

Donnish Journal of Research in Environmental Studies
Vol 2(2) pp. 005-017 March, 2015.
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Original Research Article

Analysis of Links between Climate Variables and Tea Production in the Recent Past in Kenya

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Accepted 30th January, 2015.

Tea is grown in Kenya under rain-fed conditions and therefore depends heavily on weather stability. An assessment of tea vulnerability to climate change using statistical analysis linking historical climate data trends with tea yields in Kenya based on time data series was carried out. The aim of the study was to link tea yields to the following climate variables: air temperature, radiation, rainfall and soil water deficits. The study was carried out at the Timbilil Tea Estate, Kericho district, Magura Tea Estate in Sotik and Kangaita farm in Kirinyaga district. Data on weather and tea production was obtained from the Tea Research Foundation of Kenya agro-meteorological stations and respective Tea Estates management respectively. Data was statistically analyzed using GENSTAT and MSTAT. Data showed that all Estates have experienced increasing temperature trends with an annual rise of 0.020C_y-1 at Timbilil, 0.220C_y-1 in Sotik-Magura and 0.010C_y-1 in Kangaita. Rainfall distribution and patterns have also changed in all the three sites but is rather unpredictable. Tea does well in warm temperatures only if soil moisture is not inhibitive. The case of Timbilil Tea Estate showed a significant ($P \leq 0.05$, $n=270$, $r^2=0.928$) positive relationship between mean air temperature and tea yields (319 kg ha⁻¹m-10C⁻¹) when soil moisture is not limiting. This is also true for the other two sites Magura in Sotik and Kangaita in Kirinyaga.

Keywords: Climate variables, Tea, Kenya.

INTRODUCTION

Climate change is the greatest challenge facing humankind worldwide and in this century. Africa is one of the most vulnerable regions to climate change and is likely the most debilitated. Climate change is a change in average weather conditions or the distribution of events around that average (e.g., more or fewer extreme weather events) mainly due to global warming. Global warming is the observed temperature increase over the last >50 years due to the increase of greenhouse gas concentrations in the atmosphere (Solomon,

et al., 2009). Green house gases contribute to the greenhouse effect on the earth's surface. The largest contributing source of greenhouse gas is the burning of fossil fuels leading to the emission of carbon dioxide. The emission of carbon dioxide into the environment mainly from burning of fossil fuels (oil, gas, petrol, kerosene, etc.) has been increased dramatically over the past 50 years (Solomon, *et al.*, 2009).

Tea production is one enterprise that depends heavily on weather stability. Climate change therefore is alarming to the

tea industry stakeholders. Stephens and Carr (1992) lists some of the major environmental variables that affect tea (shoot) growth as temperature, saturation deficit of the air, plant and soil water deficits, rainfall and evaporation.

One of the major impacts of climate change is the occurrence of severe weather conditions, e.g. hail, frost and drought. Tea production is greatly influenced by extreme weather events, particularly drought, frost and hailstorms. The crop requires a well-distributed annual rainfall above 1200mm, temperature range of 18-30°C and well drained soils.

Frost bite, although a rare phenomenon in the past, is becoming a threat with tea yield losses of up to 30% for three consecutive months whenever it occurs for instance January, 2012. In areas like Kericho, Sotik and Nandi Hills, net loss of tea green leaf due to hail is estimated at 2.7 million kilograms per year basing on the reports from Kericho, Nandi and Sotik areas.

The climate change challenge is complicated further by limited climate change research resources. Therefore, climate dynamics are still poorly understood. This project aims to build capacity within the Kenyan tea sector on climate change impacts and identify the most vulnerable producers in Kenya. This will assist in policy making in climate change mitigation to ensure vulnerable producers secure their future livelihoods and make these livelihoods more environmentally and economically sustainable.

Study Area

Tea (*Camellia sinensis* (L.) O. Kuntze) is Kenya's leading foreign exchange earner. It is produced on approximately 157,720 hectares, of which 64% is managed under smallholder units and 36% under large estates (Tea board of Kenya Annual report, 2009/2010) most of which is processed for black tea. Annual production is 398,500,000 kgs. at 2010 (the highest production ever), which is valued at slightly over US dollars 1.4 billion as a contribution to Kenya's foreign exchange.

Currently the tea growing areas in Kenya are in the following districts: Bomet, Embu, Kakamega, Kericho, Kiambu, Kirinyaga, Kisii, Meru, Murang'a, Nakuru, Nandi, Nithi, Nyamira, Nyeri, Trans-Nzoia and Vihiga. The optimum tea-producing zone in Kenya is within an altitude between 1500 - 2700 meters above sea level. In Kenya, tea farming is mainly rain-fed and most of the tea growing areas go through a regular 3-months drought between December and March. The tea yield loss attributed to this drought period is estimated at 14-20% and up to 30% in more pronounced droughts. However, this is prone to change in time-span and intensity due to climate change.

