UNIVERSITY OF NAIROBI

ECOHYDROLOGIC EFFECTS OF SHADE TREES SPACING ON SOIL CHARACTERISTICS AFFECTING TEA YIELDS AND QUALITY: A CASE STUDY OF MONIERE ESTATE IN KIPKEBE OF SOTIK SUB-COUNTY

BY

DENNIS MAKORI BARAKA NYANGOTO

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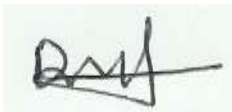
JULY, 2023

DECLARATION

This thesis is my original work and it has not been submitted for examination to other institution or university.



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NYANGOTO, DENNIS MAKORI BARAKA — Date

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This thesis has been submitted with our approval as university supervisors for examination.

Date 19/06/2023

PROF GEORGE O. KRHODA

THE DEPARTMENT OF GEOGRAPHY, POPULATION AND ENVIRONMENTAL STUDIES UNIVERSITY OF NAIROBI

Date: 19/06/2023

DR. ISAIAH A. NYANDEGA

THE DEPARTMENT OF GEOGRAPHY, POPULATION AND ENVIRONMENTAL STUDIES, UNIVERSITY OF NAIROBI

DEDICATION

To my father, mother and siblings for their motivation and help that they gave me, which made it possible for me to do all it takes to finish this work. My love for you is unmeasurable and I forever greatly appreciate and cherish you. May God in a special way bless and keep you.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	-	Analysis of variance
CED	-	Crop environment
EGC	-	Epicatechin Gallate
EGCG	-	Epigallocatechin Gallate
GC	-	Gallocatechin
KTDA	-	Kenya tea development authority
LSD	-	Least Significant Difference
MOA	-	Ministry of Agriculture
PCA	-	Principal component analysis
RCBD	-	Randomized complete block design
SEMC	-	Sustainable ecosystem, management and conservation.
SOM	-	Soil organic matter
TFs	-	Theaflavins
TPC	-	Total Polyphenol Content
TPVA	-	Tea processing and value addition
TRFK	-	Tea research foundation of Kenya
TRI	-	Tea Research Institute
TRIEA	-	Tea research institute of East Africa
TRs	-	Thearubigins

ABSTRACT

Shades are used to modify the micro-climatic and environmental conditions which in turn affect soil hydrologic attributes such as moisture content, hydraulic conductivity, porosity and the rate infiltration that determine growth and development of tea. They are also a key source of organic matter which affects soil stability and health that determines all the other soil hydrological properties. Their use and subsequent effects on soil hydrologic properties and resultant impacts on tea yield and quality in tea farms are wide spread in Kenya. The study addressed the issue of deterioration of soil hydrologic characteristics due to soil pollution and unsustainable agricultural practices that causes soil compaction, loss of pore space and structure which negatively impacts tea yield and quality in tea farms. The main focus of the study was to identify and characterize shade spacing ecohydrologic effects on soil properties and their resultant effects on tea production. Using an experimental physical model, the ecohydrologic effects of shade trees on soil hydrological characteristics affecting tea production were investigated using data on soil moisture content, hydraulic conductivity, soil porosity tea yield and tea quality collected from nine experimental fields with three varying shade tree spacing of 6m by 6m, 8m by 8m and the control. The soil hydrologic properties were derived from three soil samples of 0-20cm, 20-40 cm and 40-60cm depths respectively from each experimental field at each shade tree spacing characteristic. Tea yield and tea quality were derived from tea leaves harvest associated with each shade tree spacing characteristic. The study employed random sampling technique of grid each marked with random numbers to ensure consistency in sample collection of soil and tea leaves samples. The soil hydrologic properties of the samples soils were determined both in the field for soil infiltration using infiltrometer gadgets and in the soil laboratory determining soil porosity by water absorption method, hydraulic conductivity by constant head method and moisture content by gravimetric method. Tea yields and tea quality were also determined in the laboratory using the ISO Procedure for total polyphenol content, thearubigins by Roberts and Smith method and Flavognost method for theaflavins. To associate and measure differences between shade trees spacing, soil hydrologic characteristics, tea yield and tea quality statistical techniques of Pearson's correlation, ANOVA and PCA were used in which significance tests in all cases were at α 0.05. Results obtained showed that the soil hydrological characteristics were affected or varied significantly ($P \leq 0.05$) with shade trees spacing while all their interaction with depth and seasons were insignificant except hydraulic conductivity that varied significantly ($P \leq 0.01$) in relation to seasons. Tea yield and tea quality were insignificant at ($P \leq 0.05$) alongside all other interactions in relation to shade trees spacing. The correlation between soil infiltration rate and porosity, hydraulic conductivity and the total polyphenol content were significant ($P \leq 0.05$) while all the others were insignificant. This study found that both the 6m by 6m and 8m by 8m shade trees spacing showed similar results hence they can be used in tea farms in similar hydro-meteorological areas in Kenya for high production of tea and environmental conservation.

CHAPTER ONE

INTRODUCTION

1.1 Study Background

Shade trees are critical component in the hydrologic cycle since the roles of plant-water interactions are of major interest in ecohydrology (Asbjornsen *et al*., 2011) . Availability of water determine the structure, distribution and composition of plant communities directly due to the fact that it is critical for plant life (Caylor *et al.*, 2009). This is because they modify the climatic and environmental conditions that affect the growth of tea hence impacting the tea yields and quality(Mohotti *et al*., 2020) and they affect plant water-interactions in tea farms by their ecohydrologic effects on soil characteristics such as porosity ,hydraulic conductivity, infiltration rate and soil moisture content because of the organic matter that they produce and the interactions between their roots and the soil (Yang *et al*., 2020).

Shade trees are trees, which are used for providing shade over the tea plantation. They are also referred to as tree shade (Albertin & Nair, 2004).They are very important because they provide the best growing environmental conditions mostly to crops that forest understory origin as a result of their spreading canopy and crown. In addition, they are also a source of wood energy for curing tea leaves in tea manufacturing industries (Li, 2004) . Throughout the tea growing areas in the world, shade trees have become a major component in agroforestry in farms (Bosselmann *et al*., 2009). Among the research problems in tea production that have been well investigated shade is possibly one of them. It attracted the attention of tea scientists worldwide, particularly since the Second World War; its role in tea growing was intensively debated in east Africa (child, 1961), Sri Lanka (Joachim, 1961; Visser 1961 a; b), South India and Tockli (Hadfield, 1974a; b). Varied findings from assessments that were done in different tea growing areas made the problem to gain more importance and urgency. Despite the controversies, it is quite clear that agroforestry is key in the management of tea ecosystems and improving ecohydrology of the soil, hence shade trees are very important for optimum tea farming. Highlands varying in altitude from 970m to 2700m a.s.l. are ideal for tea farming and it is managed as a low bush. Beneficial yield responses due to shelter have been reported in tea during the cool, dry weather after the rainy season (Carr, 1985) wind speed plays a major role in evaporation stress, carbon dioxide and soil moisture depletion and in cold air drainage and mixing. Shade reduces the average wind speed and near the surface since the horizontal air movements is reduced by friction with surface in contact (Mwakha, 1983). According to Ng'etich, 1990 it was established that shelter belts of *cassia siamea* (cassod tree) were effective in controlling soil erosion by wind while (silky oak) shade had the highest hydraulic conductivity (Ks) (Ng'etich et. al 2006 (a)). Ng'etich *et al*., (2006) found that higher hydraulic conductivity (Ks) values at *G. robusta* (silky oak) than artificial or no shade are attributed to double benefit of tea and shade trees.

Shade trees contribute many environmental effects to tea plants: Reduction of sunlight (Barua, 1961) and McCulloh et al., 1965), lowering of air and leaf temperatures, influence of soil moisture (Visser, 1961a) and temperature (Anon.1962), turnover of nutrients from lower soil layers by shade trees thus adding organic matter as leaf fall and addition of nitrogen by leguminous shade (Visser, 1961b). However, *Grevellia robusta* (silky oak) shades have been found (Othieno, 1983) to reduce the uptake of nutrients. Shade trees also offer protection to the tea plants against hail stone impacts on leaves and tender branches of tea bushes (Hafield, 1974 b). They act as wind shelterbelts in strong wind-prone tea areas, thus reducing the rate of transpiration of tea plants especially during the dry weather (Callander *et al*., 1981, Gee *et al*., 1982 and Squire 1978). Shade trees also create an environment which affects pests and diseases (De Weille, 1959a, Eden, 1977 and Mkwalla 1982).

Visser in 1961b reported that *Gricidia Maculata* and *Erythrina lithosperma* (coral tree). Shade trees conserved moisture during the beginning of drought, but adversely affected it when the drought was of prolonged duration. Soil moisture determinations in un-shaded tea and tea shaded by *Grevillia robusta* (silky oak), *Gricidia maculate* and *Albizzia gummifera* (peacock flower) indicated presence of minimal variations of amount of moisture in the first 0.3 meters of soil depth (Visser, 1961a). Below 1.5 meters the moisture available under *G. robusta* (silky oak) and *G. maculate* was was low compared to A. *gummifera* (peacock flower)   and even much lower than when no shade was present.

In North-east of India, east of Pakistan and some tea growing areas in Kenya like Nandi and Kericho crop loss majorly result from the damage caused by hail (Handerson, 1966 and Mwakha 1983) to tea as well as soil erosion (Othieno, 1975). In these areas the cultural practice of using appropriate shade trees on tea could be means of reducing these crop losses.

Excavation and root-washing of *Grevellia robusta* (silky oak) trees and tea bushes showed that shade species are rooted to depths of 3.7 meters to 6.1 meters. Under these conditions of soil and climate the tea-root system seemed to be able to exploit soil more effectively than the roots of shade trees (Kerfoot, 1962 and McCulloh *et al*., 1964). Soil moisture profiles to 3.05 meters depth in the dry season confirmed this observation- an increase in number of tea bush per acre having a much greater soil drying effect than presence of *Grevellia robusta* (silky oak) shade trees (McCulloh *et al*., 1964). It was therefore important to set up an experiment and make a study to examine the ecohydrological impacts of different shade spacing on soil characteristics that affect tea cultivation.

1.2 Problem Statement

The main focus of the study was on addressing shade trees spacing effects on soil hydrologic properties that impact tea yields and quality that have been damaged by poor agricultural methods, soil pollution, and use of machinery that cause soil degradation, soil moisture deficit, and loss of porosity, stability and organic matter due to compaction. Soil hydraulic conductivity, moisture content, porosity and infiltration rate are important soil factors influencing tea production but they have not received enough emphasis in research as required. Little knowledge exists on use of shade trees, their spacing in tea farms and their ecohydrologic effects on soil hydraulic conductivity, moisture content, porosity and infiltration rate and their impacts in tea production. The study addressed the role that is played by the above soil characteristics on the amount and concentration of Total polyphenol content, thearubigins, theaflavins and yield of tea produced in tea farms and the relationship between the shade trees spacing, soil characteristics and tea production. Shade trees affect soil hydraulic conductivity, moisture content, porosity and infiltration rate through the decomposition of fallen leaves that add organic matter which affects various soil characteristics and processes. These includes; soil water retention since SOM as a water absorbing agent enhances water availability, acceptance, porosity, hydraulic conductivity infiltration and percolation. The deterioration of soil hydraulic conductivity, moisture content, and porosity and infiltration rate has continuously occurred due to over cultivation, soil pollution by excessive use of fertilizers and oil spills from farm machinery and poor agricultural methods and technologies used in tea farm and this has negatively affected the tea environment. This is due to the fact that they cause structural degradation i.e., loss of porosity or pore space continuity that has leads to formation of hard crust resulting in decreased infiltration rate, increased run off and often increased soil erosion. It has also led to formation of a pan by general compaction that has resulted in decreased water storage; a lower availability of water stored and decreased ability of water to move. The combination of all the above factors have greatly affected tea yields and tea quality in farms. Today, the management of hydrologic soil properties has become a major challenge in in tea farms. This has led to low yields in farms because the type of crops grown for example tea are very specific to soil hydrologic characteristics that favors their growth and productivity. Shade trees with different spacing have been used as one of the agroforestry technique for the management of soil properties because of their ecohydrologic effects in tea farms. They impact the tea production as a result of their ecohydrologic effects on soil characteristics caused by their different spacing in farms.

In spite of the high annual expenditure in the establishment and management of shade trees because of their ecohydrologic effects by the tea industry, at present there is no valid scientific basis on the ideal shade tree spacing in farms for advice to tea farmers in Kenya. Although some research on shade trees has been done, there exists a knowledge gap on shade trees spacing and their ecohydrologic effects on soil characteristics affecting tea yields and quality. Investigations on these aspects provided answers on how shade trees should be spaced to maximize on their ecohydrologic effects and hence result in optimum tea farming. It was with this in mind that a decision was made to investigate the ecohydrological effects of shade tree spacing on soil characteristics affecting the growth and development of tea.

1.3 Research Questions

In this study the key questions addressed were as follows:

i. How does shade trees spacing affect soil hydrologic characteristics (water movement (infiltration), water content, pore space and hydraulic conductivity
ii. How does shade trees spacing affect the quality and yield of tea produced in tea farms.
iii. What is the relationship between shade trees spacing, soil hydrologic characteristics and tea produced

1.4 Study Objectives

1.4.1 General objective

To determine ecohydrologic effects of shade trees spacing on soil characteristics, affecting tea yields and quality.

1.4.2 Specific objectives

To establish:

i. Effects of shade trees spacing on soil hydrologic characteristics (water movement (infiltration), water content, pore space and hydraulic conductivity)
ii. Effects of shade trees spacing on tea yield and quality
iii. The co-relationship between shade tree spacing, soil hydrologic characteristics and tea production.

1.5 Hypotheses

i. Shade tree spacing has no significant effects on soil hydrologic characteristics (water movement (infiltration), water content, pore space and hydraulic conductivity)
ii. Shade trees spacing has no significant effect on the quality and yield of the tea produced.
iii. There is no significant relationship between shade trees spacing, soil characteristics, tea yield and quality

1.6 Justification of the Study

Shades in tea have been one of the most controversial subjects and also an extensively investigated cultural practice in tea cultivation because of their ability to modify the micro-climatic and environmental conditions that results from their ecohydrologic effects. There is no much investigations done about ecohydrologic impacts of shade spacing on soil characteristics affecting tea yields and quality. Research on the management of soil hydrological properties by use of shade trees and their different spacing has not been given the seriousness it deserves and farmers have paid a high price of low yields because of this. For successful use and gain of optimum benefits of shades in tea farms the importance of practically oriented research on ecohydrologic effects of shade trees spacing on soil characteristics affecting tea yields and quality cannot be overemphasized.

This study was very important due to the fact that it lead to the identification of the best shade trees spacing that provided ideal ecohydrologic effects on soil characteristics that affects tea yield and quality in tea farms. Moreover, from the study outcomes the role of soil hydrologic characteristics on tea yield and quality was shown clearly. The study found out the relationship between shade tree spacing soil hydrologic characteristics and tea yield and quality. The study was critical because the results from this work offered valuable information for policy formulation and implementation on the use shade trees and their ideal spacing as a biological and environmentally friendly alternative to improve the hydrological soil properties for farmers, government, non-governmental organization, scientists and the various shareholders in tea sector for policy formulation, knowledge and sustainable tea production. Moreover it helped in gathering knowledge, informing action, gathering evidence for theories and aided in knowledge development and better mastery of the ecohydrological impacts of shades spacing on soil characteristics affecting tea yields and quality in tea farms.

1.7 Scope and Limitations of the Study

The main focus of the study centered on evaluating the ecohydrologic effects of different shade tree spacing on soil hydrologic characteristics affecting tea yields and quality. It tackled soil hydrologic characteristics which included; moisture content, hydraulic conductivity, porosity and infiltration rate because they are major ones that affect subsurface water movement through infiltration and percolation and surface flow of water through evaporation and surface run off hence impacting the hydrological cycle processes and tea production since soil-water relationships is a major component in ecohydrology. *Thearubigins*, total polyphenol content and theaflavins tea quality parameters were analysed because they are the most dominant in black tea which is consumed in Kenya while the other tea quality parameters are almost trace. Moreover since climatic season was a factor of analysis data for both cool and wet and hot and dry seasons was collected.

Data collection was done in all the nine plots that were under the experiment. Soil sampling for analysis of hydrological characteristics and leaf sampling for tea quality analysis were done on the same day for uniformity and consistency. Tea for yield determination was collected on an interval of 7-10 days as per the schedule of the estate. Soils that were sampled encompassed three depths that included; 0-20, 20-40 and 40-60 Centimeters because as you move down into the earth surface the soil profile changes and maximum tea root depth is approximately 60cm. The study was only limited to one clone of tea which was BB35 because it is the one that is mostly grown in area. Two types of shade trees spacing that is 6m by 6m and 8m by 8m were the only ones taken into consideration because they are the two major shade trees spacing used in tea farms in Kenya. *Militia dura* trees were used as shade trees in the experiment because it is one of the major shade trees used in Kenya and that does well in the region.

1.8 Operational Definitions

Ecohydrologic effect	:	Impacts of shade on soil water content, porosity, hydraulic conductivity, and infiltration rate.
Hydraulic conductivity	:	The ease of water movement across pore spaces or fractures in the soil
Infiltration capacity	:	The highest amount of infiltration that is measured in meters per day or distance over time if necessary.
Rate of infiltration	:	Speed of water entering into the soil (cm/min)
Moisture content	:	Water available in the soil pore spaces.
Pore space	:	The size of empty space in soil.
Shade tree spacing	:	Distance in meters between two shade trees.
Shade tree	:	A tree used for providing shade to the tea plant.
Soil characteristics	:	Properties of the soil which include porosity, hydraulic conductivity, moisture content and infiltration rate.
Tea quality	:	The generalization of all the desirable attributes of tea including both external and internal characteristics
Tea weight	:	The measurement obtained from a weighing scale when an object is placed on it (gram or kilogram)
Tea yield	:	The amount of tea harvested per month in kilograms from each plot.
Temperature	:	Kinetic energy in a given mass of air measured using a thermometer daily in the study area.
Texture	:	The physical feel and ingredients of the soil that is the composition of particles in relation to sizes which can be sand, clay and loam.

Theaflavins	:	a chemical found in black tea that formed from fermentation of green tea that is responsible for the bright and red colour in black tea.
Thearubigins	:	polymeric catechins that are formed during oxidation of tea Leaves.

CHAPTER TWO

LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

2.1 Introduction

It was done extensively to have a clear mastery about the research problem in connection the past and current studies that have been done and to establish the research gaps. Current issues on shade trees, soil characteristics, tea yield and quality that necessitated and justified this study were identified. It aided in understanding the theories that were applied in the study.

The review aided in formulation of the conceptual frame work that encompassed all the parameters in the study of the research problem that enabled data collection. The methodologies for conducting the study and the likely outcomes were also identified. The review done was on shade trees in tea production, their origin, types, establishment and management, species and their roles in tea farms. It entailed soil hydrologic characteristics and their importance, the relationship between shade trees and soil hydrologic characteristics and the ecology of tea. It also consisted of tea soils, their classification and properties, their effect on the yield and quality of tea, shade effects on soil hydrologic characteristics, tea yield and quality.

