

**EFFECTS OF CLIMATE VARIABILITY ON LARGE SCALE COFFEE  
PRODUCTION IN KIGUTHA COFFEE ESTATE IN KIAMBU  
COUNTY, KENYA**

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Master of Environmental Studies (Climate Change and Sustainability) in the  
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**DECLARATION**

**Declaration by Candidate**

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

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**DEDICATION**

This work is dedicated to my parents Mr. Henry Koge and Mrs. Nyawira Koge for their commitment and sacrifice towards my education.

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**ACRONYMNS AND ABBREVIATIONS**

<b>BBC</b>	-	Berry Blight of Coffee
<b>CBD</b>	-	Coffee Berry Disease
<b>CBK</b>	-	Coffee Board of Kenya
<b>CIAT</b>	-	International Centre for Tropical Agriculture
<b>CRF</b>	-	Coffee Research Foundation
<b>FAO</b>	-	Food and Agriculture Organization
<b>ICIPE</b>	-	International Centre of Insect Physiology and Ecology
<b>ICO</b>	-	International Coffee Organization
<b>IPCC</b>	-	Intergovernmental Panel on Climate Change
<b>KMD</b>	-	Kenya Meteorological Department
<b>UNFCCC</b>	-	United Nations Framework Convention on Climate Change
<b>WRMA</b>	-	Water Resource Management Authority

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## ABSTRACT

Dealing with declining coffee amidst challenges occasioned by climate variability is a problem affecting large-scale coffee production in Kenya. Climate variability has affected coffee output by changing distribution of pests and diseases, hindering growth and affecting amount of water supplied for irrigation. Kiambu is a major coffee producer in Kenya and coffee is mostly grown in estates. Climate variability makes it difficult for farmers to predict when to plant and interferes with coffee development cycles. Since plantations in Kiambu are within the same geographical zone with similar rainfall and temperature patterns, a study on this plantation may serve as an example on how climate variability is generally affecting large-scale coffee production in the county. Objectives of this study were; to investigate variability in rainfall and temperature patterns (1991-2010), how this has affected yield, spread of pests and diseases associated with changes in rainfall and temperature patterns, how water supply for irrigation has been affected and coping mechanisms adopted. The study was carried out in Kigutha Coffee Estate in Kiambu County and took 16 months (January 2012-April 2013). Purposive sampling was used to select 10 permanent workers and 20 casuals. Questionnaires were distributed to permanent workers and interviews conducted. Focus group discussions were conducted with casual workers who have been there for not less than 10 years. Statistical analysis was used to calculate Pearson correlation( $r$ ) with significance of 0.05 using SPSS to determine relationship between the two climate parameters and yield and water supplied for irrigation. Negative correlation ( $r = -0.7$ ) suggests that when temperature increases, yield reduces and positive correlation ( $r = 0.494$ ) shows when rainfall reduces, yield also reduces. Temperature has generally increased (1991-2010), with annual temperatures falling below overall mean with lows of  $17.7^{\circ}\text{C}$  in 1995 and  $17.89^{\circ}\text{C}$  in both 1992 and 1993, then rising above the mean from 2002 to 2010 with highs of  $19^{\circ}\text{C}$  in 2008 and  $18.75^{\circ}\text{C}$  in 2009. Erratic rainfall, dry spells and high temperature affect water supplied for irrigation;  $r = 0.411$  suggests that when temperature increases, water supplied to the estate for irrigation increases and  $r = -0.477$  shows when rainfall increases, water supply for irrigation reduces. Time series graph shows fluctuations in rainfall averages with 5-year moving average; from 84.19mm (1991-1995), to 94.41mm (1996-2000), to 84.38mm (2001-2005) to 96.95mm (2006-2010). Spread of pests and diseases changes with changing rainfall and temperature patterns; thrips and sun-scorch associated with increase in temperature, yellow-headed borers and drought disease in dry spells and tip borers and Coffee Berry disease in wet conditions. From this study, it was concluded that fluctuations in rainfall and increase in temperature have occurred and have lowered yields by hindering growth of coffee at each of the 5 growth stages, putting pressure on water supply for irrigation and spread of pests and diseases. Recommendations include increasing yields by growing the *batian variety* which is resistant to Coffee Berry Disease, constructing rainwater harvesting facilities, growth of shade trees in between rows of coffee bushes and the need to conduct research on effective coping mechanisms particular to each climatic condition.

## CHAPTER ONE

### INTRODUCTION

#### 1.1 Background Information

The coffee sub-sector in Kenya is one of the major employers and contributes to about 5 % of export revenues (Linne, 2011). Large scale coffee farming at plantation level accounts for 40% of coffee output in Kenya (CIAT, 2010). Kenya mainly grows Arabica type of coffee which accounts for almost 100% of its national production. Kiambu is a major producer of coffee in Kenya and the coffee is mostly grown in estates (Laube *et al.* 2008). Climate variability has lowered coffee production through unpredictable rainfall patterns, excessive droughts and very high temperatures making crop management and disease control a nightmare. These adverse climatic conditions directly affect each stage of coffee growth and consequently affecting yield and quality of coffee berries harvested. Temperature above that which is required for the growth of coffee (19-25°C), for instance, hinders flowering and erratic rainfall hinders maturation of coffee berries, hence low production (Porter *et al.*, 1999). In addition, these climatic conditions also lead to spread and change in distribution of pests and diseases such as Coffee Berry Disease brought about by erratic rainfall, and movement of the coffee borer to higher altitudes due to global increase in temperature, consequently leading to low yields and poor quality coffee berries (Jaramillo *et al.*, 2011). This has contributed to increase in *Coffea arabica* prices over the years. Dry spells lead to drying up of water stored for irrigation hence water shortages and thus lowering coffee production. Unpredictable weather patterns leads to over-reliance on irrigation in large-scale coffee producing estates/plantations thus putting pressure on limited water resources (Porter *et al.*, 1999).

#### 1.2 Statement of the Problem and Justification

Dealing with declining coffee amidst challenges occasioned by climate variability

is a problem affecting large-scale coffee production in Kenya and a knowledge gap that should be addressed, particularly how each stage of growth of coffee has been affected, spread of pests and diseases associated with erratic rainfall conditions, dry spells and high temperatures and changes in water supply for irrigation. Overall, drought and unfavorable temperatures are the major climatic limitations for coffee production hence the focus on these two climate parameters. Coffee operates within a very narrow temperature range of (19 – 25) °C. Temperatures above that affect photosynthesis and in some cases the coffee trees dry up. For coffee to flower, it needs at least 3 months of dry weather followed by showers. In the year 2010 for instance, Kenya had rains in January, normally a very dry month during which bushes undergo “stress” before flowering. As a result of erratic rainfall, bushes are flowering when they should not have coffee berries at different stages of maturity. This means farmers have to hire labor through most of the year to pick very few kilos of coffee. This becomes a challenge to disease management and insect management. Past research has focused mainly of effects of climate variability on small scale coffee production due to their high vulnerability to effects of climate variability. Hence there is the need to pay attention to large scale coffee production as well, as they strive to meet the high demand for coffee (40% of Kenya’s output) while coping with challenges posed by climate variability.

### **1.3 Objectives**

The following were the objectives of this study:

- i. To investigate whether fluctuations in rainfall patterns and increase in temperature have occurred in the past two decades (1991-2010).
- ii. To determine whether fluctuations in rainfall patterns and increase in temperature have caused changes in growth stages of coffee and final output (yields and grades of coffee harvested).
- iii. To investigate the effects that changes in rainfall and temperature have had on water supply for irrigation and what pests and diseases are associated with these changes.

- iv. To determine what coping mechanisms have been adopted at the coffee estate in dealing with effects of climate variability.

#### **1.4 Research Questions**

The following research questions were investigated in this study:

1. Have fluctuations in rainfall and temperature patterns been experienced in Kiambu County during the past two decades (1991-2010)?
2. How have prevalent changes in rainfall and temperatures affected growth stages (flowering, pinheads, berry expansion, hardening and ripening) and yields and grades of coffee harvested during that period?
3. Have changes in rainfall and temperatures reduced affected water supplied for irrigation and spread of pests and diseases?
4. What coping mechanisms have been adopted to counter the effects of climate variability on coffee growth?

#### **1.5 Hypotheses**

The following hypotheses were derived from the objectives:

1. Fluctuations in rainfall and temperature patterns have been experienced in Kiambu County (1991-2010).
2. Low rainfall, erratic rainfall and increased temperature have hindered growth at each stage of coffee growth, consequently leading to low yields and poor grades of coffee harvested.
3. Increased temperature and erratic rainfall reduce water supplied for irrigation whereas more water is supplied for irrigation in times of low rainfall. Pests and diseases associated with each of these conditions have also lowered yields.
4. Irrigation and pest-and-disease control serve as coping mechanisms to help provide water during periods of low rainfall and reduce pests and diseases associated with fluctuations in rainfall and increase in temperature.

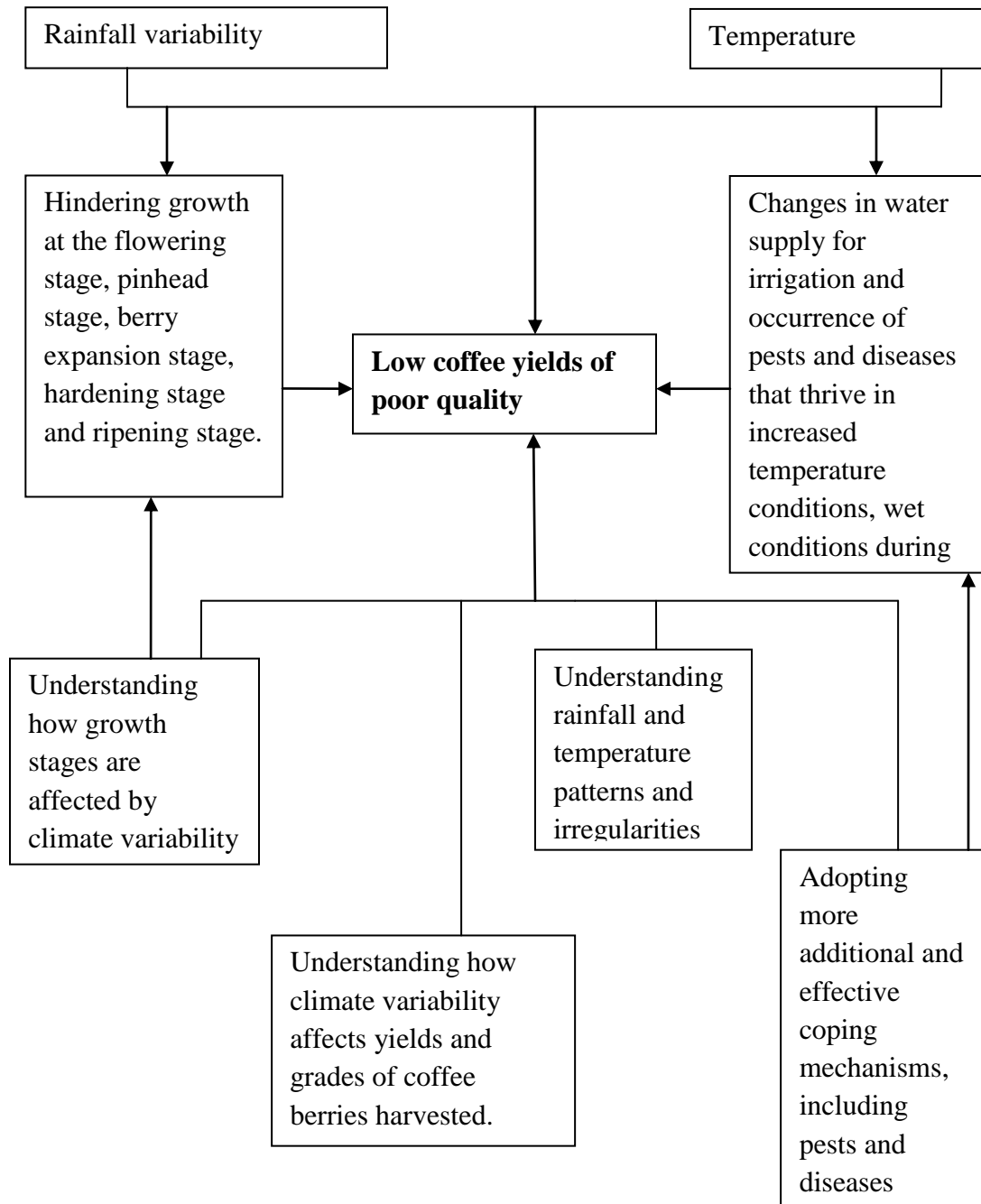
#### **1.6 Significance of the Study**

The study provides information that can be incorporated not only by the large-

scale farmers in this coffee plantation but also by other large-scale coffee farmers within the same geographical zone. Past research has mainly focused on effects of climate variability on yield and quality of berries harvested in general and spread of pests and diseases. However, there is need to also focus on each and every stage of coffee growth and how each stage is affected by climate variability so as to gain an understanding of how these impacts eventually lead to the overall change in yield and quality of coffee berries.

### **1.7 Conceptual Framework**

The major problem in the study is low quality and quantity of coffee harvested, caused by increase in temperatures, dry spells and erratic rainfall and other factors brought about by these climatic changes, i.e. low water supply for irrigation as a result of prolonged dry spells and spread of pests and diseases. These factors work together to suppress productivity of coffee in the study area. Reversing the trend calls for a proper understanding of rainfall and temperature patterns and how growth stages are affected by these climatic changes, which will consequently provide a better understanding on how the final output (yields) of coffee is affected. Combating the major problem would also require more effective coping mechanisms after investigating the coping mechanisms already in existence, including pest and disease control strategies and water management strategies.



**Figure 1.1:** Conceptual framework of the relationship between climate variability and coffee production

### **1.8 Definition of terms**

- Climate variability** - Unpredictable changes in rainfall and temperature.
- Flowering** - Stage of growth of coffee where flowers sprout and open up.
- Pinheads** - Young berries.
- Berry Expansion** - Growth and spread of berries throughout the coffee tree.
- Hardening** - Berries harden and are green in colour.
- Ripening** - Berries mature and turn red, ready for harvesting.
- Stress** - Period of dry weather (no rainfall) required in coffee growth before flowering.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Climate Variability and Coffee Growth

The Intergovernmental Panel on Climate Change (IPCC) predicts an increase in the mean global temperature of 1.4° to 5.8°C by the end of the twenty-first century (IPCC, 2007). Climate change is also projected to cause more frequent and intense El Nino-Southern Oscillation (ENSO) events leading to widespread drought in some areas and extensive flooding in others. Consequently, such events will have negative impacts on availability of water resources, food and agricultural security, human health and biodiversity. These changes in climatic conditions are also predicted to profoundly influence the population dynamics and the status of agricultural insect pests as temperature has a strong and direct influence on insect development, reproduction and survival. Over the past 30 years, changing climate and in particular global warming has already produced numerous shifts in the distribution and abundance of species (Jaramillo *et al.*, 2009). Climate change and invasive species are considered as two of the most important ecological issues facing the world today.

According to the global circulation models, climate change is forecasted to increase mean temperatures and change precipitation patterns. This will cause traditional coffee regions to disappear and new regions may appear. Climate changes such as years that are too wet or too dry can have significant effects on coffee, being that coffee is a sensitive crop. Too low or too high temperatures can affect the coffee plant's flowering stage and the coffee plant's diseases and pests become a persistent and devastating problem (Porter *et al.*, 1999). Diseases such as coffee rust can also be caused by weather that is too wet, and if the climate is not sufficiently dry after harvest it can affect the sun drying process of the coffee beans. Water available for irrigation that has been stored from rain water is also

affected by climate change by leading to water shortages and consequently low coffee harvests, particularly in times of dry spells which is when some coffee farmers tend to rely on irrigation. Overall, drought and unfavorable temperatures are the major climatic limitations for coffee production hence the focus on these two climate parameters (rainfall and temperature) Coffee trees require a few months of dry weather in the spring before the rains fall for them to flower which is known as the period of “stress”, hence erratic rainfall even during this period inhibits flowering thus inhibiting growth of berries and consequently leading to low yields (Turrall *et al.*, 2009). Erratic rains may also cause low coffee production as a result of soil erosion which is worse on plantations along hillsides; hence coffee trees do not produce to their maximum due to poor soil fertility as the soil nutrients are carried away with the top soil by the run-off from the heavy rains (Pereira, and Anand, 2007). Climate change is affecting the distribution of many species particularly insects (Jaramillo *et al.* 2011). The coffee berry borer, *Hypothenemus hampei*, is the most important biotic constrain for commercial coffee production worldwide. The geographic centre of origin of the *H. hampei* is unknown, but it is probably endemic to central Africa, becoming naturalized elsewhere due to movement of coffee plants and beans through multiple, persistent introductions.