LITERATURE REVIEW

Tea and Weather

Global weather has become unpredictable and created uncertainty in agricultural production. One of the major impacts of climate change is the occurrence of severe weather conditions, e.g. hail, frost and drought (Bore, et al., 2011). Past studies have shown that climate variability is the key factor in the annual tea yield variability of tea (Ng'etich, et al., 2006 (b)). Hence, climate change has direct and indirect impacts on tea production in Kenya. Additionally, different geographic locations have different effects on tea yield and quality (Ng'etich, 1995). Altitudinal effects vary within clonal teas due to being obtained from different geographic regions. The quality of some clones improved with altitude increase while it

decreased in some (Ng'etich, et al., 2006 (b)). Additionally, maximum yield declined with increase in altitude corresponding to reduced temperature (Ng'etich, 1995).

The yield of tea is influenced by air and soil temperature, air saturation deficits, radiation, soil water deficits, rainfall and evaporation (Carr, 1972, Squire and Callander, 1981, Stephens and Carr, 1991, Stephens et al., 1992). Temperatures are equally important in that the mean minimum air temperature required to support shoot growth is about 13° to 14 °C with an optimum in the range of 18° to 30°C. Daytime maximum temperature in excess of 30°C and night minimum temperature below about 14 °C leads to a reduction in the rate of growth (Carr, 1972), characterized by reduced shoot extension rates and low yields.

Currently, there are higher frequencies of droughts that greatly reduce tea yields. The major effects arise from deviation outside the favorable conditions such as elevated temperatures and declining soil moisture levels leading to osmotic stress that induces numerous biochemical and physiological responses in tea (Duan, 1992). Tea plant can respond to water stress at morphological, anatomical and cellular levels with modifications that allow the plant to avoid stress or to increase tolerance (Hilton et al., 1973) consequently reducing tea yield.

Analysis of the known responses of tea shoots to temperature as shown by evidence obtained in various experiments indicate that differences in mean temperatures of only 2 degrees Celsius were sufficient to cause differences in length of shoot growth cycle of up to 20 days in one clone and 10 days in another (Ng'etich et al., 2006 (b)). It is also indicated that low air temperatures at high altitudes cause a decline in growth rate and lower yields. Plants growing in warm environments produce higher amounts of dry matter than those in cooler areas and shoot growth increases with increase in altitude (Ng'etich 1995).

Radiation plays an important role during photosynthesis, which is directly related to tea leaf assimilation and dry matter production. In a long-term shade experiment, it was noted that shoot extension, leaf water potential and shoot dry mass in the artificially shaded area tea were higher than those of tea under *G. robusta* shade or unshaded and shoot population is higher in unshaded tea, hence higher yields than in other treatments (Ng'etich et al., 2006 (a)).

In the same experiment, tea under natural shading had the lowest shoot dry biomass and yields. Radiation is directly related to temperature, which also increases tea yields when soil moisture is not limiting.

Impacts of Climate Change on Crop Production

Climate change has been attributed to the increased concentrations of greenhouse gases in the atmosphere, CO₂ being one of them. Higher CO₂ levels can increase yields. The yields for some crops, like wheat and soybeans, could increase by 30% or more under a doubling of CO₂ concentrations. The yields for other crops, such as corn, exhibit a much smaller response (less than 10% increase) (United States Climate Change Science program (C.C.S.P., 2008). However, some factors may counteract these potential increases in yield. If the temperature exceeds a crop's optimal level or if sufficient water and nutrients are not available, yield increases may be reduced or reversed.

Changes in temperature, amount of carbon dioxide (CO₂), and the frequency and intensity of extreme weather could have significant impacts on crop yields. Crops tend to grow faster in warmer conditions. However, for some crops (such as grains),

faster growth reduces the amount of time that seeds have to grow and mature (United States Global Change Research Program (U.S.G.C.R.P.), 2009). Warming may benefit the types of crops that are typically planted there. However, if warming exceeds a crop's optimum temperature, yields can decline.

Dealing with drought could become a challenge in areas where temperatures are projected to increase and precipitation is projected to decrease. As water supplies are reduced, it may be more difficult to meet crop water demands. This is also true for tea farming.