2.2 The Review

2.2.1 Shade Trees in Tea Production Farms

A thorough review done on past studies has shown a remarkable lack of direct investigations on ecohydrological effects of shade trees spacing on soil characteristics affecting tea yields and quality in tea farms. According to Pender *et.al* (1999) presently there is no valid scientific basis for advice to East African tea planters as to whether or not they should plant shade trees and if they are planted how, they should be spaced and pruned. Mithamo (2013) found that it is not even known if the main objective of using shade trees is to reduce light intensity over tea (i.e., shade), to modify the speed, temperature and humidity in the air (i.e., shelter) or to provide nutrients gathered from sub-soil (i.e., leaf fall).

Grevellia robusta have been found to offer protection from the excessive solar radiation despite the fact that impacts of shade trees on water use by plants is not clear (Kerfoot, 1962; Barua and Dutta, 1961, Hadfield, 1968; McCulloh *et al*., 1965). It has been thought that since

Grevellia robusta send their roots deeper down the soil profile than tea (Kerfoot, 1962) there would be no moisture competition between them.

Shade trees contribute many beneficial effects of which the main ones are; reduction of sunlight, reduction of leaf and soil temperature, addition of organic matter as droppings of leaf stem and pod, fixation of nitrogen by the leguminous tree roots, soil moisture preservation in dry season, nutrients turnover from lower soil layers by the deep roots of the shade trees and breaking the effects of rain-drops on the soil (Silva Neto *et al.*, 2018).

Shade trees use in tea farming has become a major practice in Africa, Indonesia and north-Eastern India while in north-eastern India the trees used are not only leguminous family but also non-legumes such as: *Gravellea robusta, Cupressus benthamii*, and *Eucalyptus globullus* (Barua, 1970).

2.2.2 Origin of Shade Trees

These are trees that are used to give shade to the main crop in tea farms (Chetana & Ganesh, 2012). It is at the understorey of the forest that indigenous Assam tea was discovered (Misra *et al*., 2009). This led to the making of an assumption that tea is grown under a shade environment. This resulted to the maintenance of a partial shade condition in most tea plantations. Excessive radiation or heat and efficient conservation of soil moisture is done by shade canopy (Ripley, 1967). Deep rooted shade trees species are loped acropetally in drought prone areas from lower branches to protect the tea bushes below. There is a great competition for moisture between shallow rooted species and tea during dry seasons, hence to ensure single leaf canopy they are loped at frequent intervals (Misra *et al*., 2009). For maintenance of proper light quality that ensures better photosynthesis there should be a balance between temporary and permanent shade trees.

In north-Eastern India, the expansion of plantations resulted from deforestation. Later it was found that under a few *Albizzia chinensis* trees left over during the clearing of forests the large lived Assam variety of tea appeared to thrive better (Wight, 1959). Other tea growing countries and regions were spread with the shade trees culture of N.E India. The use of shade also started in south India, Indonesia and Sri-Lanka (Mouli, 2004). When countries in Africa started tea cultivation, they continued with the practice of old tea growing countries especially in the warmer belts and started planting shade trees (De Costa *et al*., 2007). For provision of shady environment thought as natural habitat of tea plant, shade trees were inter-planted with tea (Gogoi, 1976 and Wood *et al*., 1958). This resulted in shade trees being grown on large scale in tea plantations. In the years that followed, tea planters accepted that good tea cultural management was associated with good stand of shade trees in tea (Saini *et al*., 2003).

2.2.3 Types of Shade Trees

Shade trees are classified into two major classes; temporary and permanent shade trees (Haggar *et al*., 2011). Permanent shade takes longer time because they are planted for a longer rotation. Planting of temporary shade with permanent shades offer young tea protection from direct sunlight (Hanum & Maesen, 1997). Temporary shade are removed after 5/6 years after permanent shades have been fully established (Sana, 1989).

2.2.4 Planting Establishment and Management of Shade Trees

Assam tea variety thrived better beneath *Albizza chinensis* in 1840's (Jain & Tamang, 1987). forest conditions that are tea plant natural habitat are created by shades. Sun scorches in the absence of shade trees (Ayalew, 2018). Shade removal led to a series of disastrous consequences and therefore it was reintroduced(Hodgson, 2005). Temperature, light heterogeneity, water and soil nutrients in space and time affect the growth, development and influence pests and diseases in tea grown in an open system (Zhang, 2018).

When finding Shade Trees whose climate and soil requirements match conditions at the planting site, the most important factors to consider are climate and soil characteristics (Sjöman *et al*., 2017). The adaptability, availability of planting materials and the intended use, determine shade species for planting in a given area. Species selection, whether from indigenous or exotic sources, involves matches species' climatic and soil requirements to the conditions at the plating site (Di Sacco *et al*., 2021). The major climatic conditions to consider are the distribution and amount of rainfall and extremes of temperature received in an area. Principle soil properties include depth, texture, fertility and pH.

The establishment of shade trees should be done early during planting of rehabilitation of grass. This will ensure there is adequate shade when young tea is planted out in the field. In order to facilitate easy movement of labour during various cultural operations in tea farms, they should be planted in rows in proposed tea farms.

Moreover, in order to allow light and prevent smothering by grass the grass surrounding patch shade trees should be trimmed down. In mature tea, where there are no shade, they should be planted after pruning tea (Mukhopadhyay & Mondal, 2017). This will facilitate their easy establishment. If planted in mature tea in plucking the branches of tea bushes surrounding the shade plant should be cut to allow adequate light. In addition, the shade plants should be protected by putting up fence round each plant by putting covering with empty fertilizer bags. Both a mixture of medium and high shade should be planted (Hodgson, 2005).

2.3 Shade Tree Species and roles of shade trees in Tea Farms

Saramathe (1986 d) sets down trees species that can be used in various zonal altitudes e.g., *Albizzia odotatissim, Grevellia robusta, Dalbergia assamica* and *Erythrina indica*. He also suggests that before planting tea shade trees planting should be done well first. After the plantation of tea, shade establishment becomes difficult (Bai *et al*., 2017). In N.E India, the trees used were not confined to leguminous family, a non-leguminous like *Grevellia robusta* were successfully used (Obaga, 1984).

Shade trees provide physical shade, improve and sustain soil fertility, influence the incidences of pests and diseases in tea plant and they provide physical shade(Mohotti *et al*., 2020) . Shades conserve soil water in the soil when they are well managed. (Venkataramiani, 1961). They affect moisture, nutrient content, and biology of the soil, l temperature and partition growth of leaves (Almeida & Valle, 2007).Their litter add nutrients content to the soil(Dutta, 1960).Shade trees improve soil fertility by enhancing the microbial and earthworm activities(P Udawatta *et al*., 2019).

2.4 Soil hydrologic characteristics and their importance

2.4.1 Texture

Size categories are influenced by the particle make-up of the soil. The particle sizes have a great variability which consist of course and finer particles (Harler, 1964). Texture indicates the relative content of fine earth particles. Textural classes categorise different combinations of sand, silt and clay (Schaetzl & Thompson, 2015). Texture is the major factor of physical and chemical soil behaviour (Faloye *et al.*, 2021). It determines the hydrologic characteristics of soil, used in its classification and it is important for engineering and agronomic interpretation.

Moreover it affects soil drainage, moisture holding capacity, aeration, erosion susceptibility and ion exchange (Mann and Gokhale, 1960).

2.4.2 Structure

This is the grouping or arrangement of individual particles of the soil into aggregates with easily distinguishable shapes. It shows the way individual particles of sand, silt and clay are assembled. Structure reduces runoff and erosion by increasing infiltration hence increasing the amount availability of water for plants improving seedling emergence, root growth and rooting depth which increases permeability due to large continuous pore presence (Townsend, 1973).

2.4.3 Hydraulic Conductivity

This is the capability of the soil to transfer or to transmit water. It is the main regulator of soil water system response to imposed boundary conditions (Waarick and Amoozegar, 1986). Despite the fact that it is constant under saturated conditions in the field at any given time, it is a spatially variable characteristic. In addition, it is a pointer variable to all aspects of water and solute movement.

2.4.4 Water Retention

This is the association of soil water content and suction that determines hydraulic features of soil characterization. This correlation can be termed as moisture characteristic, water retention function and capillary pressure-saturation curve. Particle size distribution and the structure or arrangement of soil particles are the major determinants of water retention function of the soil (Salter and Williams, 1965).

2.4.5 Bulk Density

It is the quotient of mass and volume dry soil. It comprises of solid and pore space volume. It is a variable quantity for a given soil due to its structural conditions specially the ones associated with packing (Blake and Hartge, 1986). Bulk density of higher than $1.6 g/cm^3$ restricts root development, water and air movement in soil resulting to a decrease in tea yields (Ng'etich *et al*., 2002). Poor bulk density in tea farms has been brought about by mechanical harvesting of tea and human traffic in tea farms (Matano *et al*., 2015).

2.4.6 Moisture Content

Refers to the fraction of mass of water present in a sample of soil to sample mass after drying to a constant weight. In every type of soil study measurement of water content is key. It is usable in any work involving soil whether dimensionless, or ratio of two masses, two volumes or is given as mass per unit volume (Gardener, 1970).

2.4.7 Soil porosity

This is the amount of space in the middle of particles. It is usually expressed as a percentage of the total volume of the soil. Despite of the fact that there are direct negative effects of agricultural related activities on porosity, use good agronomic practices improves soil pore space and enhance high productivity (Morgan, 2005). Soil infiltration and soil moisture capacities are adversely affected by reduction in soil porosity and this may lead to soil erosion (Amir *et al*., 2010). Soil fertility extreme cases resulting from soil erosion is a big threat to tea industry because it causes the destruction and perishing of crops. (Nge'tich *et al*, 1999).Nutrients, minerals and water absorption by the plants is controlled by soil porosity. It is also a key factor when considering the soil structure quality (Lal & Shukla, 2004). Understanding soil retention, soil water movement and especially evaluating the effects of various agricultural activities in a particular soil is majorly enhanced by the characterization of soil porosity (Pagliali and vignozzi, 2006). Additionally it gives basis for establishing soil compaction related problems. It is affected negatively in tea industry by the mechanical harvester (Ng'etich *et al*., 2002).

2.5 Shade trees spacing and soil hydrologic characteristics

During the establishment and management of shade, spacing is a major factor because it affects micro-climatic and environmental conditions of soil and tea. Spacing to be used varies with place, aspect of the slope, Phenology of the plant, rooting characteristics, competitions with the tea crops etc (Schroth *et al*., 2001). Following are some suggested spacing of shade trees applicable for Bangladesh condition (Mohammed, 2003)

a. Temporary shade: 2 X 2 metres initially, thinned out to 4 X 4 metres later on.
b. Permanent shade: (based on shade given by mature *A. chinensis*). Light shade: 15.24 m x 15.24 m triangular or 13.7 meter by 13.7 meter square or wider.
c. Medium shade: 13.7 m x 13.7 m triangular or 12.2 m x 12.2 m square.

d. Heavy shade: 10.67 m x 10.67 m triangular or 9.14 m X 9.14 m square or closer. For teelas and steeply sloping land it is better that a shade spacing of the type described as heavy is used.
e. Efficient shade management enhances water availability and movement in the soil. Soil water depletion causes gaseous exchange and leaf water potential decrease that may lead to plant die-back or mortality, that is reliant on the drought resistance and severity ability of a plant (Borchert, 1994 and Otieno *et al*., 2006)

2.6 Ecology of Tea

2.6.1 Air Temperature

Despite the occurrence of snow falls during winter months and below freezing point fall of air temperature in northerly tea growing areas, tea is able to survive (Battle, 2017). However, below freezing point temperatures are destructive to tea particularly when accompanied with swift rise in day time temperatures for example below 13^0 C are likely to bring damage on foliage (Tea Growers Hand Book, 2002). Various tea clones showed varied response to air temperature (Carr, 2010). Maximum average temperature higher than 30^0 C are followed by low humidity making cessation of active growth inevitable (Tea growers' handbook, 2002).

2.6.2 Leaf Temperature

Photosynthesis of tea leaf increases regularly with the rise of leaf temperature up to 35^0C then decreases until it stops when it reaches 40^0C (Carr & Stephens, 1992).Leaf temperatures of about $30\text{-}32^0$ C are favorable for tea plant but in full sunshine can reach $40\text{-}45^0$ C (Tea growers' handbook, 2002).

2.6.3 Soil Temperature

Soil temperatures are of a major importance to growth and development of a plant as compared to air temperatures. They influence tea growth rate hence impacting yields. A Range of 20^0 C - 25^0 C are ideal soil temperatures (Tea growers' handbook, 2002), for soil non-woody root depths.

2.6.4 Altitude

There is a converse linear association between tea yields and the altitude of growing areas (Tea growers' handbook, 2002). Using the long-term data of average tea yields from estates positioned at altitudes between 1500m and 2250m above sea level, an equation calculated showed that the mean production of tea annually decreased by 200 Kg made tea for every hectare and an altitude increase of 100m(Tea growers' handbook, 2002). For high yield clones the decrease can be severe due to the fact that they are very sensitive to temperature changes, which are more sensitive to temperature changes. The changes in the amount of tea produced is a direct result of fall in air, leaf and soil temperatures (Tea growers' handbook, 2002).

2.6.5 Climatic Variables of Tea

Tea is grown in various climatic environments including the Mediterranean and hot humid. A According to Carr (1972) favorable conditions for tea farming are include warm days, long sunshine hours, high humidity and adequate rainfall which is consistent with the findings from the review of Laycock, 196, on the effects of climate and weather on the yield.

2.6.6 Climate Weather and Yield of Tea

Climatic and weather conditions that are experienced in an area determine the crops yield potential. (Carr *et al*., 1992). Without the limitation of nutrients, important weather parameters that influence yield are sunshine, temperature, and saturation deficit and soil water availability (Rao & Vijayakumar, 1992). This is because they are major determinants of crop growth and development.

2.7 Tea Soil Factors

During growth and development of plant species selection of soil is key. Economic damage can be caused by wrong selection of planting site for shade trees and tea. Hence, before plantation of any crop it is important to choose the required soil for better adaptation of the plant species (Champions, 1936).For economic yield to be realized in tea cultivation, the aspect of soil factors must be taken into consideration due to the fact that tea is very precise when it comes to soil (Mann, 1935). It is however grown on different soil types. This means that there are specific soil conditions that must be met in a given area to enable tea farming. Tea soils are deep well-drained and aerated clay loam to sandy loam, extremely course and gravelly soils. Moreover, they have 32-52% of clay content that contain 1.7-2.3% soil organic matter and 20.8-28.2% of water holding capacity. Optimum tea production requires; a soil PH of 4.0 to 6.0, 20.2-25.4^{o}C range of temperature, 1500-2000 mm range of annual precipitation and 80 to 90% humidity. Moreover, the availability of essential nutrients for tea growing are influenced by soil properties (Ruan *et al*., 2000) .

2.7.1 Classification of Tea Soils

Tea cultivation is done in different soil types which enhances the use of different terms and systems to classify soils in the world (Wilson and Clifford, 1992). This has made the classification of tea soils difficult. However, most soils in Kenya are volcanic (Scott, 1962 and Othieno, 1973) and are categorized as nitrous (Sombroek et.al, 1982) using the FAO-UNESCO classification system.

2.7.2 Properties of ideal Soils for tea farming

In Kenya soils that are found in Kericho, Kisii, slopes of Mt. Kenya e.t.c that are of volcanic origin and are the best for tea farming (Tea growers' handbook, 2002) and they are red, brownish or dark red well drained.

The best soils for tea cultivation are well drained and deep with 2 meters minimum depth (Mann and Gokhale, 1960). In addition both high water-table soils and shallow soils are I deal for tea growing. Economic tea yields can be realized in drained swamp soils under special soil management activities and practices because they are problematic (Kumar & Meena, 2016).

2.7.2.1 Soil Structure

Individual soil particles are arranged in clods and crumbs while the clay organic matter bonds the peds together in their natural condition (Wilson and Clifford, 1992). The soil structure and tilth in part is determined by the pore space between them (Russel, 1973). Tea soils are diverse hence they have diverse structures. However, the ideal structure of arable soil is that about 50% pore space. Active soil fauna ensures the crumb structure (Dey, 1969).

2.7.2.2 Organic Matter

Organic matter is made up of decomposed plant and animal tissues. (Rusell, 1973). It ranges from less than 1% in highly leached tropical soils to over 30% in other areas where tea cultivation is done. Well-established and maintained shade trees and tea plant generate more organic matter from leaf fall and pruning. (Othieno, 1992).

2.7.2.3 Water and Soils

Water is the major factor controlling the genetic development of soil profiles. Soil-water relationships can be such as to lead to the creation of soil or its destruction by erosion. (Townsend, 1973). These relationships are complex, influencing physical properties in terms of structure, expansion, contraction and strength of the soil. Maximum water capacity is highest quantity of water which the soil can hold when its drainage is entirely preclude and air is wholly displaced, while field capacity or the moisture holding capacity is the highest quantity of water that remains in soil when all outside factors determining drainage are removed and the soil itself is the only hindrance to free drainage. (Townsend, 1973).

2.8 Effects of Soil on Tea Yield

Soil characteristics have degraded as a result of long-term exploitation as a result of over-cultivation and this has made the maintenance of high yields difficult even with increased use external inputs. The degrading processes (Panigrahi, 1973) include;

i) Lowering of organic matter content
ii) Decrease in ion exchange
iii) Moisture holding capacity Reduction
iv) important organisms has been lost
v) Soil acidification (PH down to 3.8)
vi) Increase in the concentrations aluminum.
vii) Compaction of soil
viii) Soil erosion
ix) Leaching of nutrients in the soil.
x) Accumulation of toxins

2.9 Effects of Soil Characteristics on Tea Quality

Little scientific evidence has been found on the relationship between soil characteristics and tea quality. In China the characteristic flavours that distinguish tea of one district and another are described by the farmers to be as a result in the difference in soil properties (Lee *et al*., 2014). In Sumatra effects of tea quality are assumed to be partly caused by different mineralogical properties of the soil (Werkhoven, 1974).

2.10 Effects of Shade on Tea Yields

According to Mr. Goodchild in T.R.I annual report for 1956 and 1957, there is a positive beneficial effect on tea yield from the leaf fall from *Gravellea robusta* shade trees. Where leaves were removed, leaves fell and tea showed a response (i.e., a need for) phosphatic fertilizers. No such shortage of phosphates was found where leaf-fall had continued.

The second important clue was reported from the Tea Research Institute in Southern India at Tocklai where long-term yield records of small circular plots of tea planted around individual shade trees showed a striking relationship to the average light intensity over the plots. The maximum yield occurred when the average day light intensity as indicated by the Weston Photocell had been reduced to one-third of its value in the open. It was found that tea yields h reduced with increasing shade in Kericho at high altitude (O'shea, 1964). In shaded tea, McCullohet.al (1965) reported that yields were highest midway between the shade trees and lowest immediately beneath the trees. This suggested that light shade could be beneficial to tea. Mechanisms of this yield increase are not clear.

2.11 Effects of Shade on Tea Quality

Shade agroforestry in tea farms has been considered since the start of tea plantation in nearly all countries and is still under discussion in many areas (Werkhoven, 1974). Shade may be beneficial to tea quality since less banjhi, fewer woody stems will occur in the plucked material and teas will be blacker due to more chlorophyll. On the other hand, shade frequently affects the quality of tea negatively (Mukhopadhyay & Mondal, 2017). Tea plants under the shade were found to have lower polyphenol content. This conforms to the findings in Japan, where it increased the caffeine, chlorophyll contents and amino acids while it reduced polyphenol content contributing to green tea of desirable flavour and bright colour. Shade is beneficial and even necessary for successful cultivation of low-grown tea (Wijeratne, 2018).