Until the year 2000, there were no reports of *H. hampei* found attacking coffee plantations above 1,500 m, which is within the preferred altitude range of cultivated and naturally occurring *C. Arabica*; 1,400–1,600 and 1200–2000 meters, respectively. However, due to recent increasing temperatures in coffee growing regions in the world the insect can now be found also at higher altitudes, where it able to infest *C. arabica*. Increased spread of pest and diseases has largely affected crop production especially in Africa, which is considered one of the most vulnerable continents to climate change and climate variability. A 1–2°C increase could lead to an increased number of generations, dispersion and damage by the coffee berry borer (*H. hampei*); whereas a rise in temperature of 2°C and above could lead to shifts in altitudinal and latitudinal distribution of the pest according to Jaramillo *et al.*, (2009) who reported on thermal tolerance of coffee

berry borer resulting from climate change and its potential implications on the environment. Increasing temperatures are expected to make certain coffee producing areas less suitable or even completely unsuitable for coffee growing, hence production will have to shift and alternative crops will have to be grown (ICO, 2009). The quality of coffee is likely to suffer; hence the viability of current high quality producers will be limited. More coffee may need to be grown under irrigation, therefore increasing pressure on scarce water resources. All the foregoing will increase the cost of production, in addition to increasing pest incidences. Photosynthesis is also reduced when the temperatures increase and results in changes in planting periods, reducing growth and resulting in smaller yields. Low rainfall as a result of climate change causes the coffee husk to stick to the bean thus hindering maturation. On the other hand, rains during harvest season reduce the quality of coffee by hindering the drying process. Increasing strong winds as a result of climate change causes coffee flowers to fall and changing pollination.

Central American and South American coffee production dropped by 70% in 2010 and a presentation on the impact of climate change on Central American coffee production says that Central America is one of the regions that is most likely to get both hotter and drier over the course of this century (Castellaños E., Conde C., Eakin H., and Tucker C., 2003). The presentation cites studies of climate change over the last two to three decades in coffee growing areas of Mexico, Guatemala and Honduras which indicates that the temperatures in the regions have increased between 0.2°C and 1°C. Rainfall in these areas decreased by up to 15%. More erratic rainfall has been experienced and farmers' coffee trees are consequently at the risk of flowering earlier than they should. Absence of rainfall causes new coffee plants to dry out and die. Erratic rains cause farmers to wait a month between pickings as coffee beans ripen at vastly different times. Heavy rains erode hillsides, meaning trees do not produce as well or as long, and farmers must redo terracing. When coffee trees flower earlier than they should as a result of erratic rainfall, they later dry up from lack of water before the true rainy season arrives. Erratic rainfall is showing no mercy to Brazil's coffee crop as conditions turn dry

again, depriving beans of a last moisture boost that would help them swell out more before harvesting begins in about a month, according to reports by forecasters and agronomists. Heavy rains in Colombia recently helped drive coffee beans to prices not seen in more than a decade, and coffee companies are watching closely.

## **2.2 Climate Change and Coffee Production in Africa**

African coffee growing regions are also affected by climate change (Morales *et al.*, 2010). Africa's arable land will reduce by 60 to 90 million hectares by 2050 as the impact of climate change sets in according to a study conducted by ICIPE (ICIPE, 2007). Moreover, soil conditions at higher altitude deteriorate with higher temperatures, and there is a dire need to introduce shade trees to coffee plantations to improve microclimate that favors the growth of coffee. Coffee requires quite specific growing conditions. For Africa, future annual warming ranges from 0.2°C to .0.5°C per decade. Future changes in mean seasonal rainfall in Africa are less well defined. It grows in subtropical regions that have distinct wet and dry seasons (Turrall *et al.*, 2009). Although plants can live and produce fruit for decades, drought or heat in summer can diminish production and quality. Though coffee requires a dry period in the spring, heavy rains in this season can disrupt flowering. This sensitivity to climatic variables means that global climatic change is likely to have adverse impacts on coffee growing and production.

Although there are efforts of growing coffee varieties that are more heat-resistant, it will not do much to prevent losses due to the climatic variability brought on by global warming (droughts and floods, unusual cold spells) or the pests where latitudinal and altitudinal ranges will also change as temperatures rise. Farmers will be left with few choices. Areas at higher latitudes (which although too cool now to grow coffee will become warmer) could be used. If land in higher altitudes is turned into coffee farms, this means a loss of biodiversity, and deforestation of new and old coffee farms will accelerate warming trends, since trees help sequester carbon and prevent global warming. We all have a great deal at stake as the earth warms. Unfortunately, the poor developing countries, such as coffee

growing nations like Kenya for instance, often bear a large burden. Even growers of more heat-tolerant lowland Robusta coffee, where it is indigenous, stand to lose their livelihoods. In the past several decades, roughly half of the world's coffee plantations have cut down their trees, or cut down forests to plant un-shaded coffee (Morales *et al.*, 2010). This decreases the absorption of carbon dioxide by vegetation to counteract global warming, and leading to increase in temperature.

### **2.3 Climate Change and Coffee Production in East Africa**

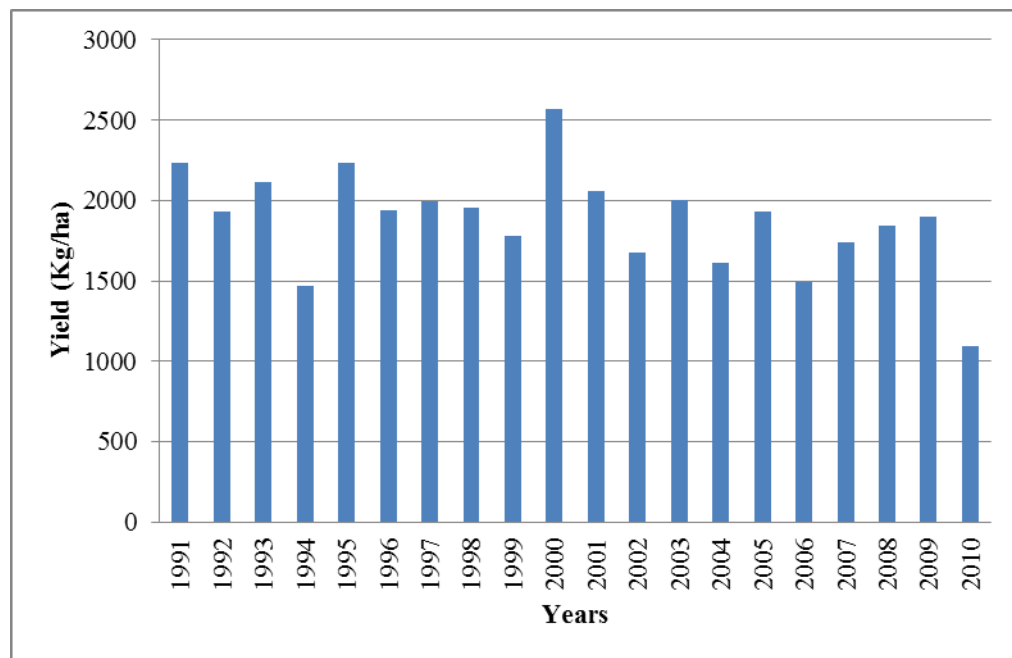
Many of the 25 million coffee farmers across the tropics have already been experiencing the negative effects of climate change; global warming in East Africa has already enhanced the spread of the coffee borer, the most popular pest in coffee plantations worldwide, which has increased damage to coffee crops and expansion in its distribution range has been reported (Jaramillo *et al.*, 2009). This situation is forecasted to become worse in the current coffee Arabica producing areas of Mount Kenya and the Kenyan side of Mount Elgon and other areas of East Africa such as Ethiopia, the Ugandan part of the Lake Victoria and Mount Elgon regions and most of Rwanda and Burundi. Models forecast that parts of equatorial East Africa will likely experience 5–20% increase in rainfall from December to February and 5–10% decrease in rainfall from June to August by 2050. Higher temperatures would result in the pests' latitudinal and altitudinal change. The calculated hypothetical number of generations per year of coffee berry borers is predicted to increase in all *arabica* producing areas from five to ten. These outcomes will have serious implications for *arabica* production and livelihoods in East Africa. The authors suggest that the best way to adapt to a rise of temperatures in coffee plantations could be via the introduction of shade trees in sun grown plantations. Increasing temperatures and low rainfall, the hallmarks of climate change, have already led to the thrips (tiny insects known to destroy coffee beans and leaves by puncturing and sucking up their contents) as shown in the figure below in the coffee growing districts, lowering farmers' output (Jaramillo *et al.*, 2011).

### **2.4 Climate Change and Coffee Production in Kenya**

Diminishing coffee in Kenya can largely be attributed to climate change according to research by the Coffee Research Foundation (CIAT, 2010); Kenya's coffee production has been in decline since the all-time high of 130, 000 metric tons in 1987-88 crop year, hitting a record low in 2009-10 due to unexpected climate variability that caused a high incidence of leaf rust. As a result of climate change, imminent rainfall in the 2007/2008 crop year, for example, resulted in the spread of the coffee berry disease countrywide that cut Kenya's output by 23% to 42 000 metric tons as farmers were caught out by rains and did not protect their crop in time. CIAT (2010) research also shows that erratic rainfall has led to the spread of CBD which attacks coffee berries causing them to turn black hence lowering their quality. Unpredictable and erratic rains have affected the quality of coffee berries, hindering their maturity or the shade drying process and causing soil erosion hence loss of soil fertility. Coffee production areas are decreasing and moving to higher altitudes as rainfall is becoming more unpredictable (Greenpeace International, 2008). Poor quality and low quantity coffee due to less rainfall, strong winds and increased temperature consequently leads to reduced income for farmers.

The spread of pests brought about by global warming has largely affected farming regions and Coffee Berry Disease has put a strain on exports. Scientists at the Nairobi base ICIPE predict increased incidences of coffee berry borer in coffee zones over the next 40 years due to changing climatic patterns. Unpredictable rainfall patterns and excessive droughts have affected Kenyan coffee production, making crop management and disease control difficult according to research reports by Kenya's Coffee Research Foundation; CRF (Gichumu and Omondi 2010). Intermittent rainfall in the 2007/08 crop year, for example, caused a terrible bout of the CBD that cut Kenyan output 23 percent to 42,000 metric tons as farmers were caught out by rains and did not protect their crop in time. Coffee Berry Disease damages berries causing them to turn black hence yield loss. Climate change has been seen in intermittent rainfall patterns, extended drought and very high temperatures and coffee operates within a very narrow temperature range of (19-25) °C according to research reports by Kenya's Coffee CRF. Hence

when temperatures are above that, it affects photosynthesis and in some cases, trees wilt and dry up, which has been happening in the marginal coffee areas. For coffee to flower, for example, it needs a couple of months of dry weather followed by showers. This year, Kenya had rains in January, normally a very dry month when the bushes undergo what is known as stress before they flower. Because of the unpredictable weather, bushes are flowering when they should not and have coffee berries at different stages of maturity. This means farmers have to hire labor through most of the year to pick very few kilos of coffee. One can look at a coffee tree and cannot determine the season because it has beans of all ages. That is a problem when it comes to disease management, insect management and the worst problem is in harvesting. The cost is enormous. The following table shows coffee production trends in Kigutha Estate in Kiambu County (1991-2010). Kigutha Estate's coffee output has been increasing and decreasing over the years, changing tremendously from one year to another (Table 1.2). For instance, yield greatly reduced from 220.3 tons in 1991 to 143.1 tons in 1992, then increasing again to 209.400 the following year.



**Figure 1.2:** Coffee production Trends at Kigutha Coffee Estate (1999-2010).

(Source: KMD)

This can be attributed to a number of factors inclusive of unpredictable weather conditions as a result of climate variability, which affects stages of growth of coffee and affects distribution of pests and diseases as discussed in detail in chapter 4. Erratic rainfall has resulted in premature flowering according to research by CRF (Gichumu B. and Omondi C. 2010) and global temperatures are projected to increase by 0.2 degrees due to global warming in every ten years therefore farmers are to plant drought and disease-resistant coffee varieties. There has also been a general demand in coffee in the international market such as China and India leading to high prices; however production remains low due to climate change. CRF research also shows leaf rust and coffee borer do well in hot temperatures affecting the crop output. In the figure above, leaf rust has caused the leaf to have orange-yellowish patches on leaves which hinder photosynthesis (Pereira, 2007). This research has focused more on spread of berry borer and CBD as a result of increased temperatures and effects of increased rainfall and erratic rainfall on general loss in output and effects on flowering but fails to go into detail on how each of the 5 stages of growth (flowering, pinhead stage, berry expansion, hardening and ripening stages) have been affected by climate variability and pests and diseases associated with unpredictable rainfall patterns, excessive droughts and very high temperatures and the variety of pests and diseases brought about by each of these three climatic changes.

## **2.5 Coping Mechanisms**

Climate change has called for the need for coping mechanisms in order to ensure continued productivity. These include growth of disease resistant varieties to reduce vulnerability of coffee to attack by diseases, use of pesticides, herbicides and fungicides to reduce the spread of pests and diseases thus prevent yield loss and poor quality berries, and water storage to reduce vulnerability of coffee trees to drying up in times of dry spells and reduce attack by pests and diseases that thrive in such climatic conditions.

### **2.5.1 Growth of Disease Resistant Varieties**

Climate change has encouraged the spread of diseases hence it is vital that resistant varieties are grown to ensure success in coffee production for instance, the batian variety, which is a true breeding *arabica* coffee variety resistant to Coffee Berry Disease (CBD) and Leaf Rust (Loland and Singh, 2004). It is a tall statured plant with vegetative features similar to those of Cultivar SL28. The cultivar produces many primary branches with horizontal but occasionally erect branching habit which tends to become semi-drooping after successive crop bearing seasons. It produces average to profuse secondary branching, and is ever green throughout the year under good management. Leaves have medium purplish colouration giving a bronze colour but occasionally absent or weak, giving a green-bronze colouration. Mature leaves have medium width which compares closely with SL28. The cultivar has long internodes on both the main stem and branches that compares closely to SL28. Ripe cherries are larger than those of SL28, elliptical in shape and deep red in colour. Mature beans are large and bold; endosperm is green while the centre cut is mostly singled and straight. CRF also proposes that batian is suitable for areas of Nyamira, Kisii, Narok and Homa Bay counties and asked farmers to grow the variety.

### **2.5.2 Use of Pesticides, Fungicides and Herbicides**

Due to the high occurrence of pests and diseases brought by variability in climate, farmers have been forced to turn to pesticides and fungicides to control the spread of pests and diseases. In a normal year, farmers spray their crop protectively against CBD as from April but because of unexpected rains, they are unable to plan. Erratic rainfall and its unpredictable nature makes pest and disease management totally difficult hence the spread of pest and diseases such as CBD. Farmers may go into spraying after an attack but the damage is already done.

### **2.5.3 Water Conservation**

The immediate solution, according to CRF (Gichumu B. and Omondi C. 2010).is for farmers to conserve whatever rainfall they receive through mulching, digging

trenches to hold water, pruning, forking and planting shade trees. Agronomic practices that conserve moisture are needed before there can be any talk about new technologies or new varieties that are drought tolerant. As a result of prolonged dry spells and loss of water from the crops through evapo-transpiration due to increased temperature, farmers are forced to over-rely on irrigation thus limiting water supply for irrigation. Therefore it is critical that farmers do all that is necessary to conserve and store water to ensure continued productivity.

## **2.6 Summary**

Climate variability has largely led to low yields and poor quality berries in plantations worldwide, with coffee producing areas reducing and moving to higher altitudes to survive as a result of unpredictable rainfall and increased temperature (Greenpeace International, 2008). Climate change has affected Kenyan coffee production through unpredictable rainfall patterns and excessive droughts, making crop management and disease control difficult, as erratic rainfall and dry spells bring about the spread of pests and diseases that thrive in those climatic conditions. Hence the frequent occurrence of the different pests and diseases that come with the changes in climatic conditions means added costs for pests and disease control as well as low yields of poor quality because farmers may not have protected their crops in time due to unpredictability of pest and disease outbreaks. Increase in global temperatures for instance has led to high occurrence of leaf rust and the coffee berry borer which do well in hot temperatures thus lowering production, whereas CBD is brought about by erratic rainfall, which attacks berries thus lowering yields as well as quality of berries. As a result of unpredictable weather, coffee bushes are flowering when they should not and have coffee berries at different stages of maturity. This means farmers have to hire labor through most of the year to pick very few kilos of coffee. For flowering to take place, the crops need a few months of dry weather followed by showers, whereby the crops undergo what is known as 'stress' before they flower. The stress period may also be crucial to allow flower pollination to take place. Hence when erratic rains fall during this period of stress before flowering, this hinders flowering hence

lowering crop output. This creates a problem when it comes to pest and disease control as the distribution of pests and diseases changes with changing weather conditions. Despite the many studies that show the impacts that climate variability has had on coffee production worldwide, the focus has mainly been on impacts on yield in general and spread of pests and diseases in coffee farms and estates in general. However, there is the need to also focus on each and every stage of coffee growth from the flowering stage to the ripening stage and how each stage is affected by climate variability separately so as to gain a better understanding of how these impacts eventually lead to the overall changes in yields and quality (grades) of coffee berries harvested. There is also the need to study a particular coffee estate so as to ensure a more detailed approach, thus taking other factors that affect production into consideration such as impacts of climate variability on water supply for irrigation and how each stage of growth is affected by weather-related pest and disease outbreaks.

