	114.5	3.8	**1151.2**
2009/10	0	0	0	0	0	228.6	149.6	368.6	249.2	282.2	28.2	15.4	**1321.8**
2010/11	1	1.3	0	0	0	22	85	200.8	196.2	108.9	131.3	3.7	**750.2**
2011/12	0	0	0	3	0	30.4	0	84.4	260.4	145.7	65.6	6.6	**596.1**
Average	**0.2**	**0.4**	**1.8**	**4.96**	**0.24**	**65.58**	**147.2**	**230.9**	**227.4**	**202.3**	**79.3**	**6**	**966.3**
2012/2013	**0.2**	**0**	**0**	**0**	**17**	**23.9**	**157.7**	**294.2**	**179.7**	**146.3**	**87.7**	**12.2**	**918.9**

Appendix VII: Marikitanda monthly air temperature (^{o}C)

	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	Apr.	May
2007/08	18.9	18.3	18.3	19.3	19.8	24.1	21.8	23	21.6	22.2	21	19.6
2008/09	18	17.8	18.5	18.5	20.4	21.9	22.2	22.9	23.2	22.9	21.5	20.3
2009/10	19.4	18	18.3	18.9	20.3	21.5	22	22	23	23.5	22.2	21
2010/11	19.5	18.5	18.3	18.4	20.3	21.7	25.1	22.2	22.6	22.2	21.6	20.2
2011/12	19.2	18.6	18.3	19.2	20	21	22	22.2	22.5	22.7	18.7	20.2
Average	**19.0**	**18.2**	**18.3**	**18.9**	**20.1**	**21.8**	**22.5**	**22.4**	**18.8**	**18.9**	**21.1**	**20.2**
2012/13	**18.8**	**18.1**	**18.1**	**18.9**	**19.8**	**20.8**	**21.7**	**22.2**	**-**	**-**	**21.5**	**20**

Appendix VIII: Marikitanda monthly rainfall (mm)

	June	July	Aug	Sept	Oct	Nov.	Dec	Jan	Feb	March	Apr	May	Total
2007/08	179.1	34	280	36.1	163.5	59.8	67.6	44.5	119	247.5	481	185.4	**1898**
2008/09	162.3	68	44.3	46.8	47.7	105.2	25.8	4.5	103	51	462	85	**1205**
2009/10	111.4	51	76	5.2	326.9	72.3	225	170	0	210.1	435	280.1	**1963**
2010/11	64.3	27	21.3	66.7	10.3	179.4	56.5	112	20.1	823.2	342	304.2	**2027**
2011/12	70.7	25	55.7	202	355.9	151.6	113	0	49.5	56.4	120	332.8	**1533**
2007/08-2012/13 average	**107.7**	**36**	**98.7**	**68.8**	**165.8**	**132**	**101**	**57**	**50.6**	**272.63**	**338**	**249.6**	**1678**
2012/2013	**58.5**	**14**	**114**	**55.5**	**90.6**	**223.6**	**117**	**11.6**	**12.7**	**247.6**	**189**	**310.2**	**1446**

Appendix XI: ANOVA Tables

ANOVA Table for Marikitanda Tea Research Institute Station shoot weight

Source of variation (sv)	Degree of freedom (df)	Sums of squares (ss)	Mean of sums of squares (ms)	F value	Pr >F
Blocks	2	0.00889622	0.00444811	0.0541	0.7273
Harvesting methods (HM)	1	0.12960000	0.1290000	1.57*	0.0056
Main plot error	2	0.16435156	0.08217578		
Fertilizer rates (N)	5	0.02240000	0.004480000	0.6469	0.8922
HM * N	5	0.00330000	0.00066000	0.095	0.9984
Sub plots error	20	0.13849622	0.006924811		
Total corrected		0.46704400			

LSD HM $_{(P=0.05)}$ = 0.0.08 and N= 0.14, %CV = 19.83, Whole error = 0.30284778
Key: * significant difference

ANOVA Table for Ngwazi Tea Research Institute Station shoot weight

Source of variation (sv)	Degree of freedom (df)	Sums of squares (ss)	Mean of sums of squares (ms)	F value	Pr >F
Blocks	2	0.00142735	0.00071368	0.006	0.9460
Harvesting methods (HM)	1	0.05522500	0.05522500	0.48*	0.0499
Main plots error	2	0.22554381	0.112771905		
Fertilizer rates (N)	5	0.02472500	0.00494500	1.75	0.8533
HM * N	5	0.01392500	0.00278500	0.983	0.9514
Sub plot error	20	0.05665235	0.0028326175		
Total corrected	35	0.37749851			

LSD $_{(P=0.05)}$ HM = 0.0783 and N = 0.1356, % CV = 21.82, Whole error = 0.28219616

Key: * significant difference

ANOVA for Marikitanda Tea Research Station experiment yield

Source of variation (sv)	Degree of freedom (df)	Sums of squares (ss)	Mean of sums of squares (ms)	Fvalue	Pr >F
Blocks	2	116548.959	58274.479	0.081	0.5367
Harvesting methods (HM)	1	441334.305	441334.305	0.611*	0.0384
Main plots error	2	1444338.256	722169.128		
Fertilizer rates (N)	5	2457821.873	491564.375	17.62*	0.0022
HM * N	5	4225091.664	45018.333	1.614	0.7768
Sub-plots error	20	557883.30	27894.165		
Total corrected total	35	5243018.301	149800.523		