Shade affects tea quality by decreasing color and briskness of the infused leaf, but it enhances the strength and color of the liquor. However, it has been found that increase in yield by shade repays more than the slight decrease in quality (McCulloh *et.al*, 1965). Maturation of tea is more uniform under shade and this also affects the quality of tea produced (Neto *et al*., 2018). Shade trees beneficial under hot and comparable conditions is related to lowering the temperature of the exposed leaf on the plucking table (Mukhopadhyay & Mondal, 2017). Research conducted showed that in central Africa and Malawi shading reduced theaflavin levels and hence briskness but increased polyphenol oxidase activity and in this way fermentation rate (Werkhoven, 1974).

2.12 Effects of Shade Trees on Soil Hydrologic Characteristics

Mr. Howard (1957) drew attention to the possible differences in soil moisture content that may result from shade spacing. It is clear that the shade trees drew the soil moisture, and hence its nutrients from the depth zones as did tea bushes but that the latter are exploiting a much greater volume of soil than are shade trees. For efficient studies on soil moisture relations in this system to be made it was clear that sampling must be very deep. In 1957 Mr. Hose good therefore carried out soil sampling Programme to a depth of 4.6 meters, both in the wet conditions in May and again in dry conditions in October,1958. Adjacent well-established gardens of 5m by 5m and 4m by 4m spacing were sampled both in rows and between the rows. In 4m by 4m spacing sampling was done both close to shade trees and in unshaded area.

The higher density of planting resulted in a lower soil moisture content; the shade trees have a similar but a smaller effect. The moisture measurements in deep sub-soil indicated drainage had already become negligible. The shade trees appeared to have caused small drying effects, substantially less than that due to hedge-planting (TRIEA, 1957). Shade decreases loss of moisture from soil by evaporation and from plants by evapo-transpiration by reducing the speed of wind (Nyabundi, 2012). Visser in 1961b reported that *Gricidia Maculata* and *Erythrinalithosperma* (Dadap) shade trees conserved moisture during the beginning of drought, but adversely affected it when the drought was of prolonged duration.

2.13 Tea Quality

Increase in the economic importance of tea has led to creation more attention towards the relationship between the growing conditions of tea and the quality of the product (Sunhong, 1918). Each growing zone produces a product of independent qualities because of climatic and environmental site conditions, approaches used in farming and manufacturing (Saito *et.al*, 2007 and Parra, 2007). Tea is categorized into; black tea, oolong and green tea by using the fermentation process as the determining factor (Kim, *et al*, 2011). Exactly what constitutes quality as from chemical point of view is not known at present and the term used both in common language and by professional tea tasters is far from clear (Werkhoven, 1974).

The term quality is used to describe characteristics used to determine the market value of tea or liquoring qualities such as color, brightness, strength, aroma, quality itself and character of the infused leaf. This means generalization of all the desirable attributes of tea including both external and internal characteristics (Werkhoven, 1974). The chemical composition of the harvested tea, its handling, processing and storage determine its quality (Yao *et.al,* 2005).

2.13.1 Total Poly Phenol Content

Polyphenols in tea depend on the leaf maturity and the extent of fermentation and correspond directly with the final product (Juan *et al*, 1998).They are abundant in tea leaves in composition and phenolic compounds in nature that affect the quality (Yao *et.al*, 2005). The TPC in black tea should have a higher TPC than or equal to 11% as per the international standards of the dry mass. Polyphenols are more in green tea as compared to the other teas (A still *et. al* 2001). Antioxidant capacity does not diminish during polymerization and other alterations occurring during fermentation of black tea (Luczaj and Skrzydlwska, 2005).

2.14 Relationship between Shade Trees and Tea Quality

Shade canopy conserve moisture by protecting tea bushes from radiation (Ripley, 1967). Shades that are deep rooted in drought prone areas, are loped from lower branches as a way of protecting tea underneath. An optimum equilibrium by temporary and permanent shade result in maintaining proper light quality and better photosynthesis (Ripley, 1967).Shade prevent leaves from excessive heating by trapping infra-red rays from the sun(Misra *et al*., 2009). effectiveness of shade is influenced by amount of light allowed to pass through them and the amount of heat removed from the tea bushes (Carr, 1972).

2.15 Theoretical Framework

The study employed the hydrological or water cycle theory that explains the continuous water movement between the atmosphere and the surface of the earth. It further states that the form of circulating water changes (to either solid, liquid or gas) while the amount remains the same and the whole process is powered by the solar energy from the sun (Dingman, 2015). It sums all the processes that enhance water movement from land and ocean to the atmosphere and back by precipitation (Kuchment, 2004). This is important because it enhances the exchange of moisture on the earth’s surface both above and below. It is the only way that water reaches plants. Water is important to plants because it helps in: seed germination, process of photosynthesis by which plants make their food, transport of nutrients and minerals to the plants, and maintenance of plant structure(Lisar *et al*., 2012). The most important processes of the hydrological cycle to plants are precipitation, infiltration, surface run-off, percolation and evaporation. The water cycle is affected by many environmental factors including vegetation and soil (Schwärzel *et al*., 2020). Vegetation intercepts precipitation and affects infiltration, surface run-off and evaporation (Hunt *et al*., 2020). Soil hydrologic characteristics determine the water movement and water availability in the soil for plants use (Manzoni *et al*., 2013). Moreover this theory is important for the study because soil-moisture relationship is key in ecohydrology (Wang *et al.*, 2019).

2.16 Conceptual Framework

The study aimed at establishing the ecohydrological impacts of shade trees spacing on soil characteristics affecting tea yields and quality. The study used a conceptual framework which presented the variables into measurable units to facilitate data collection. The independent variables were the tea cultivar, seasons (cool and wet; hot and dry), shade tree species and the shade trees spacing (6m by 6m and 8m by 8m). Soil hydrologic characteristics (infiltration rate, moisture content, porosity and hydraulic conductivity), tea yield and quality (total polyphenol contents, theaflavins, and thearubigins) were the dependent variables. The study had awareness, cost and climatic conditions as intervening variables as shown in the figure 2.1 below.

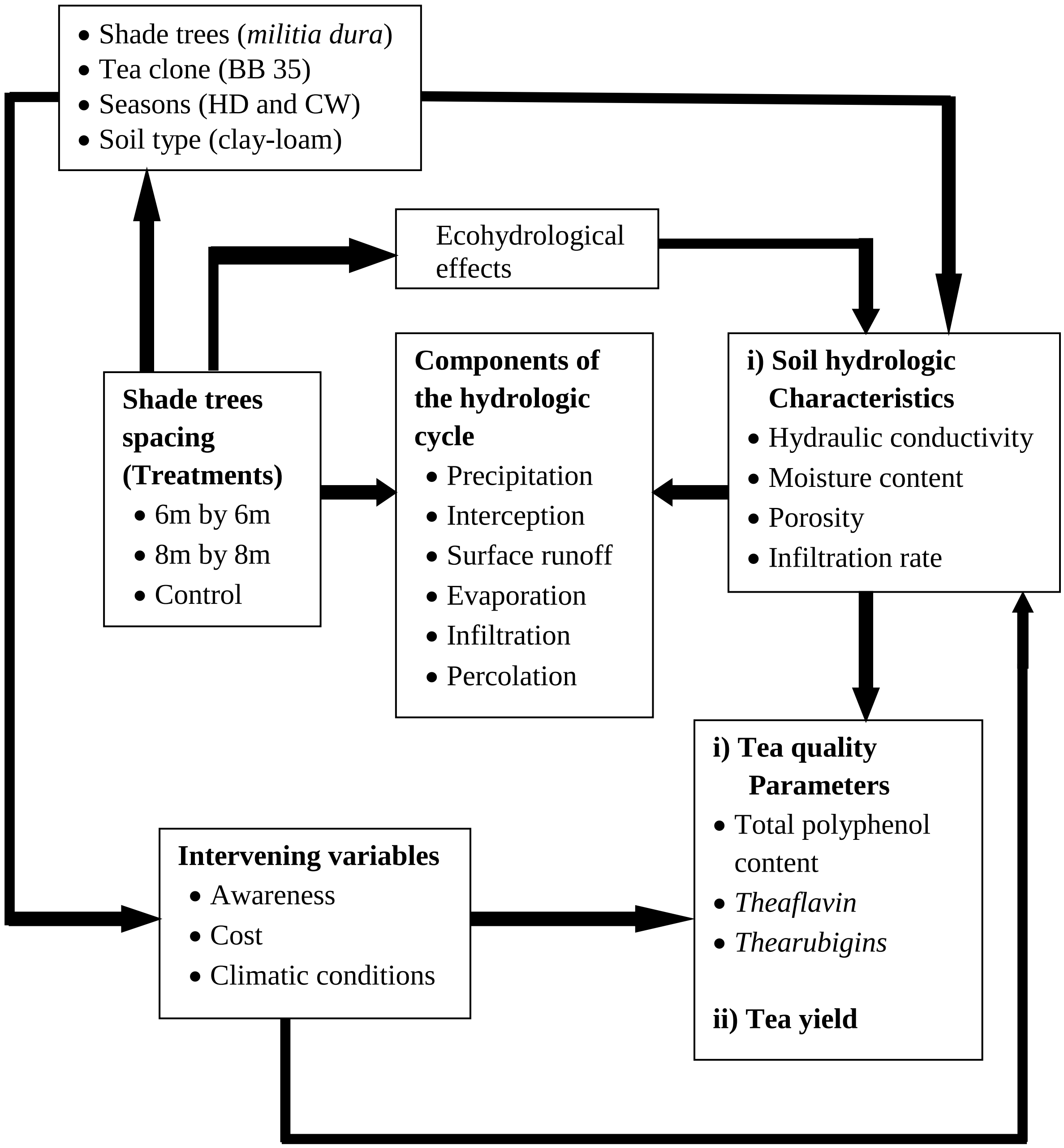


Figure 2.1: Conceptual Framework

Source: Modified from Asbjornsen *et al*., 2011

CHAPTER THREE

STUDY AREA

3.1 Location and Size

Moniere tea Estate is one of the estate (s) that belong to Sotik Tea Company , found in Kipkebe location, Sotik sub-county of Bomet County in the Kenya Rift Valley. It is located between Latitudes 0°40', 18.91" and Longitudes 35°4', 11.75" at a distance of about 400Km to the West of Nairobi, 50 Km to the South-West of Kericho town and 16Km west Sotik Township.

The estimate terrain mean elevation above sea level is 1812 meters. Moniare tea estate is neighbored by Kipkebe, Keritor, Magura, Kiptenden and Arroket tea estates. The sotik tea company was founded in 1945 and it manages all the Sotik highlands estates including Moniare tea estate with a tea plantation that occupies 1,800 ha and while another 850 ha being occupied by wood fuel plantations.

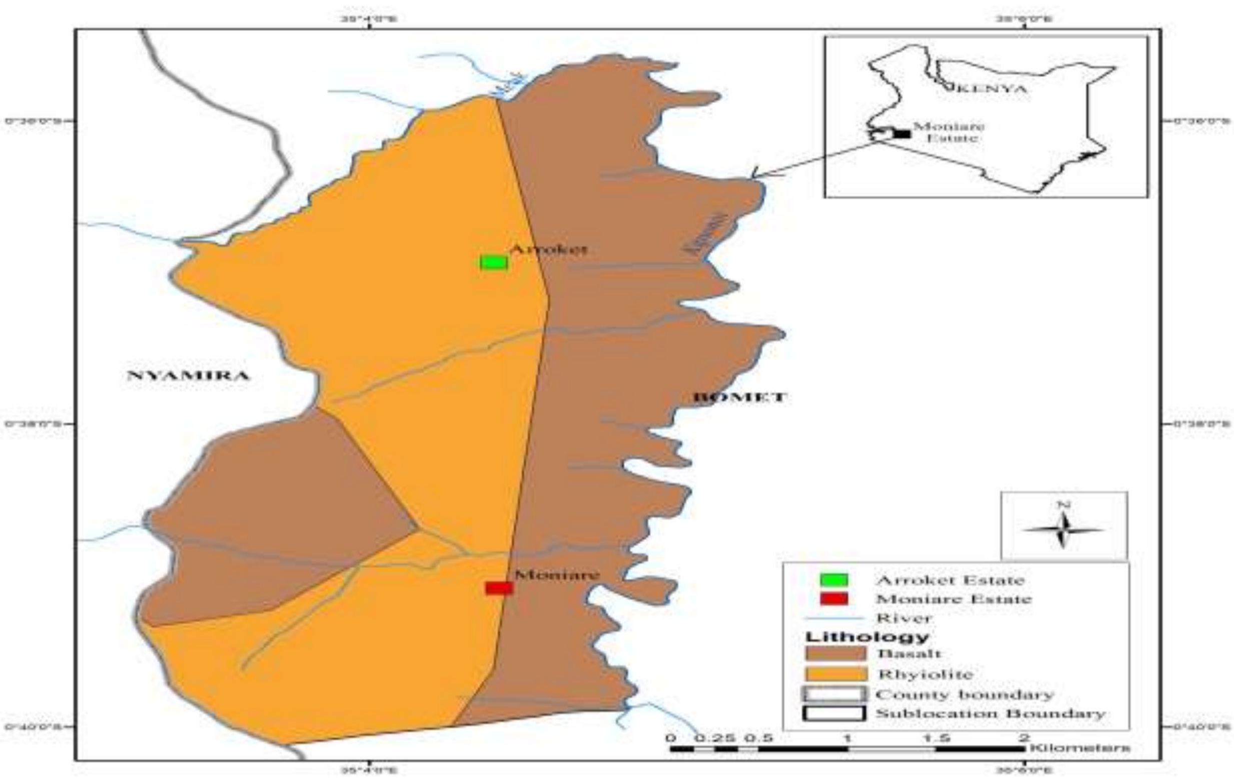


Figure 3.1 : Moniare Estate

Source: Derived from Survey of Kenya, 2011

3.2 Physiography

3.2.1 Geology and soils

The geographical location in the Great Rift-valley and Mau complex and the altitude of Moniere puts it in a unique environmental setting. The area displays almost every facet of geological phenomena such as soil erosion and pollution that results from human induced activities.

The site geology is made up of volcanic, igneous and metamorphic complex though it is majorly underlied by tertiary and intermediate rocks and mainly red volcanic soils with a pH ranging from 4.6-5.6 (acidic).

The area has intermediate and basic volcanic rocks (phonolites) mostly. However, in the South there is out cropping of undifferentiated Basement System rocks granite. It is mainly covered by clay-loam soils that are generally well developed, well drained and that have adequate nutrients well enough for agricultural activities especially tea farming.

3.3.2 Topography

The topography ranges from undulating to rolling with a flatter terrain in the south and sloping westward which results in its drainage being in the same direction, at least in the eastern part, cutting deep valleys (Ralph and Schmidt, 1982. It contains moderate variations in elevation within 2 miles topography, with a maximum difference in elevation of 149 meters and a mean elevation above sea level of 1789.2 meters, within 16.66 Kilometers and Within 80.47 Kilometers it contains very significant variations in elevation of 1862.938 Meters.

3.3.3 Climate

It is generally temperate, hot and humid with rain falling in the evenings. The area temperature variation throughout the year is insignificant hence it is not meaningful to discuss hot and cold seasons (TRI, 2019). The temperature range is between 12.8°C to 26.7°C and mean air temperature is 17.2 (TRI, 2019). The average percentage cloud cover of the sky of seasonal variation is experienced all over annually whereby the clearer part starts approximately on 15th June and ends by 2nd October. The clearest day of the year is 31st August. It is cloudier as from 2nd October to around 15th June. In April 18th which is the cloudiest day of the year the sky is 87% overclouded or predominantly cloudy (TRFK journal, 2002). A precipitation of 1.02. Millimeters makes up a wet day in the area. Probability of wet days varies significantly during the year. Wet season starts in 22nd October and ends in May with a greater than 44% probability of a given day being a wet day. Dry season begins in 25th May to 22nd October. However these patterns have continuously varied due to climate change. The area experiences seasonal variation rainfall monthly throughout the year. Most rain is experienced in 31 days centered on 20th April, with a total mean accumulation of 193.04 millimeters. The minimum rain is experienced around 14th July, with a total mean accumulation of 30.48 millimeters (TRI, 2019).

The day length has an insignificant variation during the year, with a limit of 9 minutes of 12 hours all through. June 21 is the shortest day having12 hours, 5 minutes of daytime while December 21 is the longest day, having 12 hours, 10 minutes of daylight. 6:18 am on November 5 is the earliest sunrise, while the latest sunrise occurs 31 minutes later at 6:49 a.m. on February 13. The earliest sunset happens at 6:27 PM on 1st November while the latest sunset occurs on 10th February at 7:28 PM (TRFK journal, 2002). Topography and other factors determine the wind experienced in the area. There is a wider variation than hourly means in instantaneous wind speed and direction. There is insignificant variation in average hourly wind speed over the course of the year, ranging between 0.5 miles per hour and 5.5 miles per hour. The predominant wind direction throughout the year is from the east (TRFK journal, 2002).

3.3.4 Vegetation

Vegetation in the area is fairly diverse whereby in accordance with the optimum conditions of each crop they are grown in the area. However tea is the major crop grown in the area. Other vegetation in the area is eucalyptus in the man-made forest in the area and the shade trees in tea farms. Moreover there are isolated patches of forests that are too small to be individually mapped that are resulting from human pressures on the land. The general complexity of vegetation in the area is that of culturally induced instability. The reliable rainfall and fertile soils form a basis for the diverse vegetation and thriving in crop farming in the area.

3.3.5 Socio-Economic Activities

The population of the area is mainly made up of labourers who work in the estate and factories in the area. The pattern of the population is clustered in that it is found around factories and the estates. Agriculture forms the main economic activity in the area because both food and cash crops are grown in the area both at large and small scales. However cash crop farming of tea by multinational companies is dominant in the area. Moreover there are also livestock activities that are carried out in the area. There is also extensive eucalyptus cultivation for wood fuel for use in factories. There are various industries for tea manufacturing in the area. The tea factories include Kipkebe, Magura and Arroret. The primary business of the factories is tea processing and export through Mombasa. Green leaf to the factories is supplied from the estate farms and from selected out growers in the region. 40 % of green leaf intake is contributed to the factories by the out growers.

CHAPTER FOUR

METHODOLOGY

4.1 Study Design

This study was based on an experimental design of a randomized complete block design (RCBD) which was being used in a larger experimental work at the Tea Research Institute of Kenya. The design structure was modified to be made up of nine Blocks of shade trees treatments, each sub-divided into three experimental plots. The three experimental plots were of 8m by 8m shade spacing treatment, 6m by 6m shade spacing treatment, and a control which had no shade trees, all surrounded by complete guard-rows (figure 4.1).

In the selection of the experimental site, a standard design for agricultural experiments of a randomized complete block design(Masood et al., 2008), was used to determine the impacts of shade spacing on soil hydrological characteristics in relation to tea quality and yield (figure 4.1). The design enabled the grouping of the shade trees treatments into blocks or replicates. The RCBD was selected to be used because it controls variation in the experiment by accounting for spatial or drainage effects in the field, it has high precision and it allowed some plots to be more replicated than others (Grant, 2010) hence suitable for studying the ecohydrologic effects of shade trees spacing. Since the field was divided into similar experimental units to enhance variation, any differences observed were mainly due to true differences between treatments.