## **CHAPTER THREE**

### **METHODOLOGY**

#### **3.1 Study Area**

The study was conducted in Kigutha Coffee Estate in Kiambu County (see fig.1.1). The coffee estate is located along Ruiru – Kiambu Road, which connects Ruiru and Kiambu. The area under coffee is 99.08 hectares. The types of coffee grown are SL 27, SL 28 and French Mission. The Estate is located about 1732 meters above sea level. For the past 2 decades (1991-2010) the area received between 640mm and 1660mm, and was highest during the month of April and lowest in August (KMD, 2010). The soils are deep well drained red volcanic soils. Coffee harvesting is usually done from August to October (early crop) and January to March (main season). Production is about 1094-2570 kilograms per hectare. Shade trees grown are *Gravellia* and other indigenous trees. There are forests on the lower areas of the Kigutha Estate planted with indigenous trees and Eucalyptus trees, giving a beautiful view of the surrounding natural sites and making a home for various wild animals such as porcupines, squirrels and monkeys among others.

#### **3.2 Research Design**

Descriptive research design was used in the study which comprised of description of data, recording, analysis and interpretation as well as comparison of data to establish relationships between variables. Annual temperature and rainfall amounts (1991-2010) were compared to the quantity and grades of coffee in each crop year for the same number of years to establish the relationship between the climate variables and the quantity and quality of coffee harvested.

#### **3.3 Target Population**

The study population comprised of permanent workers and casual workers who have been there for not less than a decade. The manager of the plantation is in charge of overseeing every operation undertaken in the farm and is basically in

charge of managing the entire plantation and ensuring everything goes smoothly. These include ensuring all the equipment required for sustaining the crops and protective gear for the workers, monitoring the processes undertaken to sustain the crops such as irrigation and pest and disease control, overseeing the hiring of workers, monitoring the post-harvest processes such as drying and sales from coffee berries. The agronomists' responsibilities lie in the sustenance of crops by ensuring all activities such as pest and disease control, irrigation and supervision of these activities are carried out and provide their expertise on coffee production to ensure continued productivity are implemented by the farmers on the ground and casual workers. Supervisors of field activities oversee all the activities carried out by casual workers to sustain the crops; pruning, removal of unwanted suckers, harvesting, irrigation, spraying of pesticides and fungicides and foliage feeding. The sales manager was in charge of sales and kept all records showing production and sales per year. Casual workers are hired to harvest coffee and nurture the coffee trees by carrying out all the necessary tasks required to ensure their growth. These include irrigating the crops, pruning the trees, mulching and spraying of pesticides and fungicides among others

### **3.4 Sample Size and Sampling Procedure**

Kigutha Coffee Estate in Kiambu County was selected purposively, Kiambu County being one of the largest coffee producers in Kenya. Past research has mainly focused on effects of climate variability on small scale coffee production hence the need for more studies on how large scale coffee production is affected by climate variability, as it contributes to 40% of Kenya's coffee output. The minimum sample size was obtained using a formula as used by Fisher *et al* (1998) for calculating sample sizes whose target population is less than 10 000 persons as shown below;

$$nf = n/1 + (n/N)$$

Where:

nf = desired sample size when the target population is less than 10,000

$n$  = desired sample size when population is more than 10,000

$N$  = estimate study population size

$$n = (Z^2 pq) / d^2$$

$Z$  = the standard normal deviation at the required confidence level = 1.96 (95% Confidence level).

$p$  = Proportion of the target population estimated to have the desired characteristics  
=

0.5

$$q = 1 - p$$

$d$  = Degrees of freedom = 0.05

$$n = (1.96^2 \times 0.5 \times 0.5) / 0.05^2 \quad n = 384$$

$$nf = 384 / (1 + (384/300))$$

$$nf = 168$$

However, despite the intended 168 sample size out of a population size of 300 respondents (100 permanent workers and 200 casual workers), a sample size of 30 respondents who had the required knowledge regarding the purpose of the study were made available by the Estate to avoid time wastage. 10 of the respondents comprised of permanent workers and 20 casual workers who have been there for not less than a decade. Therefore purposive sampling was used to select the sample size based on the knowledge of the population and the purpose of the study. Permanent workers comprised of 1 manager, 1 head agronomist, 2 assistant agronomists, 5 supervisors of field activities and 1 sales manager. Casual workers comprised of 5 coffee pickers, 5 irrigation workers, 5 sprayers (pesticides and fungicides) and 5 workers doing the pruning, weeding, mulching and de-suckering.

### **3.5 Data Collection**

#### **3.5.1. Pre-Testing the Research Instruments**

A pilot study was conducted to test the suitability of the permanent workers' interview schedules and the questionnaires. Five permanent workers from the study area were randomly selected from the 10 permanent workers made available

and interviewed. The manager and head agronomist also participated in the pre-testing exercise.

### **3.5.2. Data Collection Tools**

Questionnaires, interviews, direct observation, focus group discussions and secondary data were used to collect data. Semi-structured questionnaires (see Appendix II) were used. These were distributed to all key respondents (permanent workers) and comprised of both open-ended questions and close-ended questions. Interview sessions were conducted with permanent workers. This helped to ensure that any responses that were left out as well as any vague responses given in the questionnaires were covered in a more elaborate manner, as well as providing responses to questions that were not included in the questionnaires. Records on water supplied for irrigation (cm<sup>3</sup>) annual yield (kg/ha) and percentage of P1 (best quality) & MB (poorest quality) grades of coffee harvested annually were provided by the estate. Direct observation was used which involved accurately watching and noting the visual impacts that climate variability has had on the coffee trees and the quality of coffee berries. By doing so, this helped in picking any information that was left out by the respondents and provided an opportunity to ascertain the existence of what was observed by discussing it with the respondents. Focus group discussions were conducted with coffee harvesters who have worked there for at least five years or more to discuss how climate variability have affected yields. Secondary data included published literature; books and journals, as well as the internet and KMD records. Monthly Rainfall data (1991-2010) and maximum and minimum monthly temperature data (1991-2010) was collected from KMD records featuring monthly and annual rainfall (mm) and maximum and minimum monthly temperatures(°C) for that period for Kiambu County.

### **3.6 Data Analysis**

For the first objective, time series was used to calculate a 5 year moving average using Microsoft Excel, to determine rainfall moving average for Kiambu area for

the period 1991-2010 to show how rainfall has been increasing or decreasing after every 5 years within that period of 1991-2010. In addition, using SPSS, descriptive statistics was used to determine the frequencies in order to determine the most prevalent climatic changes experienced by respondents at Kigutha Coffee Estate. For the second objective, statistical Package for Social Sciences (SPSS) was used to calculate Pearson correlation( $r$ ) with significance of 0.05 to determine relationship between climatic parameters{(annual rainfall (mm) and temperature ( $^{\circ}$ C))} and coffee yield (kg/ha) and grades (MB and P1) from 1991-2010. Data on yields and percentages of grades of coffee harvested was available in records provided by the estate. For the third objective, Pearson correlation( $r$ ) with significance of 0.05 to determine relationship between climatic parameters {(annual rainfall and temperature) and water supplied for irrigation ( $\text{cm}^3$ ) from 1991 to 2010, the impacts of climatic changes (in rainfall and temperature) have had on each stage of growth of coffee from the flowering stage to the ripening stage and pests and diseases brought about by these climatic changes.

## **CHAPTER FOUR**

### **RESULTS AND DISCUSSION**

#### **4.1 Introduction**

Results show variability in total annual and monthly rainfall patterns (1991-2010) and mean monthly temperature patterns (Objective 1), correlation relationships between the 2 climate parameters (rainfall and temperature) and coffee (yields and grades) harvested (Objective 2). In addition, results show correlation relationship between the 2 climate parameters and water supply for irrigation, impacts of climate variability on each stage of growth of coffee from the flowering stage to the ripening stage and pests and diseases brought about by climate variability (objective 3). Lastly, this chapter also presents pest and disease control mechanisms adopted as coping strategies to ensure continued productivity (chapter 4).

#### **4.2 Evidence of Climate Variability**

Climate variability has indeed been experienced at Kigutha Coffee Estate. This has manifested itself through changes in mean maximum monthly temperatures and mean minimum monthly temperatures and changes in monthly and annual rainfall for the past two decades (1991-2010). Changes in temperature and rainfall have been experienced. Temperature in some months varied greatly from one year to another and rainfall varied from one year to the next as shown in the results and discussion that follow, thus creating unpredictability of weather conditions.

##### **4.2.1 Farmers' Perceptions on Climatic Changes**

According to the responses given by Kigutha Coffee Estate permanent workers, climatic conditions have changed within the last 10 years thus emphasizing that there has been climate variability over the years. In addition, during the focus group discussions held with the casual workers, they all agreed that they have noticed unpredictable changes in climatic conditions such as prolonged dry spells

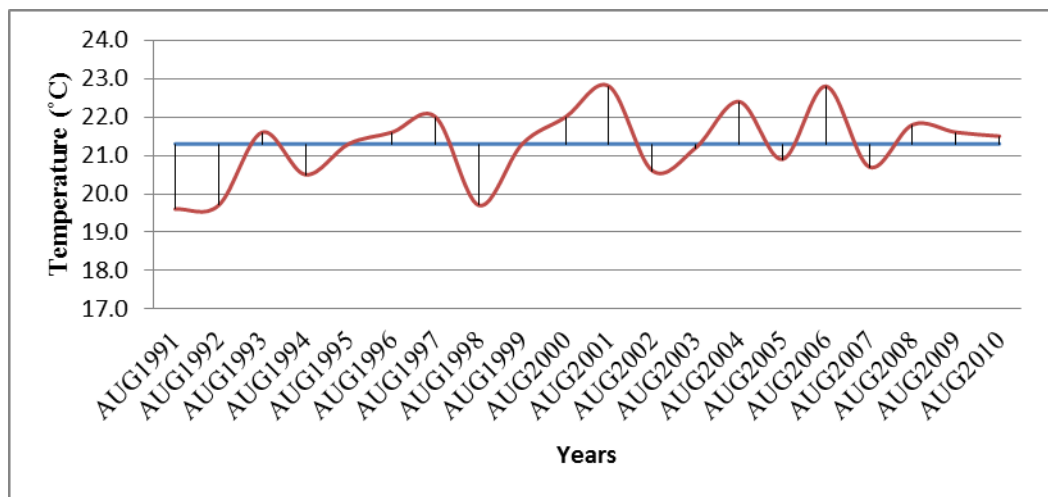
when rains are expected and sudden rains when not expected. Unpredictable climatic conditions affect growth of coffee as shall be seen later on in this chapter.

#### 4.2.2 Variability in Temperature

Changes in temperature were observed over the years in the past 2 decades, with some months experiencing bigger changes in both maximum and minimum temperature than others and whose temperatures greatly vary from the mean temperature for those months. This has further been elaborated in the form of line graphs that show sharp increases and decreases in temperature as temperature for a particular month varies over the years.

##### 4.2.2.1 Changes in Maximum Temperatures (°C)

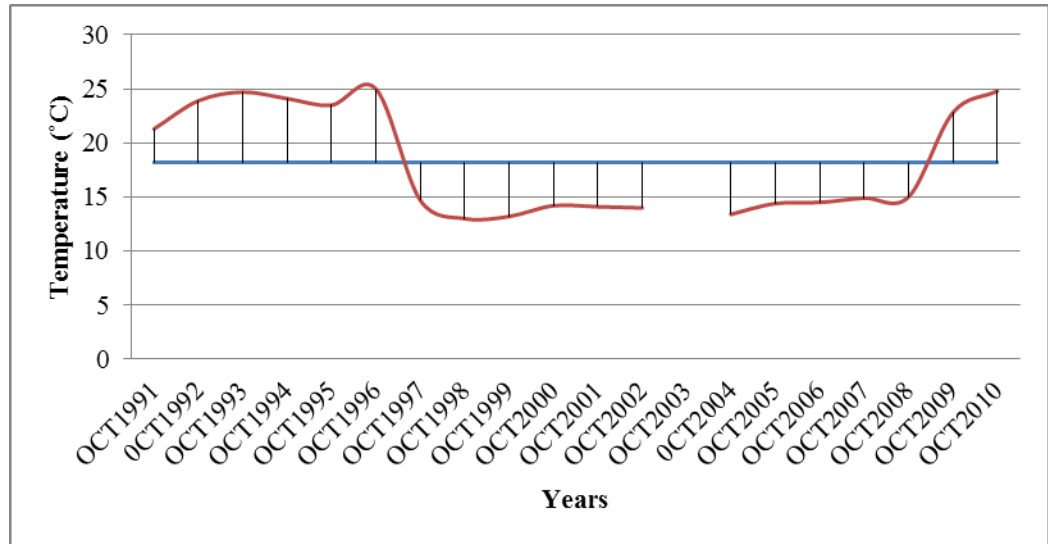
Months with the biggest changes in temperature from 1991-2010 according to KMD records were August and October (Figures 4.1 and 4.2), with large increases and decreases in temperature and great variations from mean maximum temperature for the months of August and October for all the 20 years (1991-2010). Increases and decreases in maximum temperature were recorded in the month of August each year and temperatures varied from the mean; 21.3 (Figure 4.1).



**Figure 4.1:** Changes in monthly maximum temperature the month of August of each year (1991-2010). Kiambu County. (Source: KMD: Kinale Station).

Highest increases in temperature occurred from 19.7 in 1992 to 21.6 in 1993 from

19.7 in 1998 to 21.3 in 1999 and from 20.9 in 2005 to 22.8 in 2006. Highest decreases in temperature occurred from 22.0°C in 1997 to 19.7 in 1998, from 22.8 in 2001 to 20.6 in 2002, from 22.4 in 2004 to 20.9 in 2005 and from 22.8 in 2006 to 20.7 in 2007. Largest variations from the mean occurred in 1991 (19.6), 1992 (19.7), 1998 (19.7), 2001 (22.8) and 2006 (22.8).

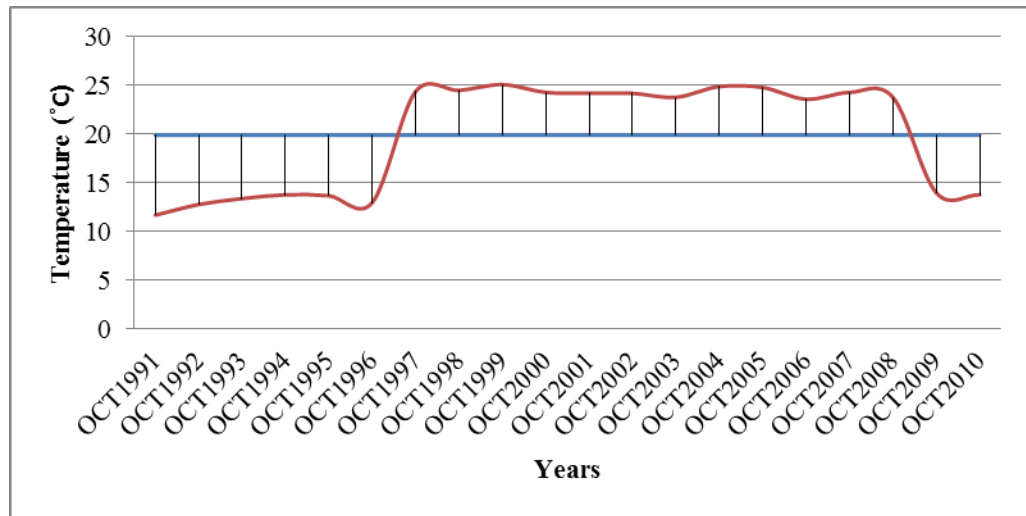


**Figure 4.2:** Changes in monthly maximum temperature for the month of October of each year (1991-2010). Kiambu County. (Source: KMD: Kinale Station). Changes in monthly maximum temperatures were observed in all the months of October (1991 to 2010), with large variations from mean maximum temperature; 18.2 in some of the years (Figure 4.2). Highest increase in temperature occurred from 15.0 in 2008 to 22.8 in 2009, though there were also increases from 21.3 in 1991 to 23.9 in 1992 and from 23.5 in 1995 to 25.0 in 1996. Highest decrease in temperature occurred from 25.0 in 1996 to 14.7°C in 1997. There was no recorded temperature in 2003. Largest variations from the mean occurred in 1993 (24.7), 1994 (24.1), 1996 (25) and 2010 (24.8).