Many weeds, pests and fungi thrive under warmer temperatures, wetter climates, and increased CO₂ levels. The incidences of weeds and pests are likely to increase and this would cause new problems for farmers' crops previously unexposed to these species. Tea production in Kenya is currently under optimum ecological conditions and the use of pesticides unheard of. But with climate change, weeds and pests emergence may necessitate the use of pesticides. Introducing the use of pesticides and fungicides to tea farming may negatively affect human health and the environment as a whole.

Currently, studies relating to the effects of temperature and CO₂ concentrations on the tea plant in a controlled environment have not been undertaken. Studies evaluating the short term relationship between weather parameters and tea yields in Kenya have been done in the past, but long-term effect of climate change on tea production has not been evaluated. It is therefore, important to analyze the effects of weather parameter on tea yields with a view to relating these effects likely to be real scenarios due to climate change. The study will also utilize the weather data which have been generated in the recent past.

MAIN OBJECTIVE

To evaluate the relationship of weather and tea productivity in Kenya.

Specific objectives

1. To analyze the relationship between temperature and tea productivity in Kenya
2. To analyze the relationship between radiation and tea productivity in Kenya
3. To analyze the relationship between soil moisture deficits and tea productivity in Kenya
4. To analyze the relationship between rainfall and tea productivity in Kenya

METHODOLOGY

Data Collection

The Tea Research Foundation of Kenya (TRFK) has three agro-meteorological stations, one in each of the following areas: Timbilil in Kericho (TRFK head quarters), Sotik (one of the warmest tea growing areas) and Kangaita TRFK sub-station (one of the coolest tea growing areas).

The daily data on weather parameters: air temperature °C, radiation (MJm⁻²d⁻¹), rainfall (mm) and soil water deficits (mm) for three agro-meteorological stations were collected from weather record files at the Timbilil Estate in Tea Research Foundation of Kenya. The Estates tea production for the respective Estates was sourced from the respective estate management.

Data Analysis

The mean monthly and annual data was determined using the daily data. The monthly data on tea yields were presented in kg green leaf per hectare (kg gl. ha⁻¹m⁻¹). Annual data was presented in kg green leaf per hectare (kg gl. ha⁻¹yr⁻¹) i.e. summation of monthly yields divided by the land size. Monthly weather data and tea yields were correlated using statistical analysis softwares MSTAT and GENSTAT. Excel was used for regression analysis. Lagged correlations for both Kendall's tau b and Spearman's rho Correlation Coefficients were done using SPSS.

RESULTS AND DISCUSSION

Mean Air Temperature

Results indicated that the Timbilil Tea Estate experienced an increasing temperature trend with a rise of about 0.02^oCy⁻¹ (r=0.5899) from 1958 to 2011 (Figure 1(a)). The mean air temperatures for every ten year showed a strong positive correlation with time (10yrs) (r²=0.819) (Figure 1(b)). Assuming the 0.02^oCy⁻¹ rise in temperature remains constant for the next 20 years, the temperature will have increased by 0.4^oC and a 1^oC in the next 50 years.

Radiation

The mean annual radiation at Timbilil in Kericho shows an increase of 0.091MJm⁻²y⁻¹ (r²=0.646) from 1980 to 2011 (Figure 2(a)). The lowest annual radiation was recorded in 1983 (18.1MJm⁻²d⁻¹) while highest annual radiation of 21.7MJm⁻²d⁻¹ was recorded in 2009 (Figure 2(a)). The ten year radiation average showed a positive linear relationship with time (r²=0.9230) (Figure 1(b)).

Rainfall

Rainfall distribution and patterns have changed at the Timbilil Tea Estate from 1958 to 2011. Although annual variation of rainfall does not relate with time (yrs), it shows that rainfall has been decreasing with about 4mm⁻¹ (Figure 3(a)). Ten-year rainfall average, however, illustrates a quadratic relationship of rainfall over time (r²=0.791) (Figure 3(b)).

Soil Water Deficit (SWD)

Data on the annual variation of soil water deficits from 1980 to 2011 suggests a decrease in SWD (Figure 4(a)) with the least (-429.0mm) in the year 1997. The fluctuations of these data are varied during the period and there is no relationship (r²=0.003) between SWD and time (yrs). This is because SWD is dependent on rainfall, which has also been erratic. It is important to note that yield losses relates negatively with SWD (Figure 4(b)) although not significant (P≤0.05).

It has been found that in Kericho, critical SWD is about 30mm above which there is a linear decrease in yield of about 1.1 kg ha⁻¹ week⁻¹ (mm SWD)⁻¹ of water (Ng'etich, 1995). SWD also affects dry matter production in plants. Other factors affect the productivity of the plant during SWD stress, one of which is the rate of application of nitrogen fertilizer. High fertilizer rates catalyses the effects of SWD on tea plants.