4.2 Data Types and Sources

The data variables that were sought out in the Randomized complete block design were soil infiltration rate, porosity, hydraulic conductivity and moisture content, tea yields and tea quality that consisted of total polyphenol content, theaflavins and thearubigins. Data was collected at the experimental plots in Moniere estate from each shade trees spacing treatment. The soils were augured from each treatment at three depths; 0-20cm, 20-40cm and 40-60cm and taken to TRI laboratories. The rate of Infiltration was determined fresh from the RCBD experimental design in the field by use of infiltrometer gadgets. Soil Moisture content, porosity and hydraulic conductivity were all determined from the RCBD experimental design in the Tea Research Institute of Kenya laboratories using the soil samples from the field. Tea for determining yield and quality was hand plucked and put into a plucking basket. The weights for yield determination were measured and recorded fresh from the RCBD experimental design in the field while tea for determining quality was taken to the Tea Research institute factory for processing. The total polyphenol content, thearubigins and theaflavins were analyzed and determined from The RCBD experimental design in the TRI laboratories.

4.3 Data Collection

Data collection was done at the experimental site as per the research work plan (appendix VII). It was done seasonally, during the hot and dry season and cool and wet season in the year 2021(table 4.1). The total experimental area (including guard rows) covered during the process was 4900 m^2. Each plot covered was 16m by 16 m with nine shade trees each. Data collection was done from the RCBD design in all the nine plots (figure: 4.1).

Table 4.1: Summary of Meteorological Observation of temperature and rainfall (January-July 2021) at Moniere, Kipkebe

Month	Rainfall(monthly totals in mm)	Maximum temperature (^{0}C)	Minimum temperature (^{0}C)	Mean temperature (^{0}C)	Season
January	56.5	28.8	12.8	20.8	Hot and dry
February	64.7	30.0	12.5	21.3	
March	164.6	30.2	13.0	21.6	
April	159.8	30.1	13.8	22.0	Cool and wet
May	197.1	28.3	14.3	21.3	
June	268.1	25.8	14.2	20.0	

Source: Moniere meteorological station observations, 2021

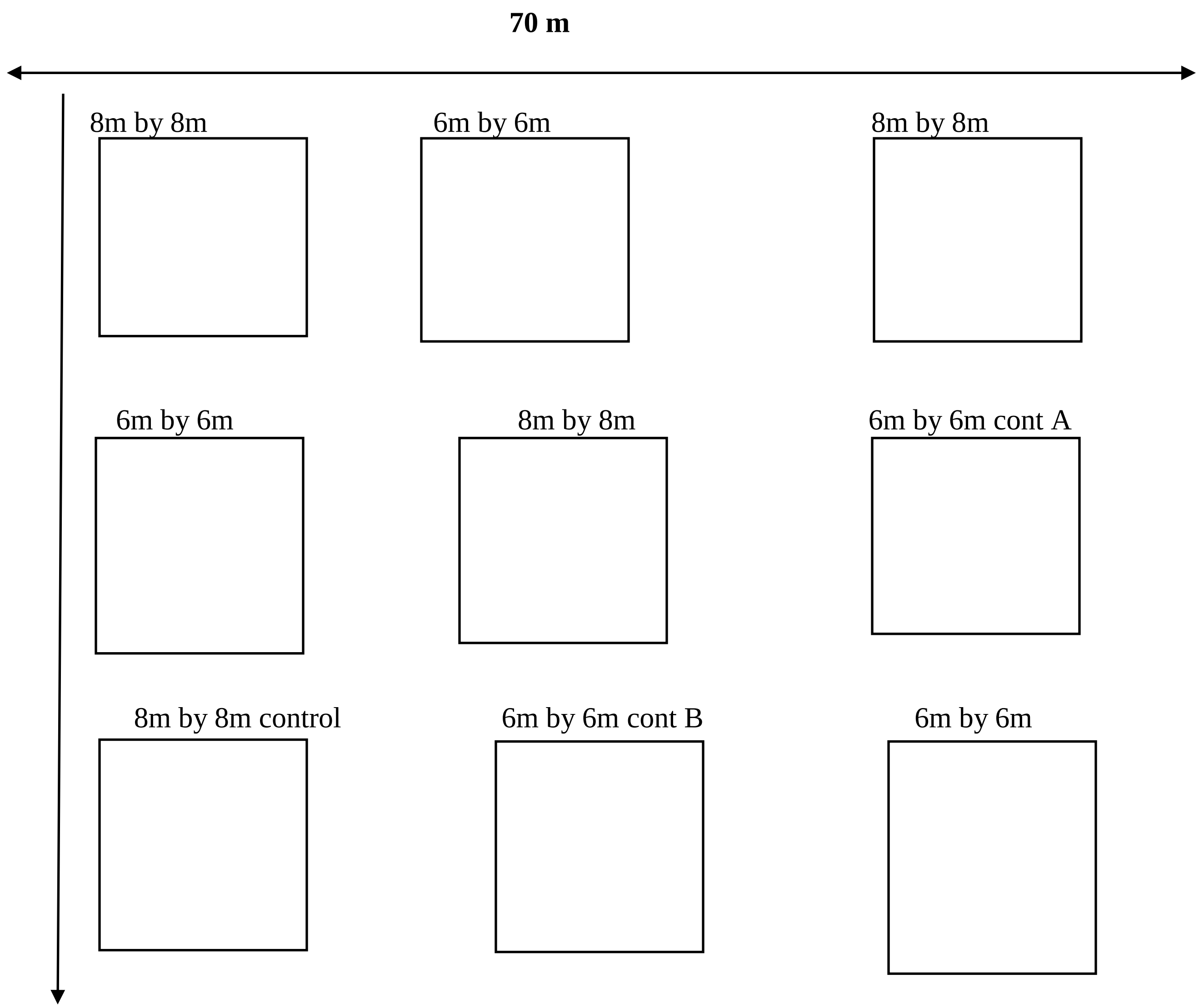


Figure 4.1: Experimental plots

Source: TRFK, 1997

4.3.1 Pre-Experiment Activities

Reconnaissance survey was conducted to familiarize with the study area, seek permission to collect data from the relevant authorities and to ascertain the climatic and environmental conditions of the area. It enhanced the determination of the feasibility of the research design before beginning the study. This was important because it helped in determining and coming up with the target population, sample size and selection, data collection methods, instruments, amount of labor and coming up with the schedule and data collection criteria. During this time the reliability and accuracy of measurement instruments were tested. Moreover, a flow chart of the whole process from start to finish was created. It provided preliminary data that was run as trial data through the proposed statistical analysis to see whether it was appropriate for the data set.

4.3.2 Target Population and Sample Size

The target population was all the nine plots in the area and this were the ones under experiment because they all had shade trees and guard rows between each of them and they included 8m by 8m shade trees spacing, 6m by 6m shade trees spacing which are commonly used in Kenya with *militia dura* shade tree and a control with no shade trees. All of them were replicated thrice.

The sample size of soil was 54 samples for both the cool and wet and hot and dry season composing of three depths; 0-20cm, 20-40 cm and 40-60 cm from each plot because the soil profile changes with depth and the maximum rooting depth of tea plant is 60cm while the sample size for tea quality and yield was made up of 18 samples two from each shade trees spacing treatment each for both the cool and wet and hot and dry season. All the plots were taken into consideration under the study because of the fact that they were the ones under an ongoing experiment by TRI and already with matured shade trees. The sample size was guided and determined by the population target of the nine plots under the study.

4.3.3 Data Collection Instruments

Various instruments were used during the study to collect data for infiltration rate, moisture content, porosity and hydraulic conductivity, tea yield, total polyphenol content, theaflavins and thearubigins both at the field and in the laboratory. An auger was used to sample the soils in the field that were put into sleeves and transported to Tea research institute laboratory for analysis. Labelling of samples was done using a permanent marker. In the field data recording was done using a pen and a note book. Double ring infiltrometer was used to determine the rate of infiltration while time was measured using a stop watch. Label stickers were used to differentiate and for easier identification of the samples. Tea leaves for yield determination and quality analysis were hand plucked and placed in a plucking basket.

An oven was used to dry the samples in the laboratory while Coffee miller (moulinex china) was used for grounding tea which was preserved in a dark environment using aluminum bag for tea quality analyses to avoid oxidation. Measuring cylinders were used for the determination of porosity. Extraction tube was used in the extraction of total polyphenol content while the vortex mixer (model MV-1000) was used to mix solutions in the laboratory. The UV spectrophotometer was used to determine sample absorbance in the determination of total polyphenol content, thearubigins and theaflavins. Tarred vacuum flask was used to prepare tea infusion for the determination of thearubigins and total theaflavins.

4.3.4 Experimental Treatments

The experiment was done on an ongoing larger experiment by the Tea research Institute of Kenya, that was initiated in 1997.It was set on all the nine plots in the study area, where by six plots had shade trees with a spacing of 6m by 6m and 8m by 8m which were under study while the other three plots had no shade trees and they formed a control. *Millitia dura* shade tree species that were planted in the year 1997 with two different spacing (6m by 6m and 8m by 8m) when the experiment was initiated were used as treatments and a control (no shade) treatment that formed a basis for comparison with the other shade tree spacing treatments was also established. Guard rows were created in between the plots to avoid edge effects in the experiment. The shade tree *militia dura* is an indigenous tree, originally seen at Mt. Kenya as secondary shrub at forest edges. It is known to thrive above elevations of 1200m to 15000m a.m.s.l *Millitia dura* grows to a height of 10m to 12 m high. BB35 tea clone was used because it is the most commonly grown tea cultivar in the area. Two spacing that are majorly used in tea farms in Kenya which include; 6m by 6m and 8m by 8m were considered. The shade trees provided the ecohydrologic effects on soil characteristics that in return affected the tea yields and tea quality. The tea under shade in the two shade trees spacing and the one under control provided tea for yield and quality determination. The total area covered by the experiment was 4900 $m^{2.}$ The Study was carried out in the experiment for a duration of six months. During the setup of the experiment it was assumed that shade trees spacing was the major cause of ecohydrologic effect on soil characteristics and all other factors in the study area were the same hence their impacts as a source of variation in the experiment was minimal.

4.3.4.1 Sampling and Extraction of Soil

Soils were sampled randomly by auguring three holes at the center of each treatment and extracting soils from 0-20, 20-40 and 40-60 Centimeters (plate1). The soil of each depth was mixed to form composite giving three samples. Soil sampling was done in February for the hot and dry season and in May for the cool and wet season. They were put in labelled polythene sleeves before they were transported to Tea Research Institute laboratory for analysis (plate 6). Soil field-moist subsample was scooped and set aside for acquiring Soil moisture content by use of gravimetric method in the laboratory. Remaining samples were air dried (plate 4.2) for 48 hours in order for the excess moisture to be removed and then they were sieved using 2mm sieve and stored awaiting analysis.

Plate 4.1: Soil Sampling **Plate 4.2: Air drying of soils**

4.3.4.2 Extraction Of Soil Hydrologic Characteristics

4.3.4.2.1 Measuring Infiltration Rate

The soil infiltration rate was determined in the field using infiltrometer gadgets (Plate 4.3). The inner and outer rings of the double-ring infiltrometer were placed on the ground with the cutting edge on the ground and the driving plates attached by means of the adjustable screws. A profile was dug into the soil layer to test if the soil layer was below the surface level. The inner ring was struck firmly; using the impact absorbing hammer supplied until it entered the soil at right angles approximately 10 cm. The outer ring was similarly hammered into the ground.

The outer ring and inner rings were then filled with water to saturate soil after which the measuring rod was attached using the adjustable screws. Once this set up was complete the readings based on the attached measuring rod were taken at an interval of one minute by first recording the initial position below the reference level against the time reference (t=0). This recording went on for a period of 15 minutes. The resulting measurement records were then used to determine infiltration rate in centimeters per minute. Measuring ceased once the rate of infiltration reached a constant reading. The results were recorded as shown in table 4.2 below.

Plate 4.3: Measuring of the rate of infiltration within the 8m by 8 m plot

4.3.4.2.2 Determining Soil Hydraulic Conductivity

It was determined using the constant head method (plate 4.4). One end of each sample was put a blockade that enclosed it in the core. For this case a 1mm sieve that had high conductance to a level that the water lost through it was insignificant as compared to the one across the soil core was used. Re-circulating water supply system was started and an empty cylinder was attached to the peak of a sample using a bad of rubber that is wide. A blotting paper was put on top of the sample and water was poured slowly into the top cylinder to a two-third level of the cylinder. A wide spatula was slid below the sample and it was quickly and carefully transferred to the rack and immediately one of the siphons was started to keep a constant head of water but drainage from the top of the sample was not allowed. After stabilization of the water level at the top of the sample, the collection of the percolate into a beaker took place and volume of water that passed in time (t) and the hydraulic head difference determined by measuring vertical distance from the upper water level to the bottom of the cone (Plate 9). Soil hydraulic conductivity was calculated using the formula below and results recorded (table 4.3)

Conductivity (Ks) = V1 /At (H2-H1)……… (1)

Where;

V1 = the volume of water that flows

A = area of cross-section

T = Time taken

H_1 = Initial height of water

H_2 = final height of water

Plate 4.4: Determining hydraulic conductivity from the sample soil in the Laboratory at TRI

4.3.4.2.3 Determination Of Porosity

Soil porosity was determined using water absorption method using the undisturbed soil samples. 60 $cm^3$of each of the soil samples from each treatment site and depth was measured and put in a measuring cylinder. A known volume of water was added to saturate the soil samples. The volume of the remaining water after soil saturation was measured by a measuring cylinder (plate 4.5). The volume of pore space was finally calculated by subtracting the remaining (final) volume of water from the initial volume of water. The results were as shown in table 4.3.

Plate 4.5: Determining soil porosity from the sample soil in the Laboratory at TRI

4.3.4.2.4 Determination Of Soil Moisture Content

Gravimetric method applied using the undisturbed soil samples. The initial weight of soil sample from each plot and depth was measured and recorded. It was then oven dried at 105 ^{0}C for 48 hours and its dry weight determined (Plate 4.6). Soil moisture in percentage was calculated by finding the difference in weights and dividing it by initial weight and multiplying it by 100%. The results were as shown in table 4.3 below.

% moisture content= $(W_1-W_2)/W_1$ X100

Where;

W_1- weight of wet soil

W_2-weight of dry soil

Plate 4.6: Determining moisture content from the sample soil in the Laboratory at TRI

Table 4.2: Shade Trees Spacing, season and Soil Infiltration Rate

Shade trees spacing (treatment)	Infiltration rate (cm/min)	
	Season 1	Season 2
6m by 6m Rep I	17.05	10.49
6m by 6m Rep II	16.45	16.31
6m by 6m Rep III	15.86	16.25
6m by 6m Control Rep I	16.33	11.29
8m by 8m Rep I	17.39	11.16
8m by 8m Rep II	16.75	16.57
8m by 8m Rep III	13.56	16.45
8m by 8m Control Rep I	9.61	10.98
8m by 8m Control Rep II	15.19	10.38

Season 1- Hot and dry, Season 2- Cool and wet

Table 4.3: Shade trees spacing, depths, season and soil porosity, moisture content and hydraulic conductivity

Shade trees spacing(treatments)	Depth(cm)	Porosity (%)		Hydraulic conductivity (ks)		Moisture content (%)	
		Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
6m by 6m Rep I	0-20	44	41	8.58	3.31	23.98	24.21
	20-40	43	43	8.52	3.32	24.05	20.59
	40-60	36	39	7.46	4.81	24.4	23.2
6m by 6m Rep II	0-20	43	41	6.17	6.14	26	29.4
	20-40	34	45	7.59	6.87	27.47	24.58
	40-60	47	43	5.19	3.42	31.03	18.51
6m by 6m Rep III	0-20	36	44	2.85	8.4	24.01	36.9
	20-40	41	39	8.41	13.26	26.3	33.12
	40-60	36	47	12.82	5.95	24.8	31.36
6m by 6m Control Rep I	0-20	34	22	13.43	17.01	30.97	28.59
	20-40	31	33	13.35	9.1	30.79	30.31
	40-60	40	35	14.76	8.79	28.58	29.67
8m by 8m Rep I	0-20	49	35	6.06	9.06	25.65	3.02
	20-40	40	40	5.84	7.7	27.73	25.4
	40-60	43	34	5.7	5.02	25.96	25.13
8m by 8m Rep II	0-20	42	34	11.16	7.36	27.08	23.41
	20-40	31	39	15.65	9.02	28.65	29.41
	40-60	37	44	11.6	6.12	26.97	32.08
8m by 8m Rep III	0-20	41	49	9.64	6.02	26.55	28.59
	20-40	45	44	13.21	5.38	28.46	30.31
	40-60	44	42	7.51	3.3	24.93	29.67
8m by 8m Control Rep I	0-20	23	29	17.47	10.02	31.21	29.62
	20-40	31	39	12.81	10.19	27.52	32.51
	40-60	33	33	14.3	9.02	28.82	35.64
8m by 8m Control Rep II	0-20	42	31	7.39	11.79	28.04	28.23
	20-40	38	37	13.45	7.82	27.13	29.27
	40-60	38	39	5.64	5.02	27.5	26.74

Season 1- Hot and dry, Season 2- Cool and wet

4.3.4.3 Leaf Sampling

Leaf sampling was done from each plot for determination of the quality of tea produced under the different shade trees spacing and the control0.5 kilograms of pluckable shoots (two leaves and a bud) were plucked separately from each plot and put in khaki bags that were well labelled (plate 4.7). They were then transported to the TRI laboratory and dried immediately using a microwave (Samsung GE109MST, Malaysia) so that enzyme polyphenol oxidase may be deactivated. afterward they were oven dried for 24hours at 100^0C,ground using coffee miller

(Moulinex, China) to powder and placed in aluminum bags for preservation in a dark dry environment awaiting further analysis for total polyphenol content, *theaflavins* and *thearubigins* (Magoma et al.,2000).

Plate 4.7: Leaf Sampling in 8m by 8m shade trees spacing in Monieri tea estate.

4.3.5.4 Tea Quality Data Extraction

4.3.5.4.1 Determination of the Total Polyphenol Content

Individual total polyphenol content were extracted using the ISO procedure. Each of the samples was milled before analysis. 0.2g of each test sample was weighed and put into extraction tube, 5ml of hot 70% v/v methanol / distilled water extraction mixture dispensed into the tube containing the sample and then it was vortexed using a vortex mixer (Model VM-1000). Heating of the extraction tube containing the sample was done in a water bath maintained at 70^0C for 10 minutes with mixing in the vortex mixer after every 5 minutes. (The sample was vortexed immediately, after every 5 minutes and 10 minutes). The samples were then centrifuged at 3500 revolution per minute (rpm) for 10 minutes (hscen-204). The supernatant was decanted into a graduated tube and the extraction procedure repeated. The extracts were then combined and made up to 10ml with cold 70% methanol/water mixture.

The *Folin-Ciocalteu* phenol reagent method was used to determine total polyphenol contents as described by Pourmorad *et al*., (2006). The amount of total polyphenol (TP) from the test samples were determined from a standard curve generated using garlic acid as a standard, and expressed as amount of garlic acid equivalent. Total polyphenol content was expressed as percentage by mass on dry matter basis following procedures outlined in British Standard ISO document [BS ISO 14502-1:2005(E)]. Polyphenols quantification was accomplished by the method described by Cheruiyot *et al*., (2008) as described below.