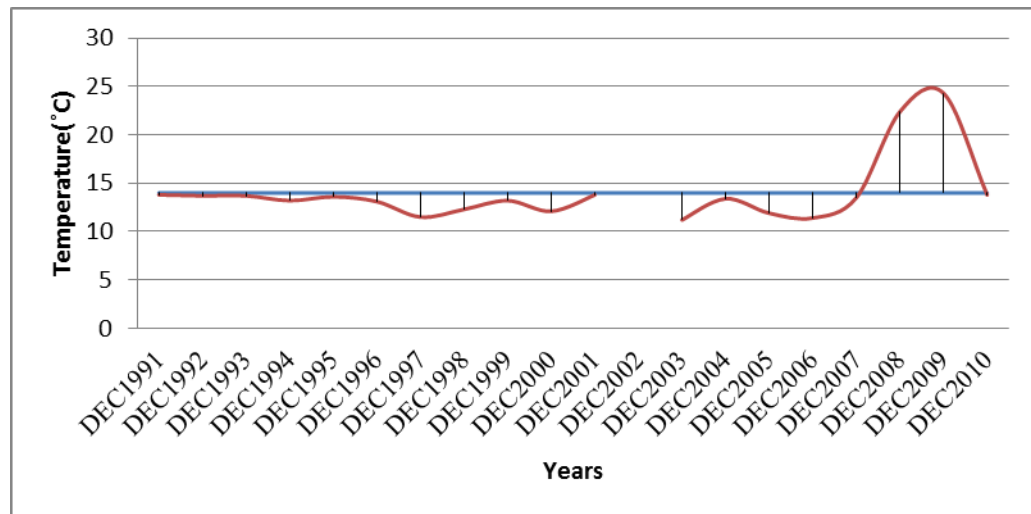
#### 4.2.2.2 Changes in Minimum Monthly Temperatures (°C)

The months with most changes in monthly minimum temperatures according to KMD records were October and December (Figures 4.3 and 4.4), with large increases and decreases in temperature and variations from mean minimum

temperature (1991-2010).



**Figure 4.3:** Changes in monthly minimum temperature for the month of October of each year (1991-2010). Kiambu County. (Source: KMD: Kinale Station). Changes in monthly minimum temperatures were recorded in all months of October (1991-2010) with some of these temperatures greatly varying from the mean; 20 (Figure 4.3). Highest increase in temperature occurred from 1996 and 1997 (13.0 in 1996 to 24.4 in 1997 though there was also an increase in temperature from 1991 (11.7) to 1994 (13.8). Highest decreases in temperature occurred from 23.8 in 2008 to 14.0 in 2009. Highest variations from the mean occurred in 1991(11.7), 1992 (12.8) and 1996 (13)



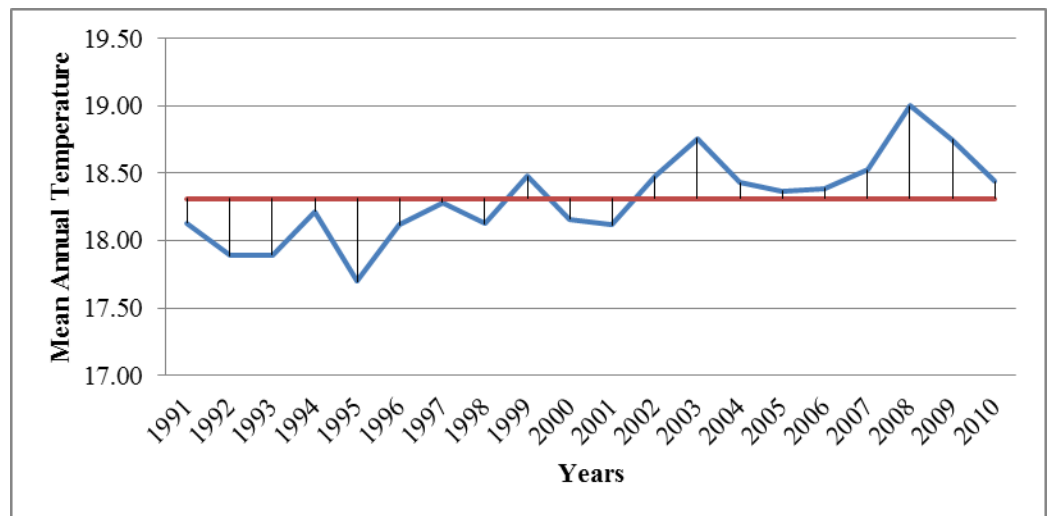
**Figure 4.4:** Changes in monthly temperature for the month of December of each

year (1991-2010). Kiambu County. (Source: KMD: Kinale Station).

Changes in monthly minimum temperatures were observed in all months of December (1991-2010) and these temperatures greatly vary from the mean (14) in some of the years (Figure 4.4). Highest increases in temperature occurred from 2007 to 2009 (11.4 -24.3) though there was also an increase from 1997 to 1999 (11.5 -13.2). Highest decreases in temperature occurred from 24.3 in 2009 to 13.8 in 2010. There was no recorded temperature in 2002. Largest variations from the mean occurred in 2008 (22.4) and 2009 (24.3).

#### 4.2.2.3 Evidence of General Increase in Temperature (°C)

Temperature has generally increased over the years for the past 2 decades (1991-2010), with annual temperatures falling below the overall mean from 1991-2001 then rising above the mean from 2002 to 2010 (Figure 4.5).



**Figure 4.5:** Increase in mean annual temperature (1991-2010). Source: KMD, Kiambu County, Kinale Station.

Mean annual temperatures that fell below the mean were as low as 17.7 in 1995 and 17.89 in both 1992 and 1993, whereas mean annual temperatures that rose above the mean were as high as 19 in 2008 and 18.75 in 2009.

#### 4.2.3 Most Prevalent Climatic Changes

According to responses from permanent workers, 40% cited increased temperature

and another 40% cited erratic rainfall as the most prevalent climatic changes. Only 20% indicated dry spells as the most prevalent climatic change. These responses support the fluctuations in rainfall patterns for the past two decades shown below (Figure 4.5). There were extremities of high rainfall, dry spells/drought, and increases in temperature (Figures 4.1 - 4.4). These results support reports by CIAT (2010) which state that climate change in Kenya has manifested itself through erratic rainfall, prolonged droughts and high temperatures.

#### 4.2.4 Flow of Rainfall from 1991-1995 Using 5 –Year Moving Averages

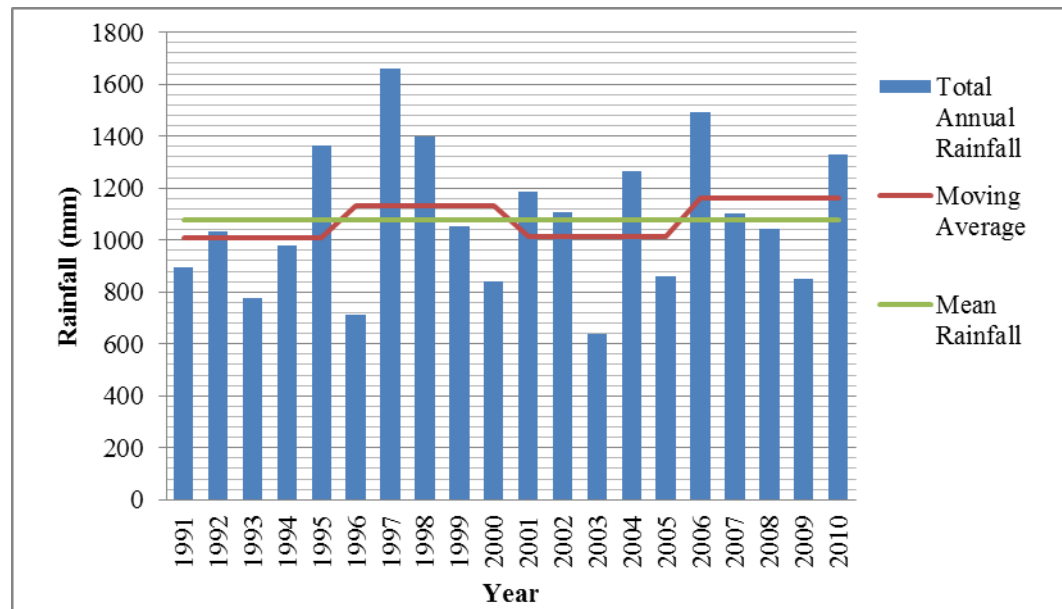
Rainfall distribution has changed within 5 year periods from 1991 to 2010, with average rainfall changing every 5 years thus showing variability in rainfall (Table 4.1).

**Table 4.1:** 5-Year averages for total annual rainfall (mm); 1991-2010. Kiambu County.

Years	Average Rainfall (mm)
1991-1995	1010.28
1996-2000	1132.92
2001-2005	1012.52
2006-2010	1163.36

**Source:** KMD records, Kiambu County. Kinale Station.

Average rainfall for the first five years increased by 122.64mm to the second 5 year period then decreased by 120.4mm in the third 5 year period (Table 4.1). These values have been plotted against the total annual rainfall (Figure 4.5) showing changes in rainfall distribution for the past 2 decades (1991-2010). Fluctuations in rainfall have been experienced, with consecutive years having wet and dry periods (Figure 4.5), as amount of rainfall rose above and fell below overall mean (1079.8mm).



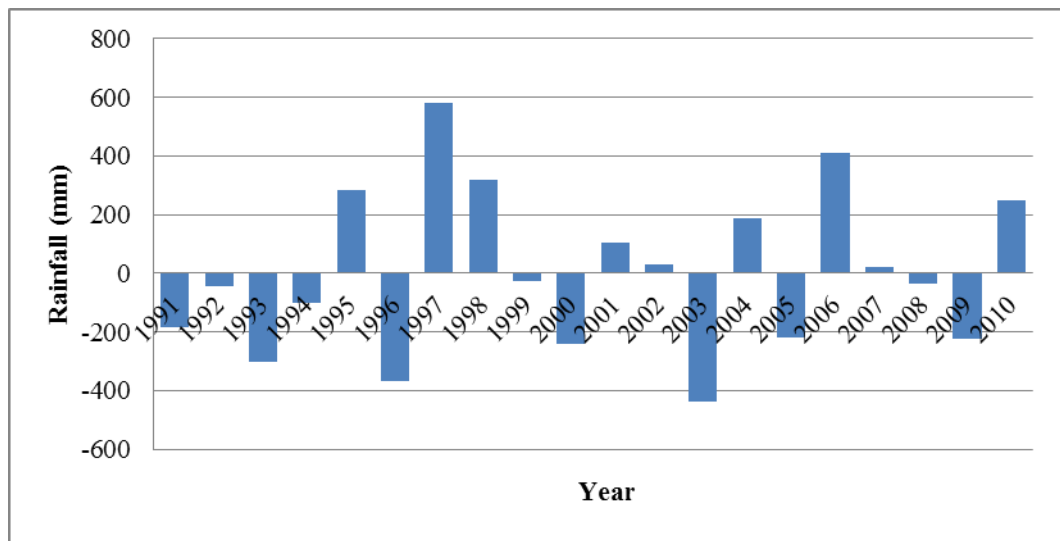
**Figure 4.6:** Flow of rainfall using 5-year moving averages (1991-2020). Kiambu County. KMD: Kinale Station.

Five year averages vary from average rainfall (1079.8mm) for past two decades (1991-2010), with averages moving from as low as 1012.52mm from 2001 to 2005 to as high as 1163.36mm in the next five-year period (2006-2010) thus showing unpredictability and variability in rainfall in that period (Table 4.1 and Figure 4.6). There were fluctuations in total annual rainfall from 1991 to 2010 (Figure 4.6). Extreme weather conditions occurred in between 1991 and 2000 with highest rainfall occurring in 1997, when El Niño occurred and total annual rainfall was 1660.7mm, dry spell occurred between 2006 and 2010 and rainfall was at its lowest in 2003 with a total of 640.5mm. Fluctuations in rainfall occurred (Figure 4.6) according to KMD records. Out of 20 years, total annual rainfall was below the 20-year average (1079.8mm) for 11 years and above average for 9 years (Table 4.2): Total annual rainfall from 1991 to 2010 varied from overall mean; 1079.8mm according to KMD records (Figure 4.7). Fluctuations in rainfall occurred from one year to the next; with mean annual rainfall falling below the mean in 1996 then rising above the mean in 1997, with the same occurring from 2000 to 2001, from 2003 to 2004 and from 2009 to 2010.

**Table 4.2:** Total annual rainfall (1991-2010). Kiambu County.

Rainfall (mm)	Number of years
400-600	0
601-800	3
801-1000	5
1001-1200	6
1201-1400	4
1401-1600	1
1601-1800	1

**Source:** KMD, Kiambu County, Kinale Station.



**Figure 4.7:** Variation of total annual rainfall from overall mean (0; x-axis) [1991-2010]. Kiambu County (Source: Kiambu county, Kinale station).

Largest variations from annual mean occurred in 1997 (1660.7mm), 2003 (640.9mm) and 2006 (1490mm). These fluctuations in rainfall show variability and unpredictability in rainfall during the past 2 decades (1991-2010).

#### 4.2.5 Monthly & Annual Changes In Rainfall

Total annual rainfall fluctuated from one year to the next over the years (1991-2010) with large increases and decreases in rainfall (Table 4.3). There were also

fluctuations in monthly rainfall in some months over the past 2 decades (Figure 4.8), with some months experiencing higher range in rainfall than others, whereby highs and lows varied immensely according to KMD records.

#### **4.2.5.1 Annual Rainfall Changes (1991-2010)**

Fluctuations in annual rainfall occurred during the 2 decade period (1991-2010). The highest total annual rainfall according to KMD records was in 1997 with highs of 1660.7mm, which is also the year in which El Niño occurred (table 4.3). Flow of total annual rainfall over the past two decades (1991-2010), with rainfall increasing and decreasing from one year to the next, shows variability in rainfall (Figure 4.6). Total annual rainfall increased from 1994 to 1995 then reduced the following year and increased again in 1997 which is when El Niño occurred. Total annual rainfall increased from 878.8mm in 1994 to 1363.9mm in 1995, from 714mm in 1996 to 1660.7mm in 1997 and from 862.4mm in 2005 to 1490.3mm in 2006 (Table 4.2).

**Table 4.3:** Changes in total annual rainfall (1991-2010). Kiambu County

YEAR	TOTAL ANNUAL RAINFALL (mm)	OBSERVATIONS
1997	1660.7	-946.7mm increase in rainfall from the previous year. -Occurrence of EL Niño in Kenya.
2006	1490.3	627.9mm increase from the previous year.
1998	1398	-Decrease in rainfall from the previous year but rainfall was still higher than most years. -High yields of good quality (table 4.4), with sufficient water supply.
1995	1363.9	-385.1mm increase in rainfall from the previous year. -This year had the highest amount of coffee berries harvested of good quality.
2010	1329.4	-479.5mm increase in rainfall from the previous year. -Lowest yields of poor quality (table 4.4). Wet conditions lead to occurrence of pests and diseases as shown in tables 4.9 and 4.11
2004	1267.3	Same as above (2010)
2001	1183.9	343.3mm increase in rainfall from the previous year
2002	1108.5	-Decrease in rainfall from the previous year but rainfall was still high. -Lower yields in comparison to other years (table 4.4). Noting that the previous year also had higher rainfall, these wet conditions increase vulnerability of coffee trees to diseases (tables 4.4)
2007	1101.8	High yields (table 4.4) with sufficient water supply
1999	1051.3	Same as above (2007)
2008	1045.4	Same as above (2007)
1992	1035.3	140.2mm increase in rainfall from the previous year
1994	978.8	200.5mm increase in rainfall from the previous year
1991	895.1	-Higher yields than most years and of good quality (table 4.4)
2005	862.4	-404.9mm decrease in rainfall from the previous year.
2009	849.9	-195.5mm decrease in rainfall from the previous year.
2000	840.6	Higher yields than most years (table 4.4)
1993	778.3	257mm decrease in rainfall from the previous year.
1996	714	649.9mm decrease in rainfall from the previous year
2003	640.9	467.6mm decrease in rainfall from the previous year.

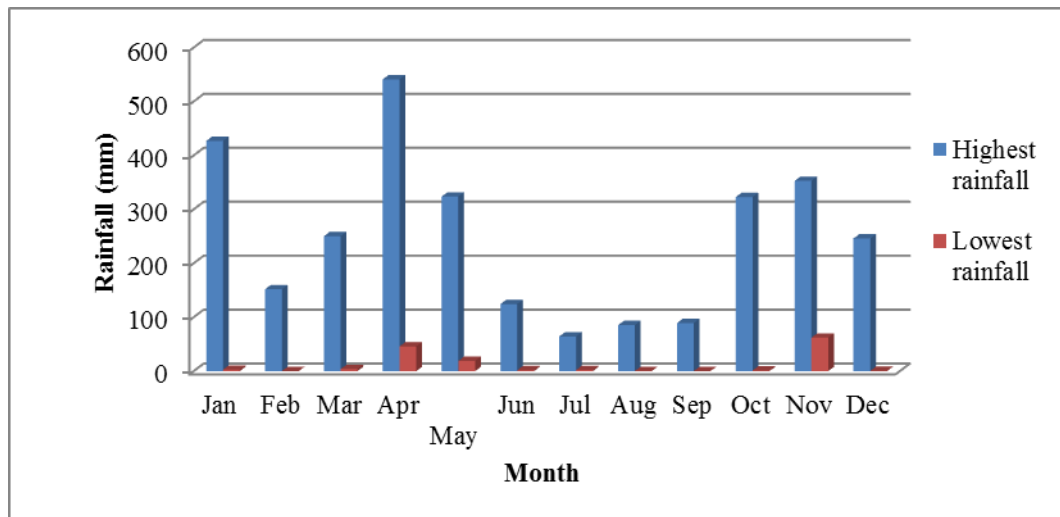
**Source:** KMD records, Kiambu County, Kinale Station.