Key: * significant
LSD($_{p=0.05}$) HM = 209 and N = 361, % CV = 13.38. The whole error =2002221.50

ANOVA for Ngwazi Tea Research Station experiment yield

Source of variation (sv)	Degree of freedom (df)	Sums of squares (ss)	Mean of sums of squares (ms)	Fvalue	Pr >F
Blocks	2	233750.4808	116875.404	14.860**	0.0247
Harvesting methods (HM)	1	334608.2588	334608.2588	42.540**	0.0018
Main plots error	2	15730.0374	7865.0187		
Fertilizer rates (N)	5	86513.4136	17302.6827	0.609	0.6633
HM * N	5	72370.6593	14474.1319	0.509	0.7402
Sub plots error	20	568358.7401	28417.937		
Total corrected	35	1311331.590			

Key: ** Significant

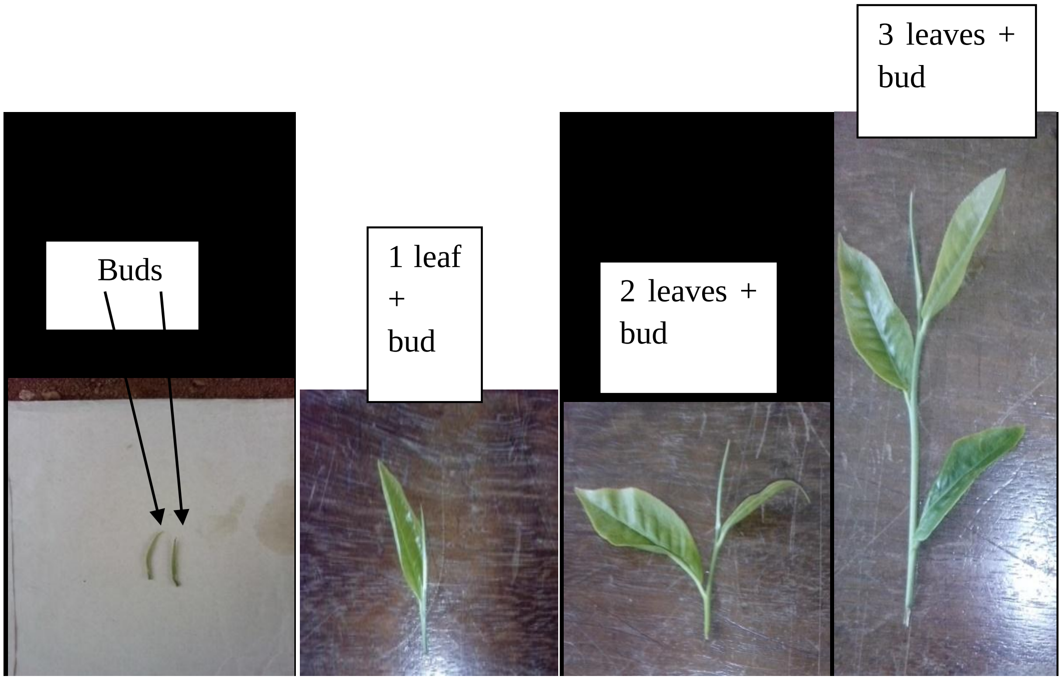
LSD ($_{p=0.05}$) HM = 113 and N= 195, %CV = 26.65. The whole error =584088.77

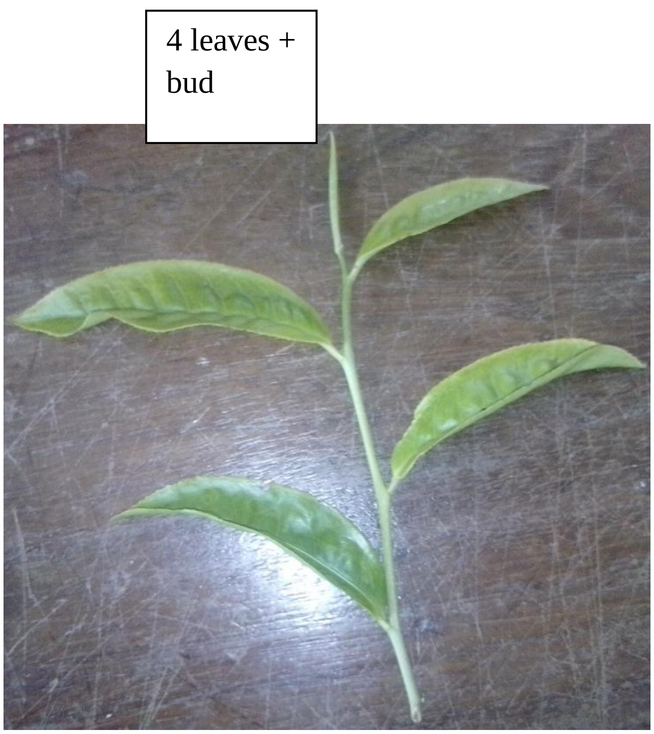
Appendix XII: Tea harvesting machines

The machine was being used by Unilever. Its use has been abandoned because it causes soil compaction

(*Source*: Author, 2013)

Appendix XIII: Shoot/leaf types





(*Source*: Author, 2013)

Appendix XIII: cont' shoot/leaf types

(*Source*: Author, 2013)