Folin Ciocalteau's phenol reagent and sodium carbonate solution (7.5% w/v) was used for complexing. *Folin Ciocalteau's* phenol contains phosphor-tungstic acids as oxidants, which on reduction by readily oxidized phenolic hydroxyl groups yield a blue colour with broad maximum absorption at 765nm. The blue colour is formed by adding 5ml Folin Ciocalteau's phenol reagent into a test tube containing 1ml of 100 fold diluted sample then 4ml of sodium carbonate solution (7.5 w/v). Sample absorbance was determined at 765nm against garlic standards using UV spectrophotometer. Each sample was analyzed in triplicate to a certain precision. The total polyphenol content was expressed as percentage based on sample dry matter basis using the formula below and the results were as shown in table 4.5 below.

$\%TP= [(OD_{sample}-OD_{intercept}) \times V \times d \times 1000]/ (Slope_{std} \times m \times 10000 \times DM))$……… (2)

Where;

TP	=	Total polyphenol
OD_{sample}	=	Optical density obtained for the sample test solution.
$OD_{intercept}$	=	Optical density at the point where the best linear calibration line Intercepts the y-axis.
$Slope_{std}$	=	Slope obtained from the best-fit linear calibration
M	=	Mass in grams of sample tests solution
V	=	Sample extraction volume in ml for leaf tea 10ml
D	=	Dilution factor used prior calorimetric etermination (typically 1.0 Ml to 100ml, thus a dilution factor of 100);

DM = Dry matter

4.3.5.4.2 Determination of *Theaflavins* (TF)

Theaflavins were determined using Flavognost method (Hilton, 1973). A tea infusion was prepared by adding 375 ml of boiling distilled water into a tarred vacuum flask with 9g black tea then it was agitated in a mechanical shaker for 10 minutes. It was then filtered through a cotton wool into a flat-bottomed flask. Tea liquor of 10ml was pipetted into a test tube and 10 ml of double distilled iso-butyl methyl ketone 4-methyl-penta-2-one (IBMK) was added and then shaken for 15 minutes and the test tube was left to stand to allow the two layers to separate. From the upper layer, 2ml was pipetted into a test tube and 4ml ethanol and 2ml of diphenylboric acid 2-amino- ethyl ester was added and shaken for exactly 2 minutes. The colour was allowed to develop by letting the test tube to stand for exactly 15 minutes and then the absorbance (A) was quickly read at 625nm. The machine was first set with blank Ethanol/IBMK (1:1 v/v) before reading the samples. The results were as shown in table 4.5 below.

Theaflavins (*m*mol/g) =A625 X 47.9 x 100/DM)……… (3)

Where DM = Dry matter

4.3.5.4.3 Determination of *Thearubigins*

The method of Roberts and Smith (1963) was used to determine total thearubigins. A tea infusion was prepared by adding 375ml of boiling water into a tared vacuum flask with 9g of black tea, corked then agitated in a mechanical shaker for 10 minutes. It was then filtered through a cotton wool into a flat-bottomed flask and allowed to cool to room temperature. Pipetting into a separating funnel under a fume-cupboard of 6ml of cooled infusion was done before 6ml of 1% (w/v) aqueous solution of anhydrous disodium hydrogen phosphate was added.

The mixture was vigorously shaken for 1 minute after adding 10 ml of ethyl acetate which did extraction the settling was allowed to take place. Two layers were formed after settling and the lower layer was drained off carefully.

Then 5mlof ethyl acetate was added to the ethyl acetate extract (upper layer) containing theaflavins fraction in the separating funnel before drawing 10ml of the extraction into a 25ml volumetric flask.

Methanol was used to top up to the mark to obtain E1 whose optical density was measured using 10mm cell at 380nm and 460 nm as was required. From the cooled tea infusion prepared above, 1ml was mixed with 9ml of distilled water and made up to 25ml in a volumetric flask with methanol where E2 was obtained whose optical density was measured as E1 above. Still from the cooled infusion of tea prepared above, 1ml was pipetted into a 25ml volumetric flask and 8ml of distilled water was added before adding 1ml of aqueous 10% oxalic acid. Methanol was used to top up to the mark and E3 was obtained ready for optical density measurement.

Optical density (absorbance) of E1, E3 at wave length of 380nm and E1, E2 at 460nm using the10mm cell were measured. The results were as shown in table 4.5 below.

Calculation of *thearubigins*=TR% 7.06(4E3-E1) X DM %)……… (4)

4.3.5.5 Derivation of Yield from Plucked Tea Leaves

Tea yield collection was done at the experimental site through plucking at intervals of 7-10 days when the shoot had developed to two mature leaves and a bud from each treatment plot as per the plucking schedule of the estate throughout the period of study. During the entire study period the green leaf weight per plot was recorded for every plucking round. Conversion of green leaf yield into kg made tea per hectare per year ($KgMtha^{-1}yr^{-1}$) was done by multiplying by a conversion factor. The conversion factor was determined by using an empirical constant of 0.225 multiplied by the number of tea plants per hectare then divided by the number of tea plants per plot. Results were as shown in table 4.4 below.

Table 4.4: Shade Trees Spacing, season and Tea Yield

Shade trees spacing(treatments)	Yield (kgs)	
	Season 1	Season 2
6m by 6m Rep I	60.3	51.8
6m by 6m Rep II	81.9	53
6m by 6m Rep III	87.5	77.4
6m by 6m Control Rep I	109.6	108.3
8m by 8m Rep I	91.5	86.6
8m by 8m Rep II	125.4	138.1
8m by 8m Rep III	147.2	136
8m by 8m Control Rep I	165.1	164.3
8m by 8m Control Rep II	154	144.1

Season 1- Hot and dry, Season 2- Cool and wet

Table 4.5: Shade Trees Spacing, season and Tea Quality

Shade Trees spacing (m)	Season	Theaflavins (TFμmole/g)	Thearubigins (TR %)	Total polyphenol content(% TP)
6m by 6m Rep I	1	18.64	12.30	18.73
8m by 8m Rep I	1	14.75	15.06	17.41
6m by 6m Rep II	1	23.13	14.70	18.10
8m by 8m Rep II	1	21.45	14.21	18.24
6m by 6m Rep III	1	20.69	13.40	17.87
8m by 8m Rep III	1	21.76	12.72	18.39
8m by 8m Control Rep I	1	20.57	14.04	17.69
8m by 8m Control Rep II	1	21.56	13.64	19.19
6m by 6m Control Rep I	1	17.76	14.54	19.71
6m by 6m Rep I	2	17.52	12.69	20.39
8m by 8m Rep I	2	13.94	16.83	20.14
6m by 6m Rep II	2	22.73	16.16	21.60
8m by 8m Rep II	2	21.45	17.33	22.24
6m by 6m Rep III	2	24.15	20.07	17.99
8m by 8m Rep III	2	21.41	14.98	19.34
8m by 8m Control Rep I	2	19.64	14.99	20.71
8m by 8m Control Rep II	2	19.05	12.11	21.37
6m by 6m Control Rep I	2	18.05	15.28	19.65

Season 1- Hot and dry, Season 2- Cool and wet

4.4 Data Processing and Analyses

4.4.1 Data Processing

Data on soil infiltration rate, soil porosity, hydraulic conductivity, moisture content, tea yield, total polyphenol content, thearubigins and theaflavins was first grouped into two major categories according to seasons (cool and wet or wet and dry). After that the data was arranged together in relation to the type of treatment, that is, all the 6m by 6m shade trees spacing, 8m by 8m shade trees spacing treatment and the controls to form three distinct clusters of data. At this level of grouping the data set in accordance to the factors of analysis the quality and integrity of data was assessed by comparing data obtained from the different replications of each treatments to check for any outliers or gaps. It was found that the data was consistent and accurate.

Data for effects of shade trees spacing on porosity, hydraulic conductivity and moisture content for both seasons were put together because they were similar since they involved depths and shade trees spacing. Data for effects of shade trees spacing on infiltration rate, tea yield and quality (total polyphenol content, *thearubigins* and *theaflavins*) for both seasons were put together because they only had one factor of analysis which was shade tree spacing. After that the transcribing and coding of the data was done. In the first set of data that had the soil depth and shade tree spacing as the factor of analysis numerical numbers were used. 1 was used to represent 0-20cm, 2 to represent 20-40 cm and 3 to represent 40-60 cm. In relation to shade trees spacing treatments 1 was used to represent 6m by 6m, 2 was used to represent 8m by 8m and 3 was used to represent the controls. Alphabetical letters were used to code the soil hydrological characteristics in the first set of data that was composed of shade trees spacing and depths where by A represented porosity, B represented Moisture content and C hydraulic conductivity.

In the second set of data that had only shade tree spacing as a factor of analysis Numerical numbers were used to transcribe and code the shade trees spacing where by 6m by 6m was coded as 1, 8m by 8m as 2 and the controls as 3. The parameters in this set of data were coded using alphabetical letters whereby A was the rate of infiltration, B yield, C total polyphenol content, D theaflavins and E thearubigins. All the above data were input into excel sheet in a computer to form two data files and stored ready for analyses.

4.4.2 Data Analysis

Analysis of variance using ANOVA on ecohydrologic effects of shade trees spacing on soil moisture content, porosity, infiltration rate and hydraulic conductivity, tea yields and quality was done using GENSTAT (15^{TH} edition) statistical software to determine significant differences between the means of the independent variables. This helped in establishing which independent variable had an interrelation with the dependent variables hence determining the driving factors behind the connection. ANOVA was used because the dependent variables were metric and it aided in determining if the mean differences in the above data sets are statistically significant. It was used because it showed how the hydrologic soil characteristics, tea yield and quality responded to the different shade trees spacing. Since in the study there were more than one independent variable two-way ANOVA test was taken into consideration. First the mean of each group of data was determined followed by overall means. After that within group mean was determined by finding the total deviation from the group mean of each member score. Then the deviation of each group mean from the overall mean was also determined and finally the ratio between group variations to within group variation was determined to give the F statistic. An assumption was made that only the residual based variances were homogeneous since randomization-based analysis was used and observations made within the sampled population are distributed normally. The data available satisfied that assumption due unit-treatment addictively consequence and the use of randomization procedure in the experiment where it was obtained from. Since there were more than two factors of analysis, general ANOVA was performed with y-variate being the parameter of choice while the factors of analysis (shade tree spacing, seasons and soil depths) formed treatment structures and replications being block structure. The significance level was $P \leq 0.05$. If the significance level was less or equal to was $P \leq 0.05$, the it indicated that the ecohydrologic effects of shade trees spacing on the parameter under study had an impact and vice versa.

Duncan Multiple Range Test (DMRT) was used to provide significance levels for the difference between the pairs of means. This study used Duncan Multiple Range Test (DMRT) was selected to be used as a method for mean separation to get the real differences between treatment means because it involved comparison of larger pairs of means, the values were in tables and due to the fact that it required larger differences between means, it guarded against type 1 error. It was also used because it enhanced all possible comparisons between treatments means and between control treatment and with the rest treatment means. Duncan Multiple Range Test (DMRT) assumed that ANOVA had been run and the results were available. First the standard error mean was calculated then the SSR values were gotten from the Duncan's table. The least significant range was calculated and the treatment means arranged in ascending order to generate table of mean differences. Finally the mean differences were compared with least significant range values. The comparison of means was at ($P \leq 0.05$) confidence level. The means that differed more than their least significant range were declared to be significantly different. Duncan Multiple Range Test (DMRT) was convenient due to the fact that it combined the ease of hypotheses testing each average to each average.

Data was further subjected to Pearson's correlation analysis using GENSTAT (15^{TH} edition) software that quantified the association between soil hydrologic characteristics, tea yield and tea quality to establish the relationships between the study parameters on the ecohydrologic effects of shade trees spacing on soil characteristics affecting tea yields and quality and measured the linear correlation between the data sets .It was used because it gave the magnitude of the correlations as well as their directions of relationships. The correlation coefficients ranged from -1 to 1 and the regression slope was a key determinant of the sign. A correlation of p value +1 implied that all data point lied on the line where by the Y values increased with X values and vice-versa while the value 0 showed there is no any linear dependency amongst the variables. Principal component analysis (PCA) that enhanced data interpretation by reducing dimensionality and minimizing on information loss was also done using GENSTAT (15^{TH} edition). The range of continuous initial variables were standardized and covariance matrix computed to identify the correlations. Then the principal components were identified by computing eigenvectors and eigenvalues of covariance matrix. Principal components to be kept were determined by creating a feature vector and finally the data was recasted along the principal component axes. Determining which variable was strongly correlating each component formed the basis of interpretation of principal components. This entailed finding out which variables are large in magnitude and far away from zero in both directions. The analyzed data was presented in tables and figures.

CHAPTER FIVE

RESULTS AND DISCUSSIONS

5.1 Introduction

It comprises study outcomes of ecohydrologic effects of shade trees spacing on soil characteristics, affecting tea yields and quality and their discussions. In addition it gives the various means (treatment, seasonal and depth), covariance and the least significance difference after data analysis. Moreover the study objectives which were: To determine shade spacing effects on soil physical attributes (water movement (infiltration), water content, pore space and hydraulic conductivity, to determine the impacts of shade spacing on tea quality and yield and to establish the relationship between shade tree spacing, soil characteristics and tea production are discussed an explained in accordance with the outcomes that were obtained. Study hypothesis included: There is no significant difference in soil physical attributes (water movement (infiltration), hydraulic conductivity, pore space,) under different shade spacing, shade tree spacing has no significant effect on the quality and yield of the tea produced and there is no significant relationship between shade tree spacing, soil hydrologic characteristics and tea attributes were also considered in depth in relation to the turn-out from the study. Furthermore in this chapter all the study research questions that included: How does shade trees spacing affect soil characteristics, what are the effects of shade trees spacing on tea yields and quality and what is the relationship between shade trees spacing, soil characteristics and tea production were also answered.

5.2 Effects of shade tree spacing on soil hydrologic characteristics

Table 5.1 below shows percentage porosity, percentage moisture content and hydraulic conductivity (Ks) of the soil samples of each soil depth, treatments and seasons. It also shows the means for seasons, depths and treatments for each parameter. In addition it gives the covariance and the least significant difference of the above parameters after the data analysis was done using GENSTAT software 15th editions and the means separation done using Duncan multiple comparison test range.

Table 5.1: Effects of shade trees spacing on soil characteristics

Treatment (Shade Spacing)	Depth (cm)	Season	Porosity (%)	Moisture content (%)	Hydraulic conductivity (ks)
6m by 6m	0-20	Hot and dry	41	24.66	5.87
	20-40		39.33	25.94	8.17
	40-60		39.67	26.74	8.49
	0-20	Cool and wet	42	30.17	5.95
	20-40		42.33	26.1	7.82
	40-60		43	24.36	4.73
8m by 8m	0-20	Hot and dry	44	26.43	8.95
	20-40		38.67	28.28	11.57
	40-60		41.33	25.95	8.27
	0-20	Cool and wet	39.33	18.34	7.48
	20-40		41	28.37	7.37
	40-60		40	28.96	4.81
Control	0-20	Hot and dry	33	30.07	12.76
	20-40		33.33	28.48	13.2
	40-60		37	28.3	11.57
	0-20	Cool and wet	27.33	28.81	12.94
	20-40		36.33	30.7	9.04
	40-60		35.67	30.68	7.61
Overall means					
Treatment/ shade spacing(m)					
6m by 6m			41.22	26.33	6.837
8m by 8m			40.72	26.06	8.075
Control			33.78	29.51	11.187
Depth (cm)					
0-20			37.78	26.41	8.992
20-40			38.50	27.98	9.527
40-60			39.44	27.50	7.579
Season		Hot and dry	38.59	27.21	9.87
		Cool and wet	38.56	27.39	7.53
CV (%)			12.5	6.9	36.5
Treatments/shade spacing					
LSD ≤ 0.05			3.27	2.910	2.150
LSD ≤ 0.01			4.386	NS	2.887
LSD ≤ 0.001			5.788	NS	3.1810
Season					
LSD ≤ 0.05			NS	NS	5.388

*LSD-least significant difference *CV- coefficient of Variation * NS- not significant

5.2.1 Effects of Shade Trees Spacing on Soil Moisture Content

There was significance ($P \leq 0.05$) difference in moisture content between shade tree spacing treatments while for seasons and soil depths alongside all the interactions were insignificant. Generally, moisture content decreased with decrease in the shade spacing. Moisture content was significantly higher at the control (29.5%) and lowest at the 8m by 8m (26.06%) treatment as shown in table 5.1 above and figure 5.1 below. Similarly in all treatments moisture content was higher in 20-40 cm depth (27.98%) and lowest in 0-20 cm depth (26.41%) as shown in table 2. In the 8mby 8m shade spacing and the 6m by 6m shade spacing treatments the moisture content difference was very narrow while in the two seasons there was no significant difference in moisture content. Moisture content had a coefficients of variance (CV) of 6.9%. The results showed a negative linear relationship between the moisture content and shade trees spacing (table 5.1 and figure 5.1).

Shade trees influences the hydrologic cycle and increases soil moisture content input by horizontal interception of mist or clouds(Asbjornsen *et al*., 2011). Moreover Shaxson & Barber, 2003 found that the growth and possible die backs of shade trees break the hard pan in soil formed by human beings and machineries working in the farms and this improves soil drainage and aeration. Organic matter created by the availability of shade trees (leaf fall) influence soil structure, porosity, infiltration rate and moisture holding capacity hence determining the soil moisture content (Allison, 1973). Moreover as per the findings of Oyedele *et al*. (1999) the aggregate stability and pore are affected by the bonding properties of organic materials.

Soil moisture content patterns displayed by the results might be caused by shade trees ability to distribute water all over the soil by hydraulic lift process. Also it was determined that trees release excess water from water they draw from deep soil profile at night when trees hydraulic system returns into equilibrium into higher layers of soil. This results are consistent with the findings on similar studies done and reported by Nehemy *et al*., 2021. The results indicates that in agroforestry systems, Crop cover limit water loss due to overall change in microclimatic conditions within tea environment leading to reduced evaporative demand for the system and maintaining available soil water for tea plant. soil moisture content is insignificant in relation to depth because of soil heterogeneity (Hawley *et al*., 1983).

Moreover the soil moisture variability might have resulted from the difference in vegetation. Additionally it was observed that shade tree spacing had a weak effect on soil moisture content. The difference in moisture content observed might have been caused by the fact that shade trees act as windbreakers and decrease soil moisture by evaporation and act as a barrier to concentrate water runoff. From the results it was evident that moisture content is affected by the density of vegetation (table 5.1 and figure 4). This may likely be reason why at the control there was more moisture content because the density of vegetation was low. At the 8m by 8m and 6m by 6m shade trees spacing it was ascertained that their moisture content was more likely influenced by the shade trees and not the spacing. This was due to the fact that the shade trees provided organic matter that influenced the soil properties, intercepted rainfall and regulated temperatures hence influencing water loss by evaporation and transpiration.

5.2.2 Effects of Shade Trees Spacing On Porosity

There was a significant ($P \leq 0.05$) difference in soil porosity in all the shade spacing treatments but it was insignificant in relations to depth, seasons and all the interactions. 6m by 6m treatment shade spacing recorded the highest (41.22%) porosity while the lowest (33.7%) was recorded at the control treatment (table 5.1). There was an insignificant difference in % porosity recorded at the 6m by 6m and 8m by 8m shade tree spacing. Percentage soil pore space had a coefficient variance (CV %) of 12.5%.The results showed a linear positive relationship between shade trees spacing and percentage pore space as shown in figure 5.1 below.