On the other hand, rainfall reduced from 1363.9mm in 1995 to 714mm in 1996,

from 1035.3mm in 1992 to 778.3mm in 1993, and from 1108.5mm in 2002 to 640.9 in 2003 (Table 4.3).

#### 4.2.5.2 Monthly Rainfall Changes (1991-2010)

The highest and lowest rainfall received each year (1991-2010) in months of April, January, October and May varied immensely (Figure 4.8), thus showing variability in rainfall.



**Figure 4.8:** Monthly highs and lows for the period of 1991-2010 (Source: KMD; Kiambu County, Kinale station).

The month of April within the past two decades experienced the largest range in rainfall i.e. 495.3mm, with highest amount occurring in 1997 (541.2mm) and lowest in 1993 (45.9mm) according to KMD records (Figure 4.7). The month of January in this time period (1991-2010) followed closely with a range of 424.2mm, with the highest amount occurring in 1998 (429.6mm) and lowest amount occurring in 1997 (2.7mm). October and May followed with October receiving the highest amount in 1997 (322.9mm) and the lowest amount occurring in 1996 (1.3mm), whereas May experienced highest rainfall in 1998 (323.7mm) and the lowest amount in 2008 (19mm) respectively according to KMD records.

### 4.3 Impacts of Climate Variability on Yields and Grades of coffee

Rainfall influences amount and quality of coffee beans harvested. Coffee output

and rainfall data (Table 4.4) was used to calculate correlations between these variables, whose results are shown (Table 4.5), the relationship between climatic variables (rainfall and temperature) and coffee harvested (yield and grades), and also determine relationship between climatic variables (rainfall and temperature) and water supply for irrigation were assessed.

**Table 4.4:** Total annual rainfall (mm) versus yield (kg/ha) (1991-2010)

YEAR	TOTAL ANNUAL RAINFALL (mm)	YIELD (KG/HA)	P1 GRADE: BEST QUALITY (%)	MB GRADE: POOREST QUALITY (%)
1991	895.1	2233	66.7	3.5
1992	1035.3	1934	49.6	7.1
1993	778.3	2113	64.8	1.5
1994	978.8	1468	46.6	1.6
1995	1363.9	2232	59.8	7.7
1996	714	1936	46.2	10.0
1997	1660.7	1998	67.3	9.6
1998	1398	1956	45.2	7.0
1999	1051.3	1779	69.2	0
2000	840.6	2570	47.2	15.5
2001	1183.9	2057	63.8	0
2002	1108.5	1677	41.7	4.7
2003	640.9	2001	59.9	8.7
2004	1267.3	1613	39.9	14.7
2005	862.4	1933	67.4	0
2006	1490.3	1490	40.5	0.1
2007	1101.8	1738	56.8	10.6
2008	1045.4	1844	51.9	13.0
2009	849.9	1899	47.3	13.7
2010	1329.4	1094	52.3	12.7

**Source:** KMD records; Annual rainfall: KMD. Grades (%); Kigutha Coffee Estate

Percentage of P1 grade of coffee harvested represents the percentage of best quality coffee beans harvested from the entire yield, whereas percentage of MB grade of coffee harvested represents the percentage of poorest quality of coffee beans harvested from the entire yield each year (Table 4.3).

### 4.3.1 Correlations; Rainfall versus Yield and Quality (Grades)

Pearson correlation was used with a significance of 0.05 to determine relationship between rainfall and yield (kg/ha) harvested (1991-2010) and between rainfall and quality (grades) of coffee (Table 4.4). Rainfall affects the percentage of PI (best quality) and MB (poor quality) grades of coffee harvested.

**Table 4.5:** Correlation table of rainfall versus yield (kg/ha) and grades of coffee (P1 and MB) in the period 1991-2010

Variables	(r) value	(p) value
Rainfall (mm) and Yield (kg/ha)	0.494	0.2 (NS)
Rainfall (mm) and Grade MB; poor quality)	-0.378	0.1 (NS)
Rainfall (mm) and Grade P1; best quality	0.582	0.007 (S)

(\*S= Significant, NS= Not significant)

#### 4.3.1.1 Relationship between Rainfall and Yields

Correlation relationship between rainfall and yield shows that  $p=0.2$  which is greater than 0.05, hence the relationship was not significant. However, there was a positive relationship between the two. Positive correlation (r); 0.494 suggests that when there is a decrease in rainfall, yield decreases. Research also shows that drought is a major climatic limitation for coffee production (Damatta F. and Ramalho J., 2006). Low rainfall also causes the coffee husk to stick to the bean hindering maturation and thus fewer coffee berries are harvested (Linne, K., 2011).

#### 4.3.1.2 Relationship between Rainfall and MB Grade (Poorest Quality Beans)

Correlation relationship between rainfall and grade MB shows that  $p=0.1$  which is greater than 0.05, hence the relationship was not significant. However, there was a negative relationship between the two. Negative correlation (r); -0.378 suggests that when there is an increase in rainfall, percentage of MB grade harvested reduces and vice versa. When rainfall reduces, more poor quality beans are harvested. Hence rainfall is fundamental to the growth of healthy beans. However,

erratic rainfall can be destructive to the quality of beans which can be associated with attack by pests and diseases that thrive in wet conditions (sections 4.4.9 and 4.4.10), disruption of flowering when rain falls during the period of “stress” (section 4.4.4) and soil infertility due to erosion. These results are similar to research which shows that high rainfall after the coffee trees flower leads to heavy coffee that is of good quality as well as increased yields (CRI, 2010). This is because at this time young berries are expanding and need sufficient water supply (CIAT, 2010). According to ICO (2009) low rainfall as a result of climate change causes coffee husks to stick to beans thus hindering maturation.

#### **4.3.1.3 Relationship between Rainfall and P1 Grade (Best Quality) Beans**

Correlation relationship between rainfall and grade P1 shows that  $p=0.007$  which is less than 0.05, hence the relationship was significant. Positive correlation ( $r$ ); 0.582 suggests that when there is a decrease in rainfall, the percentage of P1 grade harvested also decreases and vice versa. Rainfall is therefore essential for full growth and maturation of healthy coffee berries. This result is similar to research that shows that coffee, being an evergreen bush, requires a high regime of soil moisture during the dry months (Awatramani, N., 1973). Prolonged dry spells lower crop production and especially during the berry expansion stage when coffee requires sufficient water supply for berries to grow and mature.

#### **4.3.2 Correlations; Temperature (°C) versus Yields (kg/ha) and Grades of Coffee Harvested**

Correlations were calculated to determine relationship between mean temperature and yield and between mean temperature and grades of coffee harvested (MB and P1) in the period 1991-2010 (Table 4.6).

**Table 4.6:** Correlation table of mean temperature (°C) versus yield (kg/ha) and grades of coffee harvested (MB and P1) in the period 1991-2010.

<b>Variables</b>	<b>(r) value</b>	<b>(p) value</b>
Temperature (°C) and Yield (kg/ha)	-0.7	0.01(S)
Temperature (°C) and Grade MB: poor quality	0.496	0.026 (S)
Temperature (°C) and Grade P1; best quality	-0.686	0.001 (S)

(\*S= Significant)

#### **4.3.2.1 Relationship between Temperature and Yield**

Results show that  $p=0.01$  which is less than 0.05, hence the relationship was significant. Negative correlation (r); -0.7 suggests that when there is an increase in temperature, yield harvested reduces and vice versa. These results may be associated with attack by pests and diseases associated with high temperature conditions as seen later on in this chapter (section 4.45). According to Jaramillo *et al.*, 2009, research shows that coffee berry borer has spread to higher altitudes, Kiambu being one of them, as a result of increasing temperatures and they attack coffee trees consequently leading to low yields. These results are in line with research according to the ICO (2009) which shows that increase in temperature inhibits photosynthesis and results in changes in planting periods, reducing growth and resulting in smaller yields.

#### **4.3.2.2 Relationship between Temperature (°C) and P1 Grade (Best Quality) Beans**

Correlation relationship between temperature and best grade of coffee (P1) harvested (1991-2010) shows that  $p= 0.001$  which is less than 0.05 hence the relationship was significant (Table 4.6). Negative correlation (r); -0.686 suggests that when there is an increase in temperature, quality of coffee reduces and vice versa, i.e. percentage of coffee that will be graded as P1 reduces, hence good quality coffee reduces as poor quality increases. These results are in line with

research according to the ICO (2009), which shows that with increase in temperature as a result of climate change, the quality of coffee is likely to suffer; hence viability of current high quality producers will be limited.

#### **4.3.2.3 Relationship between Temperature (°C) and MB (Poorest Quality) Beans**

Correlation relationship between temperature and the poorest grade of coffee (MB) harvested (1991-2010) shows that  $p= 0.026$  which is less than 0.05 hence the relationship was significant (Table 4.6). Positive correlation ( $r$ ); 0.496 suggests that when there is an increase in temperature, there is also an increase in percentage of MB grades harvested. Therefore when temperature increases above that which is required ( $15^{\circ}\text{C}$ ), more poor quality beans are harvested. On the other hand, this negative correlation also suggests that when temperature reduces, less MB (poor) grade coffee beans are harvested.

#### **4.4 Impacts of Rainfall Changes and Increased Temperature on Irrigation, Growth stages and Spread of Pests and Diseases**

Increased temperature, low rainfall and erratic rainfall affect the amount of water supplied for irrigation and stages of growth of coffee trees, from flowering to ripening stage. Each stage is affected differently by climate variability, consequently affecting end output (yield harvested and its quality). Variability in rainfall and temperature patterns also provide suitable conditions for breeding of pests and diseases as discussed later on in this chapter, thus affecting yield harvested and quality of berries.

##### **4.4.1 Impacts of Rainfall Changes and Increased Temperature on Water Supplied for Irrigation**

According to an interview with the head agronomist, prolonged dry spells lead to high production costs due to supplementing rainfall with irrigation; power costs used to draw water from the river to the plantation and labor costs of hiring casuals to help in undertaking basin irrigation. River Kiu and Kigutha Dam also dry up hence Water Resource Management Authority (WRMA) imposes bans so water

cannot be used further, thus lowering production. The common response given by respondents regarding impacts of long periods of low rainfall/dry spells on River Kiu is that level of water in the river reduces and it may dry up, resulting in closing down of water pumps leading water from River Kiu to Kigutha coffee estate by WRMA, in order for surrounding communities dependent on the river to have access to remaining water before its complete depletion.

#### 4.4.1.1 Relationship between Temperature and Irrigation Water Supplied

Correlations were calculated to determine the relationship between temperature ( $^{\circ}\text{C}$ ) and water supplied for irrigation ( $\text{cm}^3$ ) (Table 4.7). Changes in temperature and rainfall affect amount of water supplied for irrigation (Table 4.7).

**Table 4.7:** Correlation table of temperature ( $^{\circ}\text{C}$ ) and Rainfall (mm) versus irrigation water supplied to the plantation ( $\text{cm}^3$ ) in the period 1991-2010.

Variables	(r) value	(p) value
Rainfall(mm) and Irrigation water supply ( $\text{cm}^3$ )	-0.477	0.034 (S)
Temperature ( $^{\circ}\text{C}$ ) and Irrigation water supply ( $\text{cm}^3$ )	0.411	0.072 (NS)

(\*S = Significant, NS = Not significant)

Results show that  $p=0.072$  which is greater than 0.05, hence the relationship was not significant (Table 4.7). However, there was a negative relationship between the two. Positive correlation (0.411) suggests that when there is an increase in temperature, there is an increase in water supplied to the estate via irrigation and vice versa. This can be as a result of evapo-transpiration as moisture is lost from the soil and leaves of coffee trees hence the need to replace water lost so as to prevent coffee trees from drying up.

#### 4.4.1.2 Relationship between Rainfall and Irrigation Water Supplied

Results on correlation relationship between rainfall (mm) and water supplied for irrigation (Table 4.7) show that  $p=0.034$  which is less than 0.05, hence the relationship was significant. Negative correlation; -0.477 suggests that when there

is an increase in rainfall, there is a decrease in water supplied to the estate via irrigation. When coffee trees get more of the water needed for its proper growth from rainfall, there is less need for irrigation. Water supply for irrigation is therefore preserved more during high rainfall as the river, dam and borehole fill up. However, when rainfall decreases, water supply increases so as to sustain coffee trees. This poses a grave risk of depleted water supply whereby, in long periods of dry spells, water used up for irrigation is not being replaced hence water sources dry up.

Basin irrigation has been adopted by Kigutha Coffee Estate to provide water during periods of low rainfall. River Kiu which is depended upon for irrigation has had its water levels reduce and dry up during long periods of dry spells when irrigation demand is high. Hence, WRMA is forced to close down water pumps to ensure communities dependent on the river have access to it. These results agree with research which shows that dry spells cause rain water stored for irrigation to dry up, limiting water supply to coffee trees thus causing them to dry up (Porter et al., 1999). In addition, farmers are forced to turn to irrigation therefore leading to water shortages, which will continue to be the case with increasing drought, as predicted by the IPCC (2007). With no rain water supply and limited irrigation water, low yields of poor quality are expected.

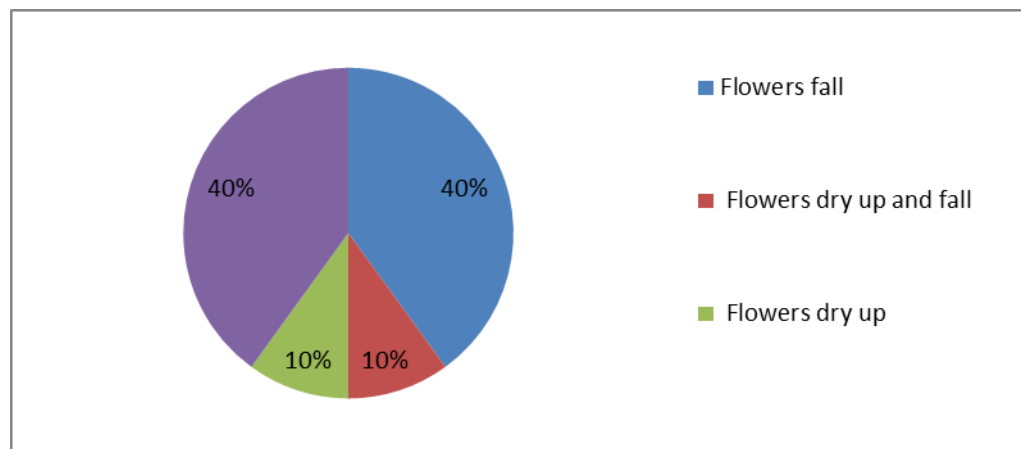
#### **4.4.2 Impacts of Increased Temperatures on Stages of Growth of Coffee**

High temperatures cause berries to become over-ripe and those that have not yet ripened are scorched hence loss in quality and yield according to interviews with the manager and head agronomist at Kigutha Coffee Estate. Increased temperatures also attract pests and diseases such as capsid bugs and sun scorch of both leaves and berries respectively as discussed later on in this chapter. Trees also dry up due to evapo-transpiration therefore mulching and irrigation are required. Therefore increased temperatures not only lead to low yields and poor quality beans but also high costs of production. These are: irrigation costs; electricity is required to draw/pump water from the source to the pipes and labour costs; particularly hiring of casual workers to dig shallow basins and fill them with

water. Increased temperatures cause low yields due to over-ripe berries thus low wages as workers are paid as per yield harvested according to focused group discussions held with casual workers. A few admitted to increased temperature having a positive outcome as a result of increased labor to carry out mulching, irrigation, pruning away tips affected by pests that occur in these climatic conditions and weeding. However, majority agreed that most workers are hired to pick coffee, hence low yields caused by increased temperature has great unemployment implications. Therefore, increased temperature does more harm than good. Below are the five stages of coffee growth and the impacts increased temperature has on each stage.

#### 4.4.2.1 Flowering Stage

Flowering stage of coffee growth is sensitive to increased temperature (Figure 4.9), that is, temperature above that which is required for coffee growth (9°C-15°C). Increased temperature reduces yield and quality of berries harvested, as each stage of growth is crucial to overall productivity. Therefore if the flowering stage is negatively affected by increased temperature, this affects the end output.