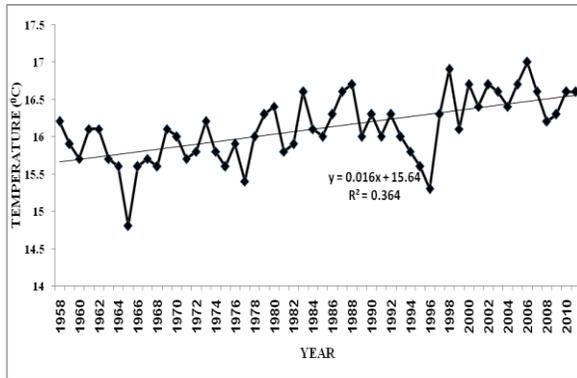


FIGURE 1(a): Mean air temperature

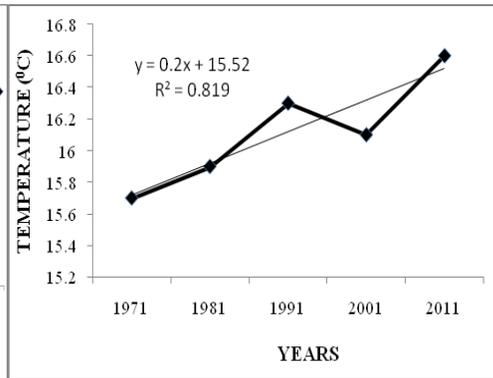


FIGURE 1(b): Mean air temperature (Decades)

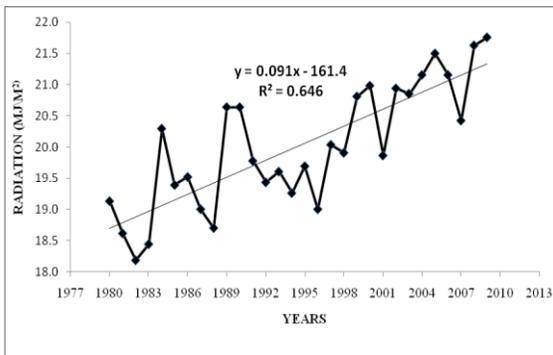


FIGURE 2(a): Mean Annual radiation

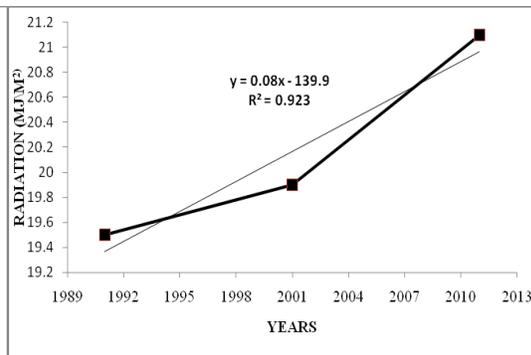


FIGURE 2(b): Annual radiation in Decades

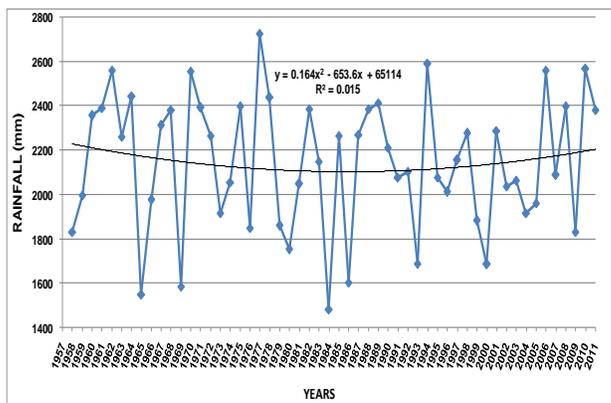


FIGURE 3(a): Annual rainfall

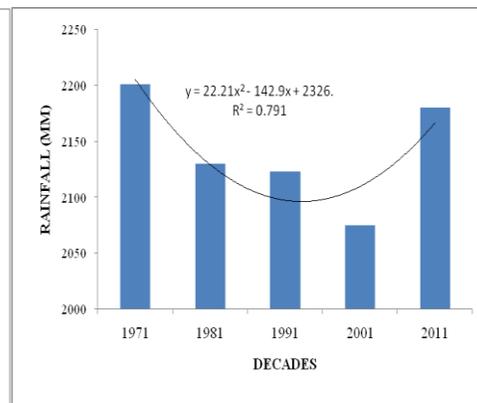


FIGURE 3(b): Mean Annual rainfall in Decades