Variation in soil pore space is in accordance with the soil type and its management .There is a high porosity for soils under vegetation due to the effect of a high biological activity. Water that can be absorbed by crops is retained by pore sizes from 0.0002 to 0.05 diameter (storage pores) (Bell, 2013). Smaller pores hold water tightly to an extent that plants cannot be able to extract it. Additionally root penetration and mineral and nutrient uptake by plants are affected by pores. From the results variation in porosity may be due to soil compaction and removal of top soil by machinery and human beings working in the farm that causes complete disappearance of large soil pores (Godefroid & Koedam, 2004). It might also be caused by shade trees which are a major source of organic matter that is very important determinant of soil porosity by influencing the proportion of large pores in clay-dominated soil(Osman, 2013).

Moreover these differences in pore size distribution is a major indication of the reduction in moisture content available in compacted soils as compared to uncompact soil. Similar results were reported in other experiments on effects of shade trees in Ghana (Aduku & Awaah, n.d.). From the results it is clear that the shade trees roots swell, shrink, die and decompose hence promoting the formation of pores (Plaster, 2013). In addition the pruning of shade trees, deposition of residues and root turnover by the shade trees provide organic matter to the soil which enhance microbial activity and fauna such as termites and earthworms which increase soil porosity (Uphoff *et al*., 2006). Also it was noted that shade trees roots improve the health of the soil by physically breaking the soil, increasing the organic matter and soil carbon that results in improving soil porosity (Muchane *et al*., 2020).

5.2.3 Effects of shade tree spacing on soil hydraulic conductivity

Hydraulic conductivity significantly ($P \leq 0.05$) influenced by shade spacing and seasons while all the interactions were insignificant. Generally the hydraulic conductivity was higher (11.187) at the control and lowest (6.837) at 6m by 6m shade spacing treatment as shown in table 5.1 above. Similarly hydraulic conductivity tended to have a positive linear relationship with shade tree spacing as shown in figure 4 below. The hot and dry season recorded a higher hydraulic conductivity (9.87) as compared to cool and wet season (7.53) as shown in table 5.1. Soil hydraulic conductivity showed a coefficient variation (CV) of 36.5 % (table5.1). The high coefficient variance (CV %) was because of the small experimental treatments and due to the fact that hydraulic conductivity is an erratic factor.

Findings of Jarvis *et al.* (2013) indicate that forest soils have a higher hydraulic conductivity than soils of other vegetation types. Beven & Germann (1982) observed and reported that both well connected pores in top soil known as macropores which determine soil hydraulic conductivity are also created by both living and decaying shade trees roots). Roots associated with macropores account for increase in hydraulic conductivity beyond the crown radius as the shade trees extend well beyond the crown (Ferro *et al*., 2003). The results shows that shade trees litter-fall or root decay increase organic matter which positively impacts soil structure and in turn results to increase in hydraulic conductivity.

The tree weight combined with movement of structural root conditions during windy conditions can compress soil over a centimeter-scale and reduce hydraulic conductivity. In addition increase in the rate of dissolution of soil minerals beneath trees, acidic litter fall cause soil acidification that reduces soil structural stability leading to loss of porosity and reduction in hydraulic conductivity (Mensah, 2015). Presence and abundance of fauna such as earthworms whose activity create more stable soil aggregates and add macroporosity is influenced by soil acidity, reduced abundance affects hydraulic conductivity negatively. (Hallam *et al*., 2020).

The impact of human (during plucking and use of machinery) particularly when the soil is wet compact the soil and therefore reduce soil hydraulic conductivity (Bogunovic *et al*., 2020). The results showed that input of organic matter by shade trees and the influence of their roots on the soil structure promote the establishment of soil hydraulic properties (Lopes *et al*., 2020). The homogeneity in hydraulic conductivity was a result of homogenous distribution of vegetation in each treatment. Hydraulic conductivity showed a positive linear relationship with the moisture content. This might also have been contributed by the percentage of clay content in the soil. This observation is consistent with the one that was found and reported by Benson & Daniel, (1990). Dry soil transmit more water than moist soil that is why hydraulic conductivity was higher during the HD season as compared to CW season.

5.2.4 Effects of shade tree spacing on the rate of infiltration

Table 5.2 below shows the rate of infiltration in centimeters per minute for all the treatments and in each season. It also shows the means for seasons and treatments. In addition it gives the covariance and the least significant difference of the rate of infiltration after the data was analyzed by GENSTAT software 15th editions and Duncan multiple test range used to separate the means

Table 5.2: Effects of Shade Trees Spacing On Soil Infiltration Rate

Shade trees spacing(m)	Season	Infiltration rate (cm/min)
6m by 6m	HD	16.45
	CW	14.35
8m by 8m	HD	16.82
	CW	13.01
Control	HD	12.79
	CW	12.6
Overall means		
Treatment /shade spacing (m)		
6m by 6m		15.40
8m by 8m		14.91
Control		12.70
Seasons	Hot and dry	15.35
	Cool and wet	13.32
CV		19.0
Treatments/shade spacing		
LSD ≤ 0.05		NS
LSD ≤ 0.01		NS
LSD ≤ 0.001		NS

*LSD-least significant difference *CV- covariance * NS- not significant *HD- Hot and dry * CW-Cool and wet

There was insignificant (P≤0.05) difference in terms of infiltration rate in all treatments and seasons alongside all the interactions. The rate of infiltration ranged from 12.70 cm/min at the control to 15.40 cm/ min at the 6m by 6m shade spacing treatment (table 5.2 above and figure 5.1 below).The rate of infiltration was higher in the hot and dry season (15.35 cm/min) as compared to (13.32cm/min) in the cool and wet season (table 5.2). The infiltration rate had a coefficient variance (CV) of 19.0% as shown in table 5.2 above. The results showed a negative linear relationship between the rate of infiltration and shade tree spacing as shown in figure 5.1 below. This is because it tended to increase with a decrease in shade tree spacing. Infiltration is among the hydrological processes in the ecosystem influencing soil erosion, run –off, water content and ground water recharge (Lozano Baez *et al*., 2019). Soil characteristics such as hydraulic conductivity, porosity, texture, swelling degree of soil colloids, organic matter, initial moisture content and chemical properties determine the rate of infiltration (Mazaheri & Mahmoodabadi, 2012).

Findings of Ilstedt *et al.*, (2016) indicate that there has been a confirmation of general impacts of shade trees on infiltration rate of which the magnitude heavily depends on distance to the nearest tree. Shade trees influence ecosystem characteristics such as soil roughness and leaf litter therefore changing the levels of runoff and affecting the rate of infiltration (Xia *et al*., 2019).

Infiltration capacity is influenced by the extent of vegetation and canopy cover (Pueyo et al., 2013). According to the findings made by Glover et.al (1962) vegetation enhanced infiltration. However the shade tree spacing appeared not to have any effect on the rate of infiltration (Belsky *et al*., 1993). This had resulted from the type of soil, perennial vegetation (tea) and lack of tillage. In addition the tea farms there is no tillage and there is no soil compaction.
Shade tree roots loosen the soil and reduce compaction hence increasing the rate of infiltration (Kozlowski, 1999). Shade tree spacing did not have substantial effect on the rate of infiltration due to heterogeneity of soils caused by shade roots (Schroth, 1998). The shade tree roots improve soil permeability resulting to increase in the rate of infiltration. Decayed process of shade trees roots could significantly reduce root density and increase relative porosity and substantially increase the rate of infiltration (Rahman *et al*., 2019).

Observation of higher infiltration rate in the shaded treatments that was made in this study (table 5.1 and figure 5.1) is likely to be associated with less compacted soil structure because of the organic matter from the shade trees that improve the soil structure and the shade tree roots that break the soil hard pan and is consisted with the results from the studies made by Lin and Richards (2007). Moreover Cannavaro *et.al* (2001) showed that high rate of infiltration is as a result of decreased runoff. Further the results showed a weak negative relationship between shade tree spacing and the rate of infiltration.

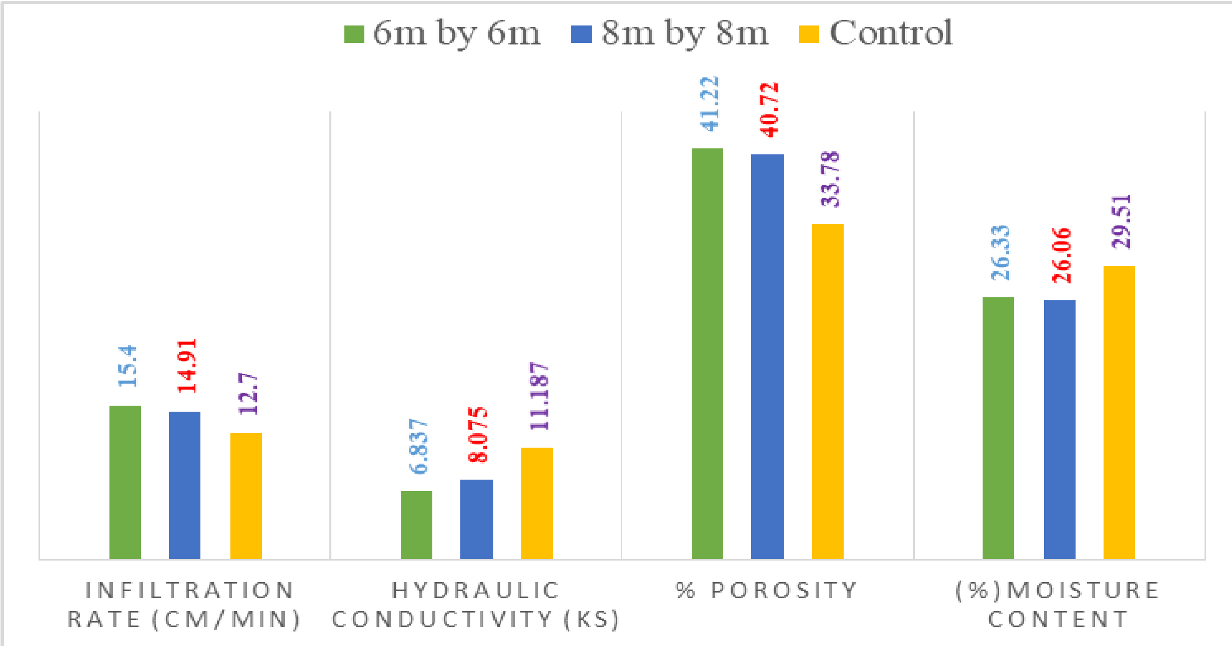


Figure 5.1: Effects of Shade Trees Spacing On Soil Characteristics

5.3 Effects of Shade Trees Spacing On Tea Yield and Quality

5.3.1 Effects of Shade Trees Spacing On Tea Yield

Table 5.3 below shows the total yields in in Kilograms of made tea from each treatment and in each season. It also shows the yields means for seasons and treatments. In addition it gives the covariance and the least significant difference of the total yields after the data shown was analyzed by GENSTAT software 15th editions and the separation of means done by Duncan multiple test range.

Table 5.3: Effects of Shade Trees Spacing On Tea Yield

Treatment/shade trees spacing(m)	Season	Yield (KGs)
6m by 6m	HD	76.6
	CW	60.7
8m by 8m	HD	108.8
	CW	111
Control	HD	155.4
	CW	148.1
Overall means		
Treatment /shade spacing (m)		
6m by 6m		68.6
8m by 8m		109.9
Control		151.8
Season	HD	113.6
	CW	106.6
CV (%)		13.4
Treatments/shade spacing		
LSD ≤ 0.05		18.98
LSD ≤ 0.01		27.00
LSD ≤ 0.001		39.08
Seasons		
LSD ≤ 0.05		NS
LSD ≤ 0.01		NS
LSD ≤ 0.001		NS

*LSD-least significant difference *CV- covariance * NS- not significant *HD-Hot and dry *CW-Cool and wet

There was significant ($P \leq 0.05$) difference in yield in all treatments while it was insignificant in relation to seasons. The total yield ranged from 68.6 Kg at the 6m by 6m shade spacing treatment to 151.8Kg at the control (table 5.3 above and figure 5.2 below). The yields were higher during the HD season (113.6Kg) as compared to the CW season (106.6) as shown in table 5.3 above. The yields had a coefficient variance (CV%) of 13.4% as shown in table 5.3 above The results indicated a linear relationship that was positive between shade trees spacing and tea yields in that yields increased with shade tree spacing as shown in figure 5 below. Shade trees depress yields when there is adequate conditions soil and water (McCulloch *et al.*, 1965). shade trees help in protecting tea from excess sunlight when soil moisture is insufficient, hence increasing tea yield (Carr, 1972). Shade removal coupled with increased doses of inorganic fertilizers produced much increased yields in Siri-lanka and East Africa.

Shade trees favour growth and development of tea by altering the environmental and micro-climatic conditions in a favorable way by reducing extreme temperatures and reducing water stress through relative humidity increase (Anglaaere, 2005). Moreover theyreduce temperature and water loss through lowering the rate of evaporation in the soil and crop transpiration. Other services such as carbon sequestration are enhanced by inclusion of shade trees (Cerda *et al.*, 2017). Shaded tea agro ecosystems enhance nutrient availability via complementary partitioning of resources. Overall all the above effects of shade trees causes increase in tea yields (Rigal *et al.*, 2020).In addition they enrich and improve soil health by addition of organic matter from leaf fall and decaying roots. Experimental results have shown that increase in organic matter leads to increase in yields (J. Wang *et al.*, 2015). They also protect tea from extreme temperatures, erosion and excessive insolation. At a given shade tree density or spacing, numerous combinations and interactions of climatic and edaphic factors and agricultural practices account for variation in tea yields (Tejwani, 2002). Yields and solar reception respond similarly to shade spacing (Mukherjee *et al.*, 2008).

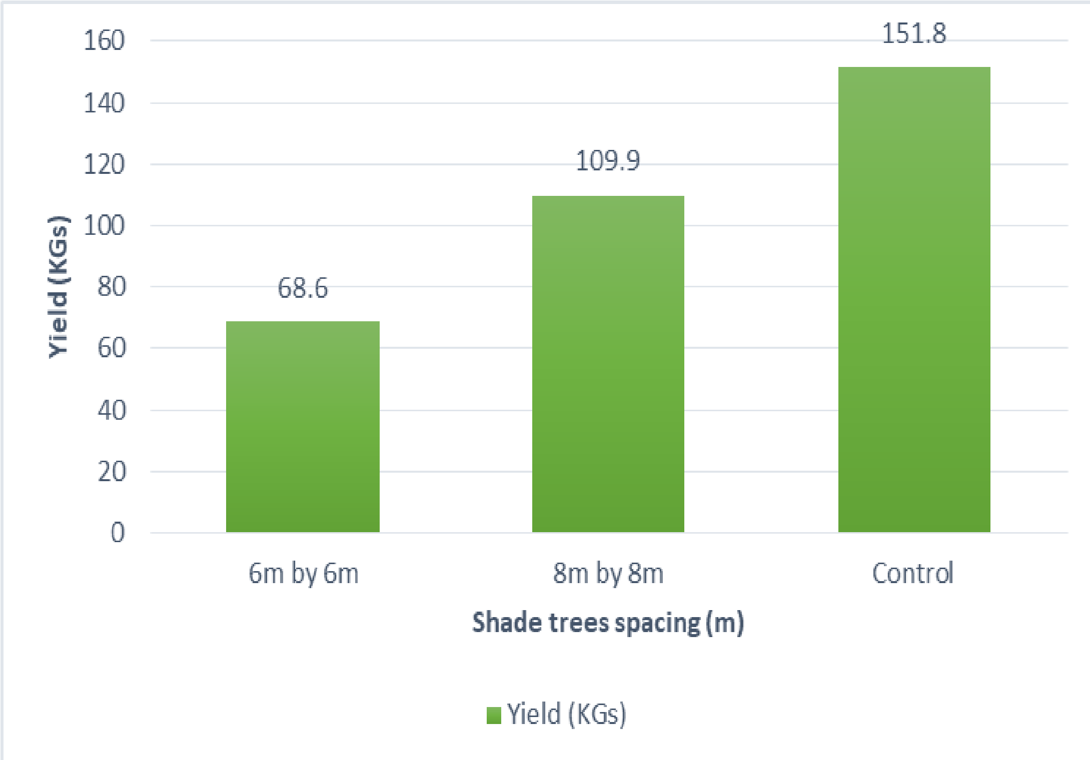


Figure 5.2 : Effects of Shade Trees Spacing On Tea Yield

5.3.2 Effects of shade trees spacing on tea quality

Table 5.4 below shows percentage total polyphenol content, percentage thearubigins and theaflavins (μ/g) of the tea leaves from each treatment and in each season. It also shows the seasonal, and treatment means for each parameter. In addition it gives the covariance and the least significant difference of the parameters after the data was analyzed by GENSTAT software 15th edition and the means separated by Duncan multiple test range.

Table 5.4: Effects of Shade Trees Spacing On Tea Quality

Treatment/shade trees spacing(m)	Season	% Total polyphenol content (TP)	*Theavlavins* µ/g(TF)	(%)*Thearubigs*
6m by 6m	HD	18.23	20.82	13.47
	CW	19.99	21.47	16.31
8m by 8m	HD	18.01	19.32	13.99
	CW	20.57	18.93	16.38
Control	HD	18.86	19.96	14.07
	CW	20.58	18.91	14.13
Overall means				
Treatment /shade spacing (m)				
6m by 6m		19.11	21.14	14.89
8m by 8m		19.29	19.13	15.19
Control		19.72	19.44	14.10
Seasons	HD	18.37	20.03	13.84
	CW	20.38	19.77	15.60
CV (%)		6.2	7.8	13.6
Treatments/shade spacing				
LSD ≤ 0.05		NS	NS	NS
LSD ≤ 0.01		NS	NS	NS
LSD ≤ 0.001		NS	NS	NS
Season				
LSD ≤ 0.05		NS	NS	NS
LSD ≤ 0.01		NS	NS	NS
LSD ≤ 0.001		NS	NS	NS

*LSD-least significant difference *CV- covariance * NS- not significant *HD- Hot and dry * CW- Cool and wet

There was insignificant (P≤0.05) difference in the total polyphenol content, *theaflavins* and *thearubigins* an all the treatments and seasons including all the interactions in the study. The total polyphenol content ranged from 19.11% at the 6m by 6m shade spacing treatment to 19.72% at the control and the theaflavins ranged from 19.13 µ/g at the 8m by 8m shade trees spacing to21.14 µ/g at the 6m by 6m shade trees spacing while the *thearubigins* ranged from

14.10% at the control to 15.19 at the 8m by 8m shade trees spacing treatment (table 5.4 and figure 5.3). Total polyphenol content had a coefficient variation (CV %) of 6.2% and had a coefficient variation (CV %) of 7.8% while *thearubigns* had a coefficient variation (CV %) of 13.6% as shown in table 5.4 above. The total polyphenol content was higher at the control (19.72%) and *theaflavins* were higher (21.14 µ/g) at the 6m by 6m shade trees spacing while the *thearubigins* were higher (15.119%) at the 8m by 8m shade trees spacing (figure 6 below).From the results it was observed that the shade trees spacing had a positive linear relationship with the total polyphenol content and thearubigins while showed a negative linear relationship with the *theaflavins* (figure 5.3 below).

High quality tea production requires a typical agro-climatic conditions (Shah & Pate, 2016). Shade management in tea farms influence the amount of quality related metabolites in tea that is yet to be harvested (Tounekti *et al*., 2013). According to Lehlohonolo et al. (2013), shading defined tea quality characteristics by increasing chlorophyll content and hindering the process of photosynthesis.