**Figure 4.9:** Impacts of increase in temperature on the flowering stage of coffee growth (1991-2010) at Kigutha Coffee Estate.

Majority of the permanent workers indicated that increase in temperature leads to shedding of flowers and attack by pests such as thrips and antestia bugs (Figure 4.9) which thrive in these climatic conditions (Figure 4.). These pests attack flower

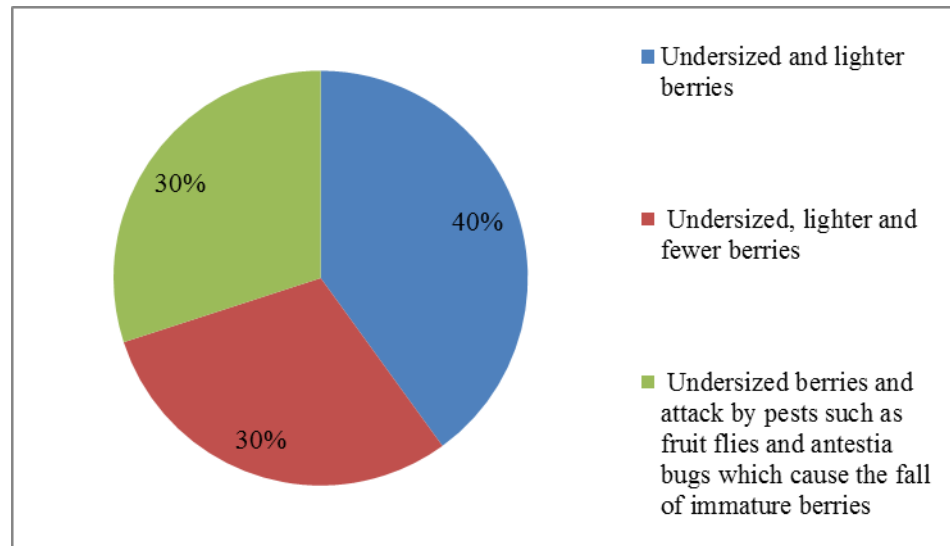
buds and petals as discussed later on in this chapter, thus hindering formation of young berries. According to Porter *et al.*, 1999, too low or too high temperatures can affect the coffee plant's flowering stage and diseases and pests become a persistent and devastating problem. These results are similar to CRF research (Gichimu and Omondi, 2010) which also shows that antestia bugs hide in berry or flower clusters and attacks flower buds and shoots causing blackening of flower buds with no flower/fruit set. Thrips, however, attack both under and upper sides of leaves at all stages of growth including the flowering stage. Attacked plant parts show irregular grey or silvery patches covered by numerous tiny black spots, which are excreta of thrips. In case of severe infestation leaves dry up and fall off.

#### **4.4.2.2 Pinhead Stage**

All permanent workers agreed that in this stage where young berries begin to form and grow, pinheads (young berries) shrivel and become undersized and may fall off thus reducing yield. These young undersized beans fail to grow and mature into bigger healthier berries thus lowering yield and quality of berries harvested. In the end, after harvesting, berries fetch little money because they weigh much less compared to healthy bigger berries.

#### **4.4.2.3 Berry Expansion Stage**

During berry expansion, the berries grow and expand throughout coffee bushes and berries begin to mature (Figure 4.9). However, coffee trees are sensitive to temperature increase and only require a certain range of temperature for proper growth of berries (19-25°C). Thus when temperatures exceed this and are prolonged over a long period of time, the following are effects on coffee berries during expansion (Figure 4.10). During berry expansion, increase in temperature according to 40% of permanent workers cause berries to become undersized, shriveled and lighter; what farmers refer to as 'lights.' which fetch little money at the market. Hence good berries that remain unaffected by these climatic conditions are fewer.



**Figure 4.10:** Impacts of increase in temperature on the berry expansion stage of coffee growth (1991-2010) at Kigutha Coffee Estate.

However, coming second by a close margin are the responses given by 30% of respondents who added attack by diseases such as sun scorch and pests such as thrips, capsid bug and antestia bugs whose effects on coffee have been discussed later on in the chapter, causing immature berries to shed. Another equal percentage (30%) added that berries become fewer as they grow at a slower rate and dry up. These results are in line with research which shows that both adults and nymphs of antestia bugs, found in low altitudes with high temperatures or prolonged dry spells cause severe damage to green berries which are still expanding by feeding and indirectly by the transmitting a fungus (*Nematospora coryli*), which causes rotting of beans (Njoroge and Kimemia,1999).

#### 4.4.2.4 Hardening Stage

Increase in temperature, according to majority of the permanent workers (70%), causes green berries to become withered and warty (with a brown dry cover) and vulnerable to attack by pests which thrive in such climatic conditions. These include berry borers which bore holes through berries hence lowering their quality. These results agree with CRI research which shows that reasons for infestation by coffee berry borer include plantations being at a too low altitude with drier climatic conditions. Symptoms of attack are one or more small round holes near

apex of large green or ripe berries, green berries being those that are found in this stage of growth

#### **4.4.2.5 Ripening Stage**

Increase temperatures cause berries to ripen at a faster rate and become over-ripe hence loss in quality according to responses from all the permanent workers. Increase in temperatures scorches mature coffee berries hence making them over-ripe. With unpredictable nature of weather conditions, high temperatures may be prolonged when cool-wet conditions are expected, thus lowering coffee production.

#### **4.4.3 Impacts of Dry spells on Stages of Coffee Growth**

Berries become smaller when there's little rain and reservoirs become depleted according to an interview held with the manager of Kigutha Estate. Berries also become lighter hence earning the farm less income as they are paid per ton of harvested berries. Nematodes attack blue grass during dry spells and this type of grass is used to control soil erosion, hence preserve nutrients and soil micro-organisms, preventing them from being eroded away together with soil. Droughts lead to increased pests such as yellow-headed borers, berry borers, antestia bugs and thrips. E.g. 2008/2009 plants were heavily attacked by yellow-headed borers during that long period of dry spells. According to interviews with the head agronomist, prolonged dry spells call for the need for mulching hence added labour costs.

Trees do not flower well and dry up and seeds fall off, causing drought disease and/or overbearing die back. Head agronomist continued to explain that dry spells also hinder berry expansion so trees yield 'lights' which are of poor quality and fetch little money at the market. During a focus group discussion with casual workers, they agreed that high temperature has caused coffee berries to dry up hence low yields. This leads to low wages thus increasing poverty levels and unemployment as they all admitted to their work at the estate as being their only source of income for them and their families to acquire basic needs such as

education. However, a few admitted to a positive outcome of increased employment opportunities in mulching, weeding, use of pesticides and fungicides and pruning sectors. Dry spells call for the need for mulching and weeding to conserve soil moisture, pruning and use of pesticides and fungicides to control spread of pests and diseases which thrive in these dry conditions. Below are five stages of coffee growth and impacts of low rainfall/dry spells on each stage.

#### **4.4.3.1 Flowering Stage**

Dry spells, i.e. with rainfall below that which is required for the proper growth of coffee (10mm per month during the flowering stage), causes flowers to dry up and fall off (Table 4.7) according to responses from all permanent workers. This consequently hinders formation of young berries thus lowering yield and quality of coffee berries. Flowers dry up due to water shortage young berries fail to form.

#### **4.4.3.2 Pinhead Stage**

Dry spells causes young berries, also called pinheads, to dry up and shrink hence become undersized and lighter according to responses from all permanent workers at Kigutha Estate (Table 4.7). Dried up pinheads may then shed, thus fewer berries are harvested in the end. For those pinheads that do not shed, they eventually lead to low sales as berries weighed are lighter than fully grown healthy berries and these berries also called 'lights' fetch little money at the market.

#### **4.4.3.3 Berry Expansion Stage**

Dry spells causes berries in this stage to become mummified/shriveled, hence loss in quality according to majority (70%) of permanent workers (Table 4.8). Mummified berries are smaller and weigh less than healthy fully grown berries thus leading to low income. Berries are weighed in containers also referred to as 'debes' by the workers, before being sold and the heavier the berries the more the sales. Those that shrivel up during this stage of coffee growth fail to grow and mature fully thus berries harvested are of poor quality and fetch less money at the market compared to healthy berries that have fully matured.

**Table 4.8:** Impacts of dry spells on stages of coffee growth.

<b>Flowering Stage</b>		
<b>Damage</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Flowers dry up and fall off	10	100
<b>Pinhead Stage</b>		
<b>Damage</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Young berries dry up and shrink thus become lighter	10	100
<b>Berry Expansion Stage</b>		
<b>Damage</b>	<b>Frequency</b>	<b>Percentage</b>
Mummified beans & loss in quality	7	70
Fewer & lighter berries and low yields of poor quality	2	20
Attack by disease e.g. Sun-scorch & withered beans	1	10
<b>Hardening Stage</b>		
<b>Damage</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Mummified/smaller beans	8	80
Mummified beans & attack by berry borers which bore holes into green berries, damaging the beans	2	20
<b>Ripening Stage</b>		
Under-ripe berries	7	70
Under-ripe & attack by pests & diseases e.g. berry borers & sun scorch (causing berries to blacken)	3	30

**Source:** Kigutha Estate, Kiambu County.

#### 4.4.3.4 Hardening Stage

Majority of permanent workers (80%) agree that dry spells causes green berries to become mummified (shrink) and become smaller hence loss in quality (Table 4.8). Dry conditions brought about by low rainfall cause berries to dry out hence shrinking. The undersized berries fail to mature poor quality berries are harvested.

#### **4.4.3.5 Ripening Stage**

Dry spells also causes berries not to ripen fully according to majority of permanent workers (70%) hence many of the berries harvested during periods of dry spells are under-ripe and of low quality (Table 4.8). According to ICO (2009) research shows that low rainfall resulting from climate change causes coffee husks to stick to coffee beans therefore hindering maturation, which is in line with the results that show beans become under-ripe as a result of dry spells thus do not mature fully.

#### **4.4.4 Impacts of Erratic Rainfall on Stages of Coffee Growth**

In the year 2009-2010, rains came earlier than expected. Trees were not fully prepared for normal flowering according to an interview with the manager of Kigutha Estate. If trees flower earlier than expected, more inputs such as water and fertilizer are used to sustain coffee therefore increasing production costs. In addition, more berries are harvested from early crop. Though early crop brings in money when coffee goes to the market early, it is not given as much attention as it should because farmers focus more on the main crop hence loss in quality and yield from early crop. Erratic rainfall increases occurrence of CBD which is a fungal infection that thrives in cold wet conditions, bringing spores which cause berries to fall easily. This increases cost of production in disease management.

Erratic rainfall may wash away pesticides hence added labor costs for spraying more pesticides & fungicides according to an interview held with the head agronomist. These are added when they were not supposed to as cropping patterns change hence added costs of fungicides which are expensive and labour costs. Coffee may flower earlier than expected and dry spells that follow cause berries to fall off. Early crop will have more berries as a result of erratic rains but will raise little money because they are all 'lights'. Coffee trees yield more unwanted suckers removed by de-suckering in intervals hence increasing labour costs. During focused group discussions, a point was raised on how they have spray fungicides following erratic rains due to control spread of diseases that highly

occur in wet conditions. Others explained that employment opportunities increase during rainy seasons as yields are high hence the need for a large number of coffee pickers and labour in pests and diseases control. Below are five stages of coffee growth and impacts that erratic rainfall has on each stage.

#### **4.4.4.1 Flowering Stage**

Majority of permanent workers (90%) indicated that erratic rainfall causes crops to be highly susceptible to attack by diseases such as CBD, Bacterial Blight of Coffee (BBC) and Leaf Rust, whose effects on coffee have been discussed later on in this chapter, hence low yields and low quality berries. Coffee Research Foundation research (Gichimu and Omondi, 2010) also shows that erratic rainfall causes coffee bushes to flower earlier than they should then afterwards dry up before the true rainy season begins. Flowering is hindered when rain falls during the period of 'stress' whereby coffee bushes should experience some months of dry weather before flowering. CBD may also infect flowers under very wet conditions, and causes brown lesions on petals, which is in line with the results.

#### **4.4.4.2 Pinhead Stage**

Erratic rainfall causes coffee trees to be highly susceptible to attack by diseases which thrive in wet conditions such as warty disease and CBD which result in shedding of pinheads according to responses from all permanent workers. These results are similar to CRF research (Gichimu and Omondi, 2010) which shows that CBD attacks young berries which are in this stage of growth, causing them to turn black.

#### **4.4.4.3 Berry Expansion**

Erratic rainfall; more than 25mm per month which is the required amount for the expansion stage; causes high occurrence of CBD according to 80% of permanent workers, whose effects are fully discussed in section 4.4.10 However, unaffected berries are heavy and of good quality. These results agree with CRF research (Gichimu and Omondi, 2010) which shows that characteristic symptom of CBD is

progressive blackening of young, expanding coffee berries. Therefore CBD is a disease that attacks coffee berries during expansion in times of erratic rainfall, whereby lesions form on berries and later become dark and sunken.

#### **4.4.4.4 Hardening Stage**

Erratic rainfall results in high occurrence of diseases that attack green berries such as CBD, leaf rust and root rot according to responses from all permanent workers, whose effects have been discussed in section 4.4.10, thus lowering crop yield and quality of beans. These diseases prevent berries from maturing thus leading to low yield and poor quality berries. The hardening stage, like every other stage of growth of coffee is crucial to productivity therefore when this stage is disrupted by attack by diseases; productivity is low in the end.

#### **4.4.4.5 Ripening Stage**

All permanent workers concur that erratic rainfall leads to crop loss due to attacks by CBD, brown blight, BBC and leaf miner whose effects on coffee trees and berries have been discussed later on in this chapter. Coffee Research Foundation research (Gichimu and Omondi, 2010) shows that erratic rainfall causes spread of CBD which affects ripening berries causing a 'brown blight' phase, which is in line with the results. This phase is characterized by typical dark, sunken lesions that envelop the red berry, consequently leading to harvesting few good quality berries.

#### **4.4.5. Pests associated with High Temperature and their Effects on Coffee**

Pests that are prevalent in these climatic conditions are thrips, antestia bugs and capsid bugs according to majority (60%) of permanent workers (Table 4.9), which affect coffee trees in various ways (Table 4.10). Results are similar to research by ICIPE which shows that pests that thrive in high temperature conditions include thrips and coffee berry borer (Jaramillo *et al.*, 2011). Research also shows that heavy outbreaks occur during periods of drought and high temperatures.

**Table 4.9:** Pests associated with high temperatures, dry spells and erratic rainfall

<b>Pests associated with high temperature</b>		
<b>Pests</b>	<b>Frequency</b>	<b>Percentage (%)</b>
thrips, capsid bug, red spider-mite, antestia bug	3	30
Thrips, antestia bug, capsid bug	6	60
Thrips, capsid bug, fruit fly	1	10
<b>Pests associated with dry spells</b>		
	<b>Frequency</b>	<b>Percentage (%)</b>
Antestia bug, yellow headed borer, berry borer, star scale	6	60
Yellow-headed borer, berry borer, thrips & fruit fly	4	40
<b>Pests associated with erratic rainfall</b>		
	<b>Frequency</b>	<b>Percentage (%)</b>
Tip borer, leaf miner	7	70
Leaf miner	1	10
Tip borer	2	20

**Source:** Kigutha Estate, Kiambu County.

Capsid bugs are found in areas of high temperatures in low latitudes where coffee trees are un-shaded (Njoroge and Kimemia, 1999). Coffee Research Foundation research (Gichimu and Omondi, 2010) also shows that heavy outbreaks of thrips occur during periods of drought and high temperatures as shown in the results.

#### **4.4.5.1 Thrips**

Thrips cause leaf damage and leave grey stripes on leaves thus hindering photosynthesis according to 40% of responses from permanent workers (Figure 4.10). Closely following with 30% are respondents who added that thrips cause leaves to die and shed. The missing 10% accounts for respondents who did not include thrips in their responses. This is similar to research according to Jaramillo *et al.*, 2011 which shows that thrips destroy coffee beans and leaves by puncturing

and sucking their contents and cause grayish stripes to form on the leaves hindering photosynthesis.

**Table 4.10:** Damage caused by pests that thrive in high temperature conditions

<b>Damage by thrips</b>		
<b>Damage</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Sucking sap/nutrients from leaves and stunted maturation of beans	2	20
Leaf damage (grey stripes) and loss of photosynthetic capacity	4	40
Leaves dry and fall off after grayish patches on leaves form	3	30
<b>Damage by antestia bugs</b>		
<b>Damage</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Prevent spikes and prevent young berry formation	2	20
Fun branching and buds are killed	2	20
Blackening of flower buds, fall of immature berries, rotting of beans and formation of 'posho' beans	3	30
Sucking of young berries causing them to rot and sucking of young plants causing malformation of branches	2	20
<b>Damage by capsid bugs</b>		
<b>Damage</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Flower buds and petals blacken	4	40
Petals and buds shrivel and style elongates causing no/less fertilization	2	20

**Source:** Kigutha Estate, Kiambu County.

Coffee Research Foundation research (Gichimu and Omondi, 2010) shows that both adults and nymphs feed on underside of leaves, but in severe infestations they also attack upper side of leaves, berries and green shoots. Attacked plant parts show irregular grey or silvery patches as shown in the results, covered by numerous tiny black spots, which are excreta of thrips. In case of severe infestation, leaves dry up and fall off. Heavy outbreaks occur during periods of drought and high temperatures.

#### **4.4.5.2 Antestia Bugs**

Antestia bugs, which are prevalent in increased temperature conditions cause flower buds to blacken, beans to rot and the pulp to turn into a white mass giving rise to ‘posho beans’ hence loss in quality, according to majority of responses from permanent workers (Table 4.10). Coming second by a small margin with 20% are responses which show that antestia bugs suck berries and young plants causing malformation of branches, fan branching and feeding on spikes hence lowering yields and quality. The missing 10% accounts for respondents who did not include antestia bugs in their responses. The antestia bug, whose first choice is green cherries, but who will settle for buds or even twigs, no one knows it has attacked until the pulping process exposes darkly stained zebra-striped parchment coatings, and beans within are shriveled and black, decayed with the fungus which often accompanies it (Kirkpatrick, 2003). Research shows that no visible surface marks/scars/wounds on berry are noticeable until seen on drying beds as "zebra" beans (Le Pelley, 2002). "Zebra" beans produce poor quality coffee and are possible avenues for fungal infection. The damaged berries either yield these “zebra” patterned beans of low appeal to consumers or they fall off. Berry drop leads to crop losses. Antestia bugs also attack and damage flower buds and flowers.

#### **4.4.5.3 Capsid Bugs**

Capsid bugs which also thrive in high temperature conditions, causes flower buds to blacken hindering berry formation (Table 4.10) according to majority of the responses from permanent workers. The missing 20% accounts for respondents who did not include capsid bugs in their responses. Research shows that females insert eggs into flower buds, and thus eggs are not visible. Nymphs are pale green and pear shaped. Wing buds are visible on older nymphs. Both adults and nymphs feed on flower buds, but they are not present they would feed on any soft green parts of coffee bushes. As a result of feeding flower buds blacken due to death of stamens and petals. The style however remains healthy and usually takes a club shaped appearance with pale green shaft and black head. Damaged flowers do not

set fruit. Other pests which, though not included by majority, are still considered by some respondents to thrive in conditions of low rainfall are red spider-mites and fruit flies. Red spider-mites cause leaves to turn yellow-brown hindering photosynthesis according to responses from permanent workers. Research shows that red spider-mites thrive in dry conditions and attack un-shaded coffee when temperatures are high (Porter *et al.*, 1999) as indicated in the results. They cling to leaves of coffee plants gradually turning them reddish until they wither and die. Responses from key respondents show that fruit flies attack the pulp of ripe and expanding berries which shed or remain on coffee tree in shriveled state thus lowering quality of berries. This is in line with research which shows that fruit flies damage coffee by laying eggs in pulps of coffee fruits, which then become an all-you-can-eat buffet for young maggots (Hill, 2003).

#### **4.4.6 Diseases associated with High Temperature and Damage to Coffee**

There are a number of diseases identified by the permanent workers as diseases that are associated with high temperatures, dry spells and wet conditions such as during periods of erratic rainfall (Table 4.11). Diseases prevalent in conditions of increased temperature, according to majority of responses from permanent workers (60%), are sun-scorch and bark disease (Table 4.11), whose effects have been discussed (Table 4.12)

##### **4.4.6.1 Bark Disease**

Bark disease caused by a fungal infection by the *fusarium stilboides* causes growth of fungus on the roots and stem and coffee trees finally die according to majority of responses from permanent workers (Table 4.12). Coffee Research Foundation research (Gichimu and Omondi, 2010) shows that suckers are attacked at the base causing depressed dark brown lesions with yellow margins at times. Pink spore masses are sometimes seen on lesions, which girdle the stem. Girdled older suckers at times continue growing with constriction of "bottle neck" at base. Weakened suckers may break from wind or picking. Barks of trees rise up in flakes on mature stems. Cankerosus regions may develop and die back can follow,

though affected stems could also survive. Infection spreads downwards from infected suckers, gradually girdling the tree base. Cankorous lesions develop round stem base at soil level. Constriction appearance may occur and die-back begin from top of tree. Mulching too close to stems may cause similar rot. Soil borne fungi may cause seedlings in the nursery to die in the same manner.

**Table 4.11:** Diseases brought about by climate variability

<b>Diseases associated with high temperature conditions</b>		
<b>Diseases</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Sun scorch, Bark disease	6	60
Sun scorch & drought	3	30
Hot & cold, sunscorch, drought	1	10
<b>Diseases associated with dry spells</b>		
<b>Diseases</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Leaf rust & drought disease	7	70
Fusarium bark disease, leaf rust, drought	3	30
<b>Diseases associated with erratic rainfall conditions</b>		
<b>Diseases</b>	<b>Frequency</b>	<b>Percentage (%)</b>
BBC, CBD, Brown blight, Warty & Root Rot	3	30
BBC, CBD, Brown Blight, & Root Rot	2	20
BBC & CBD & brown blight	4	40
BBC, CBD, root rot	1	10

**Source:** Kigutha Estate, Kiambu County.

#### **4.4.6.2 Sun-scorch (of leaves and berries) Disease**

Sun scorch causes leaves and berries to blacken, thus hindering photosynthesis and lowering quality of berries respectively, according to majority of responses from permanent workers (Table 4.12). Berries attacked by sun scorch as a result of increased temperatures shows have turned black at Kigutha Coffee Estate due to extensive exposure to heat/the sun as the unaffected green berries continue to harden (Plate 1). This is similar to research which shows that sun scorch is caused by high temperatures as shown in the results and when coffee trees are un-shaded

thus burning leaves and berries of coffee trees causing blackening (Hill, 2003).

**Table 4.12:** Effects of diseases associated with high temperatures

<b>Bark Disease</b>		
<b>Damage</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Damage of roots and purplish discoloration on sections of the roots	2	20
Presence of fungus on roots and stems until coffee trees suddenly die	3	30
<b>Sun scorch (of leaves and berries)</b>		
<b>Damage</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Withering of leaves and berries	3	30
Leaves and/or berries develop lesions or turn black thus hindering photosynthesis and lowering quality of berries respectively	5	50

**Source:** Kigutha Coffee Estate, Kiambu County.

Other diseases which, though not included by majority of the key respondents, are still considered by some respondents to thrive in low rainfall conditions are hot and cold disease and drought disease. Hot and cold causes withering of leaves which become distorted according to responses from key respondents. Research shows that hot and cold disease is a physiological effect to extremities of temperature (too hot or too cold) and is common at high altitudes. Drought, according to responses from key respondents, causes wilting of leaves hindering photosynthesis and plants eventually die. Research shows that it attacks coffee in times of drought or prevalent dry spells (Porter *et al.*, 1999).

#### **4.4.7 Pests associated with Dry spells and their Effects on Coffee**

Pests that are prevalent in conditions of dry spells according to 60% of responses from permanent workers are antestia bugs, yellow-headed borers, berry borers and star scale (table 4.9) which have had effects on coffee trees and berries as shown (Table 4.13 and Table 4.10).



**Plate1:** Coffee berries attacked by Sun Scorch at Kigutha Estate. November 14th 2013

#### **4.4.7.1 Coffee Berry Borer and Yellow headed borer and Star Scales**

All responses on damage caused by berry borers show that berry borers lower yields and quality of berries by boring holes through berries thus damaging beans inside (Table 4.13). Research shows that reasons for the infestation by coffee berry borer include when the plantation is at a too low altitude, which experience higher temperatures and prolonged dry spells (Mugo, 1999) as indicated in the results. Adult and larval stages of coffee berry borer attack both immature and mature berries (Murphy, 2002). Results also agree with CRI research (CRI, 2010), which shows that berry borers bore through the fruit pulp, penetrating the coffee bean itself, where she lays her eggs. Female berry borers fly from tree to tree to lay eggs (Njoroge and Kimemia, 1999). Star scales, according to majority of responses, attack leaves hindering photosynthesis thus lowering yields (Table 4.13).

**Table 4.13:** Damage to coffee caused by pests associated with dry spells

<b>Coffee Berry Borer</b>		
<b>Damage</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Bores holes through coffee berries thus damaging the beans	7	70
Missing system	3	30
<b>Yellow headed borer</b>		
Plants wither and phloem and xylem are damaged	2	20
Makes holes on branches and main stem and branches break	4	40
Wilted tips	1	10
<b>Star scale</b>		
Sap loss		
Drooping dead leaves thus hindering photosynthesis	20	30
<b>Missing system</b>	5	50

**Source:** Kigutha Coffee Estate, Kiambu County

Research shows that symptoms include green branches bent at nodes with pits in green bark beneath the bend, drooping dead leaves on affected nodes and numerous small red or yellow objects are found in bark crevices especially near the ground (Mugo, 1999). Yellow-headed borers make holes on branches and main stem causing branches to break according to majority of responses (Table 4.13). Research shows that larvae of yellow headed borers cause large crop losses (Le Pelley, 2002). Larvae tunnel through stem as shown in the results, rupturing and perforating barks of branches and stems. These activities disrupt continuous translocation thereby interfering with normal physiological functioning of the plant which finally leads to direct loss of berry yields (Crowe, 2002).

#### **4.4.8 Diseases associated with Dry Spells and their Effects on Coffee**

Diseases that are prevalent in conditions of low rainfall/dry spells according to

70% of the responses from permanent workers are drought disease and leaf rust (Table 4.11), whose effects on coffee are shown below (Table 4.14).

**Table 4.14:** Effects of Diseases associated with dry spells

<b>Leaf rust</b>		
<b>Damage</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Leaf fall	2	20
pale yellow/yellow orange lesions on leaves hindering photosynthesis	2	20
pale yellow/yellow orange lesions on leaves causing premature leaf fall	2	20
<b>Drought Disease</b>		
Leaves wilt hindering photosynthesis then plants die.	7	70
<b>Missing system</b>	3	30

**Source:** Kigutha Coffee Estate, Kiambu County.

#### **4.4.8.1 Drought disease and Leaf Rust**

Drought disease, according to majority of responses from permanent workers (70%), causes wilting of leaves hindering photosynthesis and plants eventually die (Table 4.14). Research also shows that indeed drought disease attacks coffee in times of drought which constitutes low rainfall or no rainfall at all for a long period of time. (Porter *et al.*, 1999). Coffee Research Foundation research (Gichimu and Omondi, 2010) shows that Leaf rust is favored by wet, warm weather. Leaf rust attacks the leaves according to all responses (Table 4.14). This hinders photosynthesis thus lowering yields and quality of berries. The missing 40% accounts for permanent workers who did not include leaf rust in their responses. Kenya's CRF research (Gichimu and Omondi, 2010) shows that, similar to the results, leaf rust thrives in dry conditions and has greatly reduced production. Leaf rust cause leaves to turn yellowish, consequently hindering photosynthesis from taking place effectively thus leading to low yields and poor

quality berries (Figure 4.14). Leaf rust causes yellowish patches on leaves hindering photosynthesis (Jaramillo *et al.*, 2009), which is similar to the damage caused by leaf rust on leaves at Kigutha Coffee Estate (Plate 2).



**Plate 2:** Leaves of a coffee tree attacked by leaf rust at Kigutha Coffee Estate. November 14th 2013.

If severe, this can cause leaf drop. Yellow to orange powdery blotches appear on the underside of leaves, chlorotic patches appear on the upper side. They grow from 2-3 mm diameter to several centimeters. On older leaves, several lesions can merge together. This produces irregular diseased areas covering much of the leaf. However, diseased leaves are usually shed before this stage. A major effect of coffee leaf rust is that it causes defoliation (Jaramillo *et al.*, 2011).

#### **4.4.9 Pests associated with Erratic Rainfall Conditions and Their Effects on Coffee**

Tip borer and leaf miner were listed as pests associated with high erratic rainfall conditions by majority (70%) of permanent workers and their effects on coffee

trees are discussed further (Table 4.15). Research shows that a cooler and more humid eco-climate within the coffee bushes is favourable for breeding of leaf miners and that wet conditions favour the breeding of tip borers (Bess, 2004) as shown in the results.

#### 4.4.9.1 Leaf Miners and Tip borers

Due to the unpredictable nature of erratic rainfall, it becomes difficult for farmers to prevent this attack and controlling the situation in time. By the time farmers apply pest control measures, damage to the crops by pests is already done.

**Table 4.15:** Damage to coffee caused by pests associated with erratic rainfall conditions

<b>Tip borer</b>		
<b>Damage</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Apical plant withering	3	30
Branches and tips of suckers dry up and later blacken	2	20
<b>Missing System</b>	5	50
<b>Leaf Miner</b>		
<b>Damage</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Brown blotches on leaves thus causing leaf damage	3	30
Brown blotches on leaves and shedding of mined leaves	3	30
<b>Missing system</b>	4	40

**Source:** Kigutha Coffee Estate: Kiambu County

Leaf miners and tip borers associated with wet conditions cause damage to various parts of coffee trees (Table 4.15). Majority of respondents indicated that tip borers attack apex (tips) of coffee plants causing them to wither. Equal number of responses indicated that leaf miners cause brown blotches on leaves and shedding of mined leaves. The missing system represents respondents that had not included those pests in their responses. Research shows that symptoms of attack by leaf miner include transparent areas in the leaf; larvae are present on the underside of the coffee leaf (Pereira *et al.*, 2007)

#### **4.4.10 Diseases associated with erratic rainfall conditions and their effects on coffee**

Majority of permanent workers (70%) cited BBC, CBD and Brown blight as those diseases that are prevalent in high erratic rainfall conditions (Table 4.11), whose effects on coffee have been discussed further (Table 4.16). These results agree with research which shows that CBD outbreak coincides with erratic rainfall (Jaramillo *et al.*, 2011). Coffee Research Foundation research also shows wet conditions and temperatures between 15 and 27.7° C favor CBD and Brown Blight development and BBC bacterium is also favored by cool wet weather, whereby during cool, wet weather, the bacterium multiplies and initiates an epidemic.

##### **4.4.10.1 CBD and BBC**

BBC attacks leaves and branches resulting in their deaths and this causes yield loss and poor quality berries according to 50% of responses from permanent workers (Table 4.16). 50% of permanent workers also indicated that CBD causes spores/dark patches on berries and shedding of affected berries, thus lowering yields and quality of berries. The missing system (10%) represents respondents that had not included those diseases in their responses. Research shows that CBD damages berries causing them to turn black as shown in the results hence yield loss (Porter *et al.*, 1999). The disease causes maximum damage to green cherries, turning them dark with decay. Under humid conditions, pink spore masses become visible on the surface of lesions. Berries often drop from the branch at an early stage of the disease. This is a characteristic feature of CBD. Lesions may also

occur on young berry stalks, causing them to be shed before lesions are visible on the berry itself. The disease also affects ripening berries causing a 'brown blight' phase. This phase is characterized by typical dark, sunken lesions that envelop the red berry. CBD may also infect flowers under very wet conditions, and causes brown lesions on petals. This disease does not kill trees, but crop losses can be more than 80%.

**Table 4.16:** Effects of Diseases that thrive in erratic rainfall conditions

<b>Coffee Berry Disease</b>		
<b>Effects</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Spores/dark patches on berries and berries fall	5	50
Yield loss	1	10
Browning of flower petals & brown sunken spots on green berries destroying the beans inside	3	30
<b>Missing System</b>	1	1
<b>Bacterial Blight of Coffee</b>		
<b>Damage</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Foliage damage/darken & turn brown	4	40
Attacks leaves & branches resulting in their death	5	50
<b>Missing system</b>	1	10
<b>Brown Blight</b>		
<b>Damage</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Causes dark patches on berries with small black dots thus lowering their quality	4	40
<b>Missing system</b>	6	60

**Source:** Kigutha Coffee Estate, Kiambu County.

#### **4.4.10.2 Brown Blight**

All permanent workers who listed Brown Blight as a disease that thrives under erratic rainfall conditions stated that brown blight causes dark brown patches with small black dots to develop on berries thus lowering their quality (Table 4.16). This slightly varies from research which shows that the characteristic symptom of Brown Blight is a progressive blackening of young, expanding coffee berries. This begins as small water-soaked lesions on fully developed berries. They rapidly become brown and sunken. As they grow they cause the whole berry to rot. Fully developed cherries then turn black and hard (Hockings, 2008)

### **4.5 Coping Mechanisms**

Kigutha Coffee Estate farmers have been forced to come up with mechanisms to deal with effects of climate variability thus ensuring continued productivity. These mechanisms comprise of pest and disease control to minimize attack of coffee trees and berries by pests and diseases brought about by changes in climatic conditions. These mechanisms at the same time help cope against other effects of climate variability such as loss of water from soil and plants through evapotranspiration and prevent soil erosion brought about by erratic rainfall by practicing mulching and growth of blue grass in between rows of coffee trees respectively.