De Costa *et al*., 2007, findings indicated that photosynthesis and other physiological plant processes that determine growth of tea were affected by shade resulting in influence on quality of tea. Guyo *et. al* (1996) and Mohotti *et al* (2020) found that High elevation shade trees had a positive effect on tea quality, due to low temperatures. Studies that were made on warm climates which are sub-optimal tea growing areas showed that tea quality was enhanced under shade(Hajiboland, 2017). This is because they improve the microclimatic conditions of tea through reducing the temperatures to more optimal ranges favorable for photosynthesis and physiological processes in tea. Yu *et .al* (2020) found that the impact of shade on total polyphenol content and corresponding black tea pigments such as theaflavins and thearubigins of newly developed leaf was of high quality. Shade enhances the amount of *theaflavin* in made tea by affecting the biochemical and physiological factors accountable for formation of theaflavins (Owuor *et al*., 1988). According to Hazarika et.al (1984) shading changed chemical tea parameters such as theaflavins and *thearubigins* were all changing in a favourable direction. Tea produced under shade had higher *theaflavin* and reduced thearubigins concentrations with a better flavor as compared to the one produced without shade (Ahmed *et al.*, 2019). According to Owuor *et al* (1988) removal of shade from tea farms led to production of low quality tea. Moreover it has been suggested theanine and caffeine concentrations in tea leaves which influences the concentration of theaflavins in tea are increased by shade levels. In addition the conversion of catechins into theaflavins in pre-harvest tea is enhanced by the use of shading in tea farms (Tounekti *et al*., 2013).

Observations made from the study showed that shade trees spacing had influence on the concentration of the three tea quality parameters in this study as shown in table 5.4 above and figure 5.3 below. This is consistent with the results from the work of Muguleta (2017) who found that shade not only influences amount of sunlight received by tea but also affects ground and air temperature, humidity and soil hydrologic characteristics. The above aspects influences leaf chemistry in various ways that affect tea quality (Mulugeta, 2017). There were differences in tea quality in each shade spacing (table 5.4 above). Shade trees spacing was more influential on the total polyphenol content than other tea quality parameters

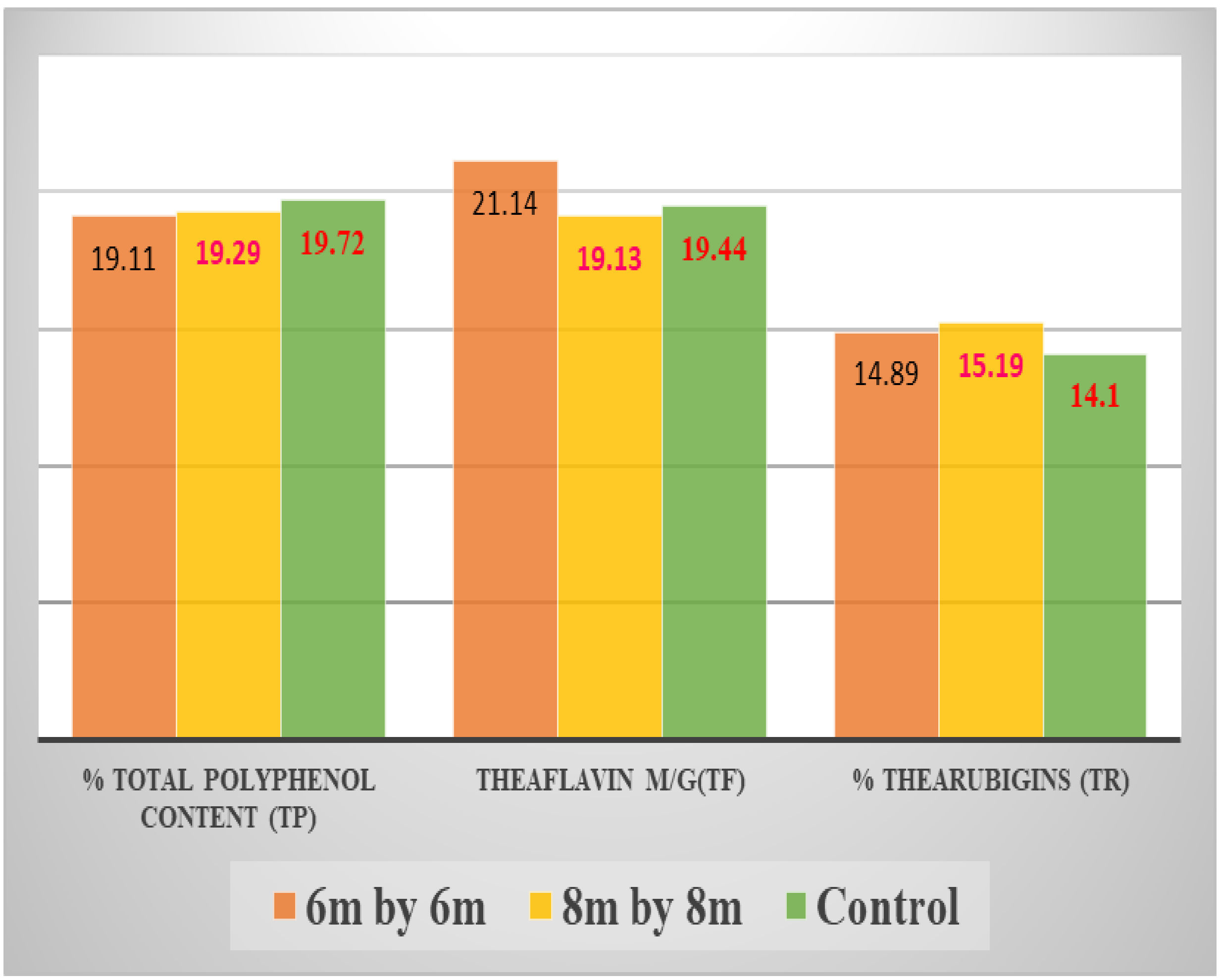


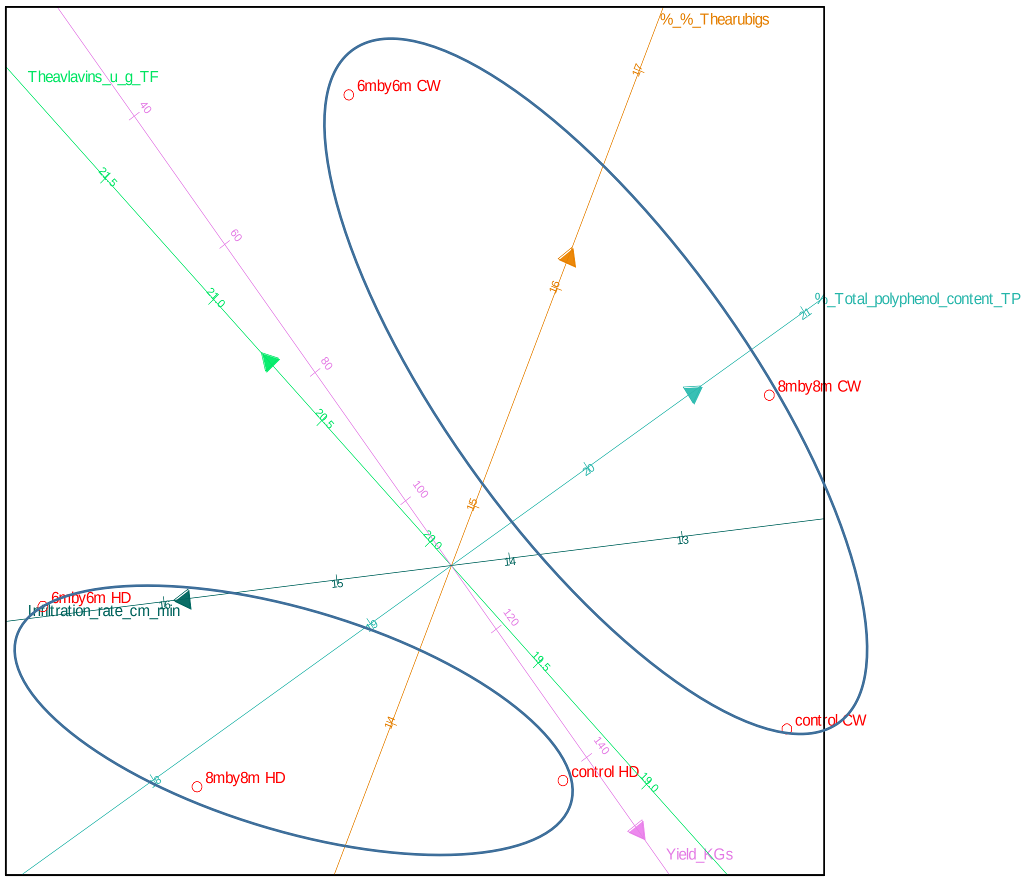
Figure 5.3: Effects of Shade Trees Spacing On Tea Quality

5.4 Principal component analysis for soil characteristics, tea yields and quality

Principal component analysis was carried out to scatter study variables (shade tree spacing, soil characteristics, tea yield and quality).

5.4.1 Principle Component Analysis of Soil Infiltration Rate, Tea Yield and Quality

Principal components biplot (86.78%)



PC-1 (50.75%)

CW -Cool and wet season, HD- Hot and dry season, and PC- principle component

Figure 5.4: Shattered Diagram Based On Shade Trees Spacing, Soil Infiltration Rate, Tea Yield and Quality

Extreme cluster separation of yields, tea quality parameters and the rate of soil infiltration occurred based seasonal conditions and shade trees spacing. 8m by 8m and 6m by 6m shade trees spacing and the control were dispersed both for CW season were dispersed to the right extremes (figure 5.4) while they were dispersed to the right all of them for the CW season. Five PCs were obtained. Principle component one accounted for 50.75% variation while principle component two accounted for 36.03% accruing the total cumulative variation to 86.78%. From the results the important parameters in PC1 was *Thearubigins* while PC2 was dominated by the total polyphenol content as shown in the figure above. Insignificant contribution to total variance was shown by yields with a variation of 0.16% (figure5.4).Moreover negative correlations were revealed for the rate of infiltration in total polyphenol content and *theaflavins*. The negative correlations were also found for yield in *thearubigins* and infiltration rate. The rate of infiltration had a negative variation in thearubigins, total polyphenol content and theaflavins while it had a positive variation with the yields (appendix III). *Thearubigins* had a positive variation with all the analyzed parameters as shown in appendix III.

5.4.2 Principal component analysis for soil characteristicS

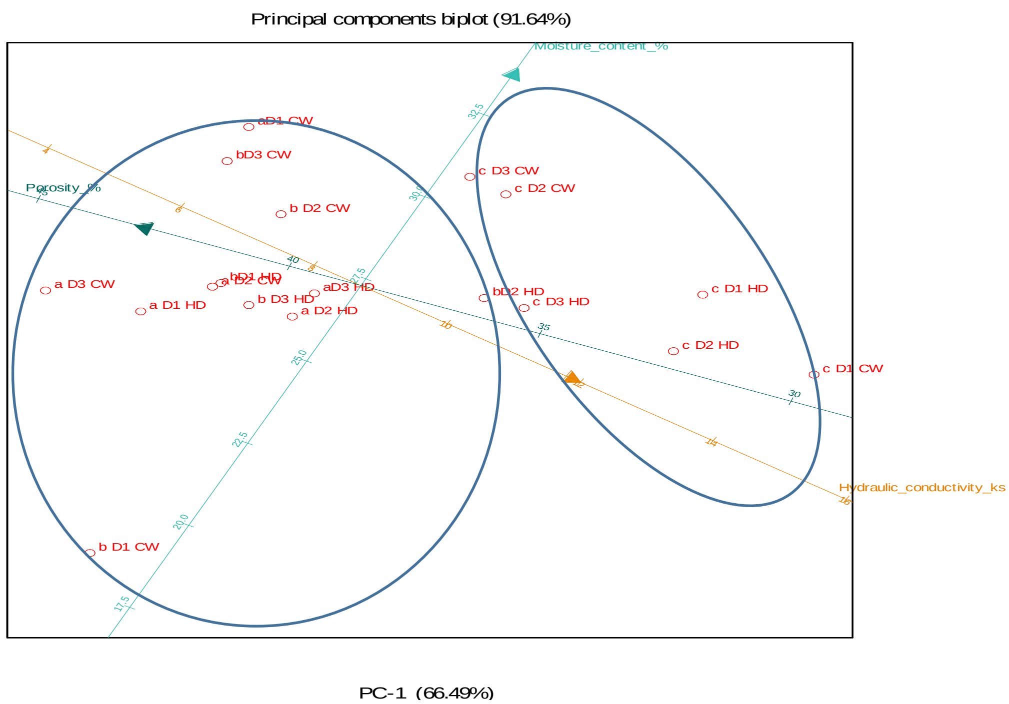


Figure 5.5: Shatter Diagram Based On Shade Trees Spacing and Soil Characteristics

a- 6m by 6m shade tree spacing, b-8m by 8m shade tree spacing, c- Control, HD- hot and dry season, CW- cool and wet season, D1;0-20cm, D2; 20-40cm, D3; 40-60 cm, PC- Principal component.

Principal component analysis was used to scatter the study variables (shade tree spacing, soil characteristics and seasons. Two distinct clusters were clearly differentiated based on shade tree spacing (figure 5.5) above. Among the 3 PCs values generated the first two components contributed to 91.64% total variation variance. The control treatment was dispersed to the extreme right while the other two shade trees treatments (6m by6m and 8m by 8m) were dispersed to the extreme left as shown in figure 5.5 above. Negative variation was revealed for hydraulic conductivity in moisture content and porosity in hydraulic conductivity. Moreover positive variation was seen for moisture content in porosity and hydraulic conductivity (appendix III). Porosity showed a negative variation with hydraulic conductivity and a positive variation with the soil moisture content as shown in appendix III. This results showed either positive or negative between the parameters that were under study as shown in table 5.6 and appendix III. Moreover from the results it was evident that the main cause of variation in the parameters was shade trees spacing that is why from the principal component analysis the variables were scattered in relation to the treatments.

5.5 Correlation between shade trees spacing, soil characteristics, tea yields and quality

Table 5.5: Pearson Similarity Coefficient Matrix

	% Moisture content	% Porosity	% Thearubigins (TR)	%total polyphenol content (TP)	Hydraulic Conductivity (Ks)	Infiltration rate (cm\min)	Theaflavins (ug\TF)	Yield (KGs)
%Moisture content	-							
%Porosity	-0.9915	-						
%*Thearubigins* (TR)	-0.9802	0.9461	-					
%Total polyphenol content(TP)	0.9353	-0.9734	-0.8468	-				
Hydraulic Conductivity (Ks)	0.9393	-0.976	-0.8528	0.9999**	-			
Infiltration rate(cm\min)	-0.971	0.9938*	0.9044	-0.9928	-0.9941	-		
Theaflavins (ug\TF)	-0.3045	0.426	0.11	-0.6219	-0.6129	0.5236	-	
Yield(KGs)	0.831	-0.8964	-0.7045	0.9741	0.9714	-0.94	-0.7829	-

*Correlation is significant at the 0.05 level

**Correlation is significant at 0.01

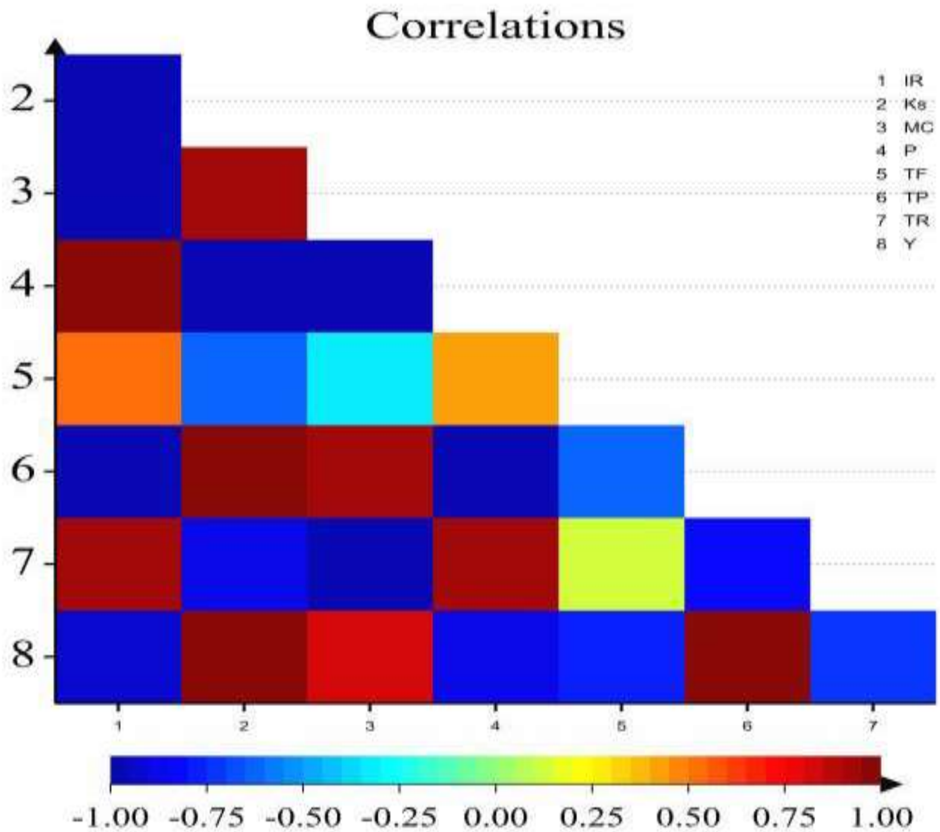


Figure 5.6: Correlation Analysis of Shade Trees Spacing, Soil Characteristics, Tea Yields and Quality

(1)IR- Infiltration rate (cm/min), (2) Ks- Hydraulic conductivity, (3) MC- % Moisture content, (4) P- % Porosity, (5) TF-Theaflavins (μ/g), (6) TP- %Total polyphenol content, (7) TR- %Thearubigins, (8) Y- Yields (Kgs)

The correlation between shade trees spacing, soil characteristics, tea quality and yield was analyzed and the results showed a significant relationship of $P \leq 0.05$ between soil infiltration rate and porosity and between hydraulic conductivity and total polyphenol content while the other relationships were insignificant. In general the rate of infiltration had a positive correlation with porosity as shown in table 5.6 and figure 5.6 above. Also the soil hydraulic conductivity had a positive correlation with total polyphenol content (table 5.6). Theaflavins had a negative correlation with the soil moisture content, hydraulic conductivity, and total polyphenol content while it showed a positive correlation with porosity, thearubigins and the soil infiltration rate (figure 5.6). There was a positive correlation of yields in moisture content, hydraulic conductivity as per Shittu *et al.* (2017) and total polyphenol content and a negative correlation in thearubigins, porosity, infiltration rate and theaflavins. Moreover soil infiltration rate had a positive correlation in porosity which was consistent with (Helalia, 1993) and thearubigins while it showed a negative correlation in porosity, total polyphenol content and hydraulic conductivity. Total polyphenol content had a positive correlation in moisture content while it showed a negative correlation in porosity and thearubigins. From the results it was clearly noted that there was either a positive or negative correlation between the soil characteristics, tea yields and tea quality that was resulting from the shade tree spacing treatments. This evident showed that both the soil characteristics, tea yields and quality are affected by shade trees spacing.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

It summarizes study results and gives recommendations depending on the findings. After completion of this study some research gaps were found and this chapter therefore gives prepositions for more research to be undertaken.