#### **4.5.1 Pest Control**

Basin irrigation has been adopted to make up for insufficient water supply to coffee trees in times of low rainfall as discussed (section 4.4.1.2) Other pest and disease management strategies adopted to control spread of pests and diseases brought about by unpredictable changes in climate are as follows, according to responses from key respondents.

#### **4.5.1.1 Biological Control**

This involves encouraging animals to feed on pests that attack coffee trees. At Kigutha Coffee Estate, this is done by pouring chemicals at the base of the tree, a process known as banding. These chemicals kill ants that climb up coffee trees to feed on leaves, berries and suck plant sap. Insects that feed on pests that attack coffee trees are therefore chased away by these ants once they climb up the trees. However, once banding is undertaken, insects that feed on coffee pests freely do so without any interference from ants. Wasps & ladybirds for instance feed on mealy bugs which are insects that attack coffee trees. Thus insects that feed on coffee pests help to reduce pest-attack.

#### **4.5.1.2 Chemical Control**

This involves use of pesticides to control spread of pests. In the course of the interview held with the manager, he identified pesticides used in the farm as dimethoate and pedtrin. These pesticides are sprayed on coffee trees and berries to kill pests and prevent them from feeding on coffee trees and berries in future. It is therefore both a preventive measure and a control strategy. Insecticides include those used in banding whereas fungicides are copper-based. The copper helps fungicides to stick to coffee trees thus ensuring they work effectively.

#### **4.5.1.3 Mechanical Control**

Controlling pests is also done manually by carrying out the following:

1. Pruning away areas affected by pests, for instance, to control attack by yellow-headed borers which causes tips to droop.
2. Mulching reduces thrips numbers considerably. Mulching conserves moisture hence preventing leaves, flowers & berries attacked by pests such as thrips from drying up further.
3. Hand removal which is commonly used to control the spread of yellow headed borers by removing the larvae using the hands.
4. Spot control i.e. Spraying pesticides on targeted spots.
5. Shading to prevent capsid bug attacks.

Mulching is done at the base of trees using dried up branches and leaves to soil moisture and prevent evaporation of water from the soil during periods of increased temperature and low dry spells (Plate 3). This prevents yield loss and poor quality berries, which would otherwise shrivel and shed from coffee trees due to insufficient water in soil. In addition, mulching prevents farmers from over-relying on irrigation, thus conserving water stored for irrigation that would otherwise be depleted much faster if mulching was not undertaken. Exotic trees are grown to provide shading at Kigutha Coffee Estate (Plate 4)



**Plate3:** Photograph of mulch (dried leaves and branches) covering the soil at the base of the trees in Kigutha Coffee Estate. November 14th 2012. These include *Gravellia* species. Indigenous trees are also grown to serve the same purpose. They act as wind breakers to help control soil erosion and provide shade thus preventing excess evapo-transpiration and reduce attacks by capsid bugs which attack coffee trees in sunny weather conditions. Other exotic species of trees grown for the same purposes are *Sesbsnia sesban* and *Moriga olifera*.



**Plate 4:** Exotic trees surrounding the coffee plantation. November 14th 2012.

#### **4.5.2 Disease Control**

According to an interview with the manager, the following disease control strategies have been adopted.

1. Spraying copper based fungicides to destroy fungal diseases. Copper helps to obtain a good distribution of fungicide throughout the tree.
2. Weeding & mulching to conserve soil moisture hence control diseases that cause the coffee trees to dry up such as drought disease, sun scorch and leaf rust. Weeding can be done manually by slashing or using hoes as well as chemically using herbicides.
3. Pruning to control CBD which is less severe when trees have been pruned hard
4. Shading to prevent sun-scorch.
5. Use of nitrogen fertilizers to encourage re-growth of new leaves.
6. Growth of blue grass which controls soil erosion hence preserving nutrients in the soil (Plate 5). Hence nutrients lost through attack by Intermittent chlorosis which causes deficiency of nutrients after replacing these

nutrients through application of fertilizer, the nutrients are prevented from being blown away with the soil through erosion by growing blue grass.

Blue grass is grown in between columns of coffee trees to control soil erosion by wind and water thus preserving soil nutrients for use by coffee trees (Plate 5). Both indigenous and exotic trees grown in the plantation to provide shading and act as wind breakers are only found on the outline of the plantations and not in between the coffee trees. Thus when erratic rain falls or when strong winds blow, unprotected coffee bushes are not strong enough to act as wind breakers and hold all the soil together with their roots. Therefore some of the top soil would otherwise be eroded by winds and runoff if it were not for blue grass grown in between coffee trees to help hold soil together and prevent erosion.



**Plate 5:** Photograph of blue grass at Kigutha Coffee Estate. November 14th 2012.

## CHAPTER FIVE

### SUMMARY, CONCLUSION AND RECOMMENDATIONS

#### 5.1 Summary

Objectives of this study were to investigate variability in rainfall and temperature patterns (1991-2010) and consequently determine whether changes in yields and grades of coffee harvested have been affected, to investigate the effects that fluctuations in rainfall and temperature have had on growth stages, irrigation and pest distribution and, lastly, to determine what coping mechanisms have been adopted at the coffee estate in dealing with climate variability. Past literature has mainly focused on impacts on yield in general and pests and diseases associated with climatic changes. However there is the need to also focus on impacts on each and every stage of coffee growth so as to gain a better understanding of how these impacts eventually lead to the overall change in yield and quality of coffee berries. Data was collected using questionnaires, focus group discussions, interviews, direct observation and taking photographs. For the first objective, results show a general increase in mean annual temperature and fluctuations in mean monthly temperature (1991-2010). Fluctuations in rainfall also occurred, with consecutive years having wet and dry periods as amount of rainfall rising above and falling below the overall mean. For the second objective, results show that increase in temperature and erratic rainfall hinder growth of coffee at the flowering, pinhead, berry expansion, hardening and ripening stages, consequently leading to yield loss and poor quality berries, as results show negative correlations which suggest that increase in temperature and erratic rainfall result in reduction in yields. For the third objective, negative correlations show that more water is supplied for irrigation during dry spells and various pests and diseases are associated with high temperature conditions (e.g. capsid bugs and sun scorch disease), wet conditions (e.g. tip borers and CBD) and dry spells (e.g. yellow-headed borers and drought disease). Time series data showed variability in rainfall averages with 5-year moving averages. For the fourth objective, results show that biological (banding),

chemical (pesticides) and mechanical control (e.g. Mulching and shading which reduces attack by thrips and capsid bugs respectively and copper-based fungicides are used in disease control. Pest and disease control is made difficult by unpredictable climatic conditions, hence the need for more stringent measures to deal with adverse effects of climate variability on coffee.

## **5.2 Conclusions**

Fluctuations in rainfall and temperature (1991-2010) show unpredictability in rainfall and temperature. Increase in temperature above that which is required for growth of coffee at Kigutha Coffee Estate (9°C-15°C), dry spells and erratic rainfall, especially in times when dry spells are required for flowering and hardening, hinder growth in all stages of coffee growth (flowering, pinhead, berry expansion, hardening and ripening). Each stage of growth is to crucial maturation of coffee and yields harvested. Therefore, when a particular stage of growth is affected, the end output (yield harvested) is affected, leading to yield loss and poor quality berries. Increased temperature reduces water supplied for irrigation as water sources dry up hence less water supplied for irrigation, whereas low rainfall calls for the need to supply more water for irrigation thus putting pressure on water sources. Spread of pests and diseases are associated with each of these conditions resulting in yield loss and poor quality berries. Basin Irrigation has been adopted to make up for insufficient water supply to coffee trees in times of low rainfall. Biological control (banding), chemical control (pesticides) and mechanical control (pruning, mulching, shading, spot control and hand removal of pests) are undertaken to control spread of pests. Disease control mechanisms adopted are pruning, weeding, mulching, growth of blue grass, spraying copper-based fungicides, use of nitrogen fertilizers and shading.

## **5.3 Recommendations**

### **5.3.1 Management Actions**

Due to attack of coffee by pests and diseases resulting from increased temperature, low rainfall and erratic rainfall as shown in the results and washing away of

fungicides and pesticides by erratic rains, there is the need for growth of disease-resistant varieties. These include the *Ruiru 11* and *batian* varieties of which the latter which can yield five tons per hectare for a farmer following sustainable agronomical practices which is more than the yields from SL 28, which is what is cultivated at Kigutha Coffee Plantation according to CRF research. As a result of drying up of coffee trees due to low rainfall and increased temperature that cause evapo-transpiration and due to attack of coffee trees by pests such as thrips, antestia bugs and capsid bugs that spread to the plantation in increased temperature conditions as shown in the study findings, growth of more shade trees in between rows of coffee trees as opposed to growing them only on the outline along footpaths can be done, which in the end may contribute to higher yields of better quality. More water supplied for irrigation in times of low rainfall puts pressure on water used for irrigation as shown in the results, for instance from River Kiu. Hence, more water conservation strategies can be adopted to store rain water, for instance, building cisterns and wells to store water and drip irrigation can be undertaken so as to save more water for use during prolonged dry spells.

### **5.3.2 Further Research**

Pest and disease control is made difficult by unpredictable climatic conditions, hence the need for more stringent measures to deal with adverse effects of climate variability on coffee. There is the need for more research on copying mechanisms that are particular to each climatic condition; how farmers can adapt to increased temperatures, prolonged dry spells, and erratic rainfall. More studies can also be conducted on drought-resistant varieties that can be grown at Kigutha Coffee Estate in addition to disease-resistant varieties.

### **5.3.3 Policy Actions**

Policy makers need to take into account aspects of climate variability and how this affects productivity when formulating policies on integration of land management practices in agriculture. Policies need to accommodate use of sustainable land management practices including sustainable agricultural practices such as those

that increase soil fertility and ensure sustainable water-use and equity in water allocation, so as to ensure natural resources that are crucial to success in agricultural productivity such as soil and water are conserved.

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**APPENDICES**

**APPENDIX I: QUESTIONNAIRE**

**THE IMPACTS OF CLIMATE VARIABILITY ON LARGE SCALE COFFEE PRODUCTION IN KIGUTHA COFFEEESTATE IN KIAMBU COUNTY, KENYA**

**FORM NO.:**.....

**DATE:**.....

This study is carried out to determine the impacts of climate variability on large scale coffee production in Kigutha Coffee Plantation which later be used to recommend suitable adaptation and coping strategies that will help to build their resilience to climate change. It is therefore conducted purely academic purposes and any information provided will be treated with privacy and confidentiality. Please put a tick in the box next to the response where applicable.

**\*Records of annual supply of water for irrigation (cm<sup>3</sup>) to be provided.**

**\*Records of total annual yields (kg/ha) and grades of coffee harvested (%/year) to be provided.**

**(Answer all questions and tick the appropriate answer for questions with multiple choices. There is no right or wrong answer).**

**SECTION A**

1. Name \_\_\_\_\_ of \_\_\_\_\_ coffee plantation.....

2. Name \_\_\_\_\_ of respondent.....

3. Job description of respondent within the plantation.....

4. Type of coffee grown.....

5. Type of farmland

a. [ ] Public/Government

- b.  Community (managed by local council)
- c.  Private
- d.  Leasehold

6. Size of farm (hectares).....

7. Number of workers

**SECTION B**

8. What are the stages of coffee growth from the time the coffee berries are about to appear up to the time they mature and ready for harvesting?

- 
- 
- 
- 

9. Using the table below, briefly describe the activities carried out in each stage of coffee growth to ensure proper growth of coffee berries

STAGE	ACTIVITIES
1.	
2.	
3.	
4.	

5.	
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**SECTION C**

10. Have you noticed any changes in climatic conditions?

Yes  No

11. (a) If yes, for how long have you noticed the changes?

- Less than a year
- 1-5 years
- 6-10 years
- More than 10 years

(b) Among 1-4 given below, indicate by filling in the box the code number of the most prevalent changes in climate that has been experienced in the region [    ]

- 1- Increase in temperature
- 2-Erratic rainfall
- 3- Increased winds
- 4- Decreased rainfall

12. Do you irrigate your crops?  Yes  No

(a)If yes, what form of irrigation is carried out?

.....

13. What are the sources of water?

- River/lake/stream (indicate the name)
- Borehole
- Piped into dwelling
- Dam
- Other

14. Have changes in climate impacted on the source of water?

Yes  No

15. Using the table below, describe how each stage of growth is affected by climate changes.

CHANGING CLIMATE	STAGE	IMPACTS ON CROPS
Increased temperature (above required)	1. .... 2. .... 3. .... 4. .... 5. ....	..... ..... ..... ..... ..... ..... ..... ..... ..... .....
Dry spells (below required)	1. .... 2. .... 3. ....	..... ..... ..... ..... ..... ..... .....



16. What pests have attacked coffee as a result of these changes in climate shown in no.19 above and what damage do they cause to the coffee plant & coffee berries? (fill in the table that follows)

Pest	Damage

17. What diseases have attacked coffee as a result of these changes in climate shown in no.19 above and what effects do they have on the coffee plant & coffee berries?

Disease	Effects

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18. What measures are being taken in dealing with these pests and diseases?

<u>Pest Control Measures</u>	<u>Disease Control Measures</u>

19. (b) In the table below, write down the pests and diseases that attack coffee as a result of the climatic changes shown

Climatic condition	Pest	Disease
Increased temperature (above required)		
Low rainfall (below required)		
High erratic rainfall (above required)		



**APPENDIX II: KEY RESPONDENTS' INTERVIEW SCHEDULE**

**IMPACTS OF CLIMATE VARIABILITY ON LARGE SCALE COFFEE PRODUCTION IN KIGUTHA COFFEEESTATE IN KIAMBU COUNTY, KENYA**

**FORM NO**.....

**DATE:**.....

**Questions are addressed to key respondents (Manager, head agronomist and farmers).**

Name of respondent:.....

Job description of respondent within the plantation?.....

Date of interview\_\_\_\_/\_\_\_\_/ 2012

Time the interview started \_\_\_\_:\_\_\_\_

The questions to be asked in this interview are for research purpose only and the findings of this study will provide information on key respondents' understanding on climate variability and its impacts on large scale coffee production in Kigutha Coffee Estate

The information provided will be treated with utmost confidentiality.

**(Answer all questions and tick the appropriate answer for questions with multiple choices. There is no right or wrong answer).**

1. Is irrigation practised at Kigutha Coffee Estate?
2. Type of coffee grown?

- (b) If so, what type of irrigation is carried out?
- (c) What is the procedure followed in undertaking it?
- (d) Who is responsible for undertaking the tasks involved?

- 3. What are the stages of coffee growth and what happens in each stage.
- 4. In what months do each of the above stages of growth take place and what is the minimum water supply provided for each stage?

STAGE OF GROWTH	PERIOD	MINIMUM WATER SUPPLY (CM <sup>3</sup> )

- 5. Have you noticed any changes in climatic conditions?
  - (b) If so, what are the most prevalent climatic changes?
    - a.  Low rainfall
    - b.  Increase temperature
    - c.  Erratic Rainfall
    - d.  Other (define)
  - (c) What are the impacts of these climatic changes on coffee trees and berries as well as water supply used for irrigation?
  - (d) What are the most prevalent pests and diseases brought about by the above climatic changes?

6. What are the control measures for pests and diseases undertaken?
  - i. Pest Control measures
  - ii. Disease Control measures
7. What other coping mechanisms have been adopted to deal with the impacts of climate variability on the coffee production process?

**APPENDIX 111: FOCUSED GROUP DISCUSSIONS SCHEDULE**

**IMPACTS OF CLIMATE VARIABILITY ON LARGE SCALE COFFEE PRODUCTION IN KIGUTHA COFFEE ESTATE IN KIAMBU COUNTY, KENYA**

**Questions are addressed to the casual workers whereby they are allowed to discuss and give their views on the matter at hand.**

**Date of discussion:** \_\_\_\_/\_\_\_\_/ 2012

**Time the interview started:** \_\_\_\_:\_\_\_\_

The results from the focus group discussions are for research purpose only and the findings of this study will provide information on key respondents' understanding on climate variability and its impacts on large scale coffee production in Kigutha Coffee Estate.

The information provided will be treated with utmost confidentiality.

**(Answer all questions and tick the appropriate answer for questions with multiple choices. There is no right or wrong answer).**

1. Have you noticed any changes in climatic conditions?

(b) If so, what are the most prevalent climatic changes?

Low rainfall

Increase temperature

Erratic Rainfall

Other (define)

2. How has coffee been affected by these climatic changes?

(b) What are the consequent social impacts on casual workers?

3. What are the work responsibilities for casual workers with respect to coffee production, for instance in sustaining the crops as well as the pest and disease control and irrigation sectors?

4. Have you noticed any pests and diseases attacking the coffee trees and berries as a result of variability in climate?