6.1 Summary of Findings

The ecological associations that occurs between shade tea (*Camellia sinensis L.kuntze*) consists of the impact on the hydrological cycle, climatic conditions, soil, crop management, pathogens and insects. Shade trees mitigate extreme climatic conditions and nutritional imbalance hence reducing the stress of tea.

Soil-moisture relationships form the epicenter of ecohydrology. This is due to the fact that plant physiology is directly linked to water availability in the soil. Shade trees are one of the major determinant of soil- moisture relationship in tea farms due to the fact that they influence factors such as soil characteristics(organic matter, hydraulic conductivity, infiltration rate, soil moisture content, porosity), temperature and evaporation rate all of which influence the amount of soil moisture.

Shade tree spacing affect the density of vegetation in a given area. Shade trees improve the soil structure by stimulating litter decomposition, nutrient cycling and providing erosion control. Moreover they mitigate climate change and enhance functional biodiversity. The following research questions guided the study:

a) *Which shade tree spacing affects soil hydrologic characteristics most significantly*
b) *Which is the most susceptible soil hydrologic characteristic to shade tree spacing*
c) *Does water availability and movement in the soil differ with the shade trees spacing.*
d) *what is the relationship between shade trees spacing, soil characteristics and the tea production*
e) *Which is the ideal shade tree spacing to be used for optimum tea farming.*

The following hypotheses were tested:

1) H_o: *There is no significant difference in soil physical attributes (water movement (infiltration), hydraulic conductivity, pore space,) under different shade spacing.*
2) H_o: *Shade tree spacing have no significant effect on tea yield and quality*

3) *H_o: There is no significant relationship between shade tree spacing, soil hydrologic characteristics and tea attributes*

6.1.1 Effects of shade trees spacing on soil hydrologic characteristics.

Shade trees spacing affects the soil characteristics by improving the structure of soil through the input of organic matter by leaf fall and root decay and regulating the soil and air temperature that prevent water loss and conserve soil moisture. Moreover the root penetration affect the pore space hence influencing water entry and movement in the soil. The results from the study as shown in Figure 4, indicated that the 6m by 6m shade trees spacing affected the soil characteristics most significantly. This is because it had the highest rate of infiltration, porosity and hydraulic conductivity as compared to the 8m by 8m shade trees spacing. Moreover the results on the effects of shade trees spacing indicated that the control treatment which had no shade had the least infiltration rate and porosity while it had the highest moisture content and hydraulic conductivity. In addition the soil characteristics results showed that the 8m by 8m shade trees spacing had only higher hydraulic conductivity when compared to other soil characteristics than the 6m by 6m shade trees spacing.

6.1.2 Most Susceptible Soil Hydrologic Characteristic to Shade Tree Spacing

All the soil characteristics that were under study were affected by the shade trees spacing as shown in table 5.2. However the findings on the effects of shade trees spacing on soil characteristics obtained from the study as shown in figure 5.4 indicated that porosity was the most susceptible soil characteristic to shade spacing since it was the one that showed the highest variation. In addition the findings indicated that the soil infiltration rate showed the least variation in relation to shade trees spacing. The findings on the impacts of shade spacing on soil characteristics also indicated almost similar differences in the hydraulic conductivity and moisture content of the soil.

6.1.3 Effect of Shade Trees Spacing On the Availability and Movement of Water in the Soil

Water availability and movement is influenced by shade trees spacing. Findings from the study on impacts of shade spacing on soil characteristics indicate that the moisture content and porosity which determines the amount of water available in the soil are influenced by shade trees spacing as shown in figure 5.4. Moreover findings from the study on soil characteristics indicate that the rate of infiltration, hydraulic conductivity, porosity and moisture content all of which determine the water movement in the soil are affected by shade tree spacing.

6.1.4 Relationship between Shade Trees Spacing, Soil Characteristics and the Tea yield and quality

Results of the correlation analysis indicated both positive and negative correlations between shade trees spacing, soil characteristics, tea yield and quality. The findings indicated that there was a positive and significant $P \leq 0.05$ relationship between porosity and the rate of infiltration and between the hydraulic conductivity and the total polyphenol content. All the other relationships both negative and positive were insignificant.

6.1.5 The Ideal Shade Tree Spacing to be used for Optimum Tea Farming

Ideal shade spacing is the one that improves soil hydrologic characteristics and enhance the production of high yield and quality of tea simultaneously. Findings obtained indicated that spacing influenced soil characteristics, tea yields and quality. Moreover the findings of ecohydrologic effect of shade spacing on tea yields and quality showed a significant difference between shade treatments and the control. However the findings indicated minimal difference between the 6m by 6m shade trees spacing and the 8m by 8m shade trees spacing since they had almost similar and equal effect on the soil characteristics, tea yields and quality. Therefore the findings of the ecohydrologic effects of shade trees spacing on soil characteristics affecting tea yields and quality indicate that both the 6m by 6m shade trees spacing and the 8m by 8m shade trees spacing are ideal for optimum tea production pending research on other shade trees spacing.

6.2 Conclusion

The major aim of the study was to gain better knowledge of ecohydrological effects of shade spacing on soil characteristics affecting tea yields and quality. The results from the study shows that Shading systems are very important in tea farms taking into consideration their ability of modifying the microclimatic and environmental conditions to favorable levels for tea plant.

The study revealed that using shade trees in tea farms for ecohydrology is of critical importance such as; soil water conservation, mitigation of climate change, regulation of air temperature and source of organic matter that improves tea productivity and conserve the environment.

The relative importance of shade trees and general influence of the various associations of shade and tea heavily relies on the site conditions. Shade spacing regimes are critical in achieving ecosystem benefits such as improved tea yields and quality. However the effects of shade trees spacing on soil characteristics are not well understood. Shade trees spacing influence organic matter inputs and nutrients which are factors that majorly determine soil properties.

Shade agroforestry in tea farms provide a number of ecohydrological effects that helps to sustain high productivity in tea farms, improve farmers livelihoods and conserve the environment and mitigation against climate change. A sustainable agricultural policy of agroforestry that focuses on increasing productivity and quality, and environment and soil conservation requires a better understanding ecohydrologic effects of shade tree spacing on soil characteristics.

6.3 Recommendations

Availability of awareness about use of shade trees to improve the micro-climatic conditions and the environment of tea is already present in a broad and extensive way. Their effects on the soil characteristics, tea yield and quality cannot be overemphasized. Results from this work have clearly shown that shade spacing in tea farms determine the extent and levels of ecohydrology of shade trees on soil characteristics that influence the tea yield and quality. The following recommendations have been proposed from the study.

In order to maintain and enhance high tea production, maintaining and conserving chemical soil properties is not enough. There is need to ensure other factors such as good agricultural practices, weather factors and soil hydrologic characteristics are kept at the required levels in order to have consistency and improved tea production by using environmental friendly techniques such as agroforestry of shade trees in tea farms.

6.4 Areas of further research

1) Further studies should be done in different geographical and hydro-meteorological sites to identify the ecohydrological impacts of shade spacing on the soil hydrological properties affecting tea yield and quality
2) Further trials need to be done to determine ecohydrologic impacts of different species of shade trees on soil characteristics
3) Study should be conducted on other cultivars and clones of tea to evaluate the effects of shade trees spacing on soil characteristics that influence tea yield and quality.
4) The current study dealt with selected soil characteristic and plain tea quality parameters, there is need for further studies that involve soil characteristics and tea quality parameters that have not been tackled.
5) Research need to be conducted on various aspects of shade such as age, height, size of canopy, shade establishment and management practices that includes different spacing and intervals of pruning and how they interact with the tea environment in farms.

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APPENDICES

APPENDIX I: Field and Laboratory Results Tables

Table (a) influence of shade trees spacing on soil characteristics

Treatment (spacing)	Depth(cm)	Porosity (%)		Hydraulic conductivity (ks)		Moisture Content (%)		Infiltration rate cm/min	
		HD	CW	HD	CW	HD	CW	HD	CW
6m by 6m Rep I	0-20	44	41	8.58	3.31	23.98	24.21	17.05	10.49
	20-40	43	43	8.52	3.32	24.05	20.59		
	40-60	36	39	7.46	4.81	24.4	23.2		
6m by 6m Rep II	0-20	43	41	6.17	6.14	26	29.4	16.45	16.3
	20-40	34	45	7.59	6.87	27.47	24.58		
	40-60	47	43	5.19	3.42	31.03	18.51		
6m by 6m Rep III	0-20	36	44	2.85	8.4	24.01	36.9	15.86	16.25
	20-40	41	39	8.41	13.26	26.3	33.12		
	40-60	36	47	12.82	5.95	24.8	31.36		
6m by 6m Control Rep I	0-20	34	22	13.43	17.01	30.97	28.59	16.33	11.29
	20-40	31	33	13.35	9.1	30.79	30.31		
	40-60	40	35	14.76	8.79	28.58	29.67		
8m by 8m Rep I	0-20	49	35	6.06	9.06	25.65	3.02	17.39	11.16
	20-40	40	40	5.84	7.7	27.73	25.4		
	40-60	43	34	5.7	5.02	25.96	25.13		
8m by 8m Rep II	0-20	42	34	11.16	7.36	27.08	23.41	16.75	16.57
	20-40	31	39	15.65	9.02	28.65	29.41		
	40-60	37	44	11.6	6.12	26.97	32.08		
8m by 8m Rep III	0-20	41	49	9.64	6.02	26.55	28.59	13.56	16.45
	20-40	45	44	13.21	5.38	28.46	30.31		
	40-60	44	42	7.51	3.3	24.93	29.67		
8m by 8m Control Rep I	0-20	23	29	17.47	10.02	31.21	29.62	9.61	10.98
	20-40	31	39	12.81	10.19	27.52	32.51		
	40-60	33	33	14.3	9.02	28.82	35.64		
8m by 8m Control Rep II	0-20	42	31	7.39	11.79	28.04	28.23	15.19	10.38
	20-40	38	37	13.45	7.82	27.13	29.27		
	40-60	38	39	5.64	5.02	27.5	26.74		

Table (b) effects of shade trees spacing on the soil infiltration rate

Treatment (Shade Trees Spacing)	Infiltration Rate (cm/min)	
	HD Season	CW Season
6m by 6m Rep I	17.05	10.49
6m by 6m Rep II	16.45	16.31
6m by 6m Rep III	15.86	16.25
6m by 6m Control Rep I	16.33	11.29
8m by 8m Rep I	17.39	11.16
8m by 8m Rep II	16.75	16.57
8m by 8m Rep III	13.56	16.45
8m by 8m Control Rep I	9.61	10.98
8m by 8m Control Rep II	15.19	10.38

Table (c) effects of shade trees spacing on tea yield

Treatment (Shade Trees Spacing)	Yield (Kgs)	
	HD season	CW season
6m by 6m Rep I	60.3	51.8
6m by 6m Rep II	81.9	53
6m by 6m Rep III	87.5	77.4
6m by 6m Control Rep I	109.6	108.3
8m by 8m Rep I	91.5	86.6
8m by 8m Rep II	125.4	138.1
8m by 8m Rep III	147.2	136
8m by 8m Control Rep I	165.1	164.3
8m by 8m Control Rep II	154	144.1

Table (d) Influence of shade trees spacing on tea quality

shade Trees spacing (m)	Season	TF (µmole/g)	TF %	TR %	% TP
6m by 6m Rep I	Hot and dry	18.64	1.66	12.30	18.73
8m by 8m Rep I		14.75	1.39	15.06	17.41
6m by 6m Rep II		23.13	1.13	14.70	18.10
8m by 8m Rep II		21.45	1.25	14.21	18.24
6m by 6m Rep III		20.69	1.40	13.40	17.87
8m by 8m Rep III		21.76	1.63	12.72	18.39
8m by 8m Control Rep I		20.57	1.86	14.04	17.69
8m by 8m Control Rep II		21.56	1.17	13.64	19.19
6m by 6m Control Rep I		17.76	1.41	14.54	19.71
6m by 6m Rep I	Cool and wet	17.52	1.14	12.69	20.39
8m by 8m Rep I		13.94	1.34	16.83	20.14
6m by 6m Rep II		22.73	1.71	16.16	21.60
8m by 8m Rep II		21.45	1.61	17.33	22.24
6m by 6m Rep III		24.15	1.86	20.07	17.99
8m by 8m Rep III		21.41	1.19	14.98	19.34
8m by 8m Control Rep I		19.64	1.24	14.99	20.71
8m by 8m Control Rep II		19.05	1.18	12.11	21.37
6m by 6m Control Rep I		18.05	1.47	15.28	19.65

APPENDIX II: Analysis of Variance Tables

1. Analysis of variance table for soil porosity, shade spacing, depths and seasons

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Shade spacing	2	623.37	311.69	13.4	<.001***
Depth	2	25.15	12.57	0.54	0.587ns
Season	1	0.02	0.02	0	0.978NS
Shade spacing. Depth	4	110.52	27.63	1.19	0.334
Shade spacing. Season	2	41.59	20.8	0.89	0.418
Depth. Season	2	78.48	39.24	1.69	0.2
Shade spacing. Depth. Season	4	19.41	4.85	0.21	0.932
Residual	34	790.63	23.25		
Total	53	1819.2			

2. Analysis of variance table for soil moisture content, shade spacing, depths and seasons

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Shade trees spacing	2	132.61	66.3	3.59	0.038*
Depth	2	23.1	11.55	0.63	0.541
Season	1	0.44	0.44	0.02	0.878
Shade spacing. Depth	4	111.92	27.98	1.52	0.219
Shade spacing. Season	2	22.94	11.47	0.62	0.543
Depth. Season	2	14.48	7.24	0.39	0.678
Shade spacing. Depth. Season	4	146.14	36.54	1.98	0.12
Residual	34	627.25	18.45		
Total	53	1206.52			

3. Analysis of variance table for infiltration rate, shade spacing and seasons.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Shade tree spacing (m)	2	24.983	12.491	1.68	0.235
Season	1	18.625	18.625	2.5	0.145
Shade tree spacing. Season	2	9.912	4.956	0.67	0.535
Residual	10	74.441	7.444		
Total	17	135.044			

4. Analysis of variance table for yield, shade spacing and seasons.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Shade trees spacing	2	20733.8	10366.9	47.62	<.001***
Season	1	219.8	219.8	1.01	0.339
Shade tree spacing. Season	2	243.2	121.6	0.56	0.589
Residual	10	2177.2	217.7		
Total	17	24527.5			

5. Analysis of variance table for soil hydraulic conductivity, shade spacing, depths and seasons

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Shade spacing	2	180.79	90.4	8.97	<.001***
Depth	2	36.46	18.23	1.81	0.179
Season	1	74.3	74.3	7.37	0.010*
Shade spacing. Depth	4	34.91	8.73	0.87	0.494
Shade spacing. Season	2	7.11	3.55	0.35	0.705
Depth. Season	2	26.95	13.47	1.34	0.276
Shade spacing. Depth. Season	4	10.31	2.58	0.26	0.904
Residual	34	342.54	10.07		
Total	53	729			

6. Analysis of variance table for tea quality, shade spacing and seasons.

a) Total polyphenol content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Shade trees spacing(m)	2	1.162	0.581	0.41	0.676
Season	1	18.205	18.205	12.79	0.005
Shade trees spacing. Season	2	0.68	0.34	0.24	0.792
Residual	10	14.239	1.424		
Total	17	35.937			

b) **Theaflavin**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Shade spacing (m)	2	14.12	7.06	2.9	0.102
Season	1	0.309	0.309	0.13	0.729
Shade spacing.Season	2	2.199	1.1	0.45	0.649
Residual	10	24.358	2.436		
Total	17	129.028			

c) Thearubigins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Shade spacing (m)	2	3.786	1.893	0.47	0.637
Season	1	13.947	13.947	3.48	0.092
Shade spacing.Season	2	6.7	3.35	0.83	0.462
Residual	10	40.13	4.013		
Total	17	66.941			

APPENDIX III: Principle Component Analysis Tables

a) Principle component analysis for soil infiltration rate, tea yield and quality

Tea quality, yield and soil infiltration rate	1	2	3	4	5
%Thearubigs	0.25409	0.63147	0.32901	0.6331	0.16618
%Total polyphenol content (TP)	0.52417	0.35557	0.02679	-0.67706	0.37375
Infiltration rate(cm/min)	-0.58126	-0.06894	0.51076	-0.12536	0.61708
Theaflavins (ug/mol)	-0.39768	0.41975	-0.75409	0.05222	0.30706
Yield (KGs)	0.40579	-0.5421	-0.24802	0.34977	0.59801

b) Principal component analysis for soil characteristics

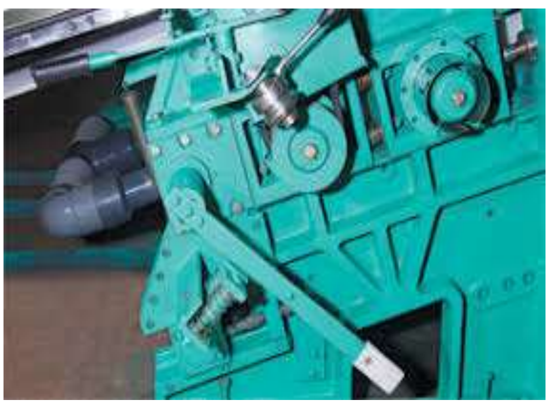
Soil characteristics	1	2	3
Hydraulic conductivity (ks)	0.62125	-0.38872	0.6804
Moisture content (%)	0.44928	0.88809	0.09716
Porosity (%)	-0.64203	0.24533	0.72637

APPENDIX IV: Study Apparatus

Soil auger

Spectrophotometer

CTC machine



Vortex mixer

rometer

APPENDIX V: Photographs from the Field

(a)*Millitia dura* shade trees

(b) Soil sampling

(c)Determination of the rate of infiltration

(d) Leaf sampling

APPENDIX VI: Photographs from the Laboratory Analysis

(e) Drying soil samples

(f) Determination of soil moisture content

(g) Determination of soil porosity

(h) Determination of hydraulic conductivity

(i) Tea quality analysis

APPENDIX VII: Work Plan

Activity	Months			
	Oct-Nov 2020	Dec 2020	Jan-July 2021	August - September2 021
Development of proposal and submission				
Development and piloting of instruments				
Data collection, data entry, organization, analysis and interpretation				
Report writing, defense, and submission of the report				

APPENDIX VIII: Research Budget

Activity	**Quantity**	**Unit cost (Kshs.)**	**Total cost (Kshs.)**
Proposal Finalization and defense at the School			
Printing	50 pages	10	500
Binding	5 copies	1000	5,000
Sub-total			5,500
Development and piloting of instruments			
Stationary cost	Lump sum	500	500
Contingency cost	Lump sum	2,000	2,000
Sub-total			2,500
Data Collection			
Hiring of Research Assistants	Lump sum	25,000	20,000
Transport	Lump sum	15,000	15,000
Lunch for staff	Lump sum	10,000	10,000
Subtotal			45,000
Data Entry, Analyses and Report Writing			
Stationary	Lump sum	1000	1000
Data entry and analysis (GENSTAT)	Lump sum	25000	25,000
Subtotal			26,000
Journals and Thesis Defense and Submission			
Printing of Project Paper	100 pages	10	900
Binding	5 copies	1000	5,000
Subtotal			5,900
Miscellaneous expenses	Lump sum	5,000	5000
Grand Total			**89,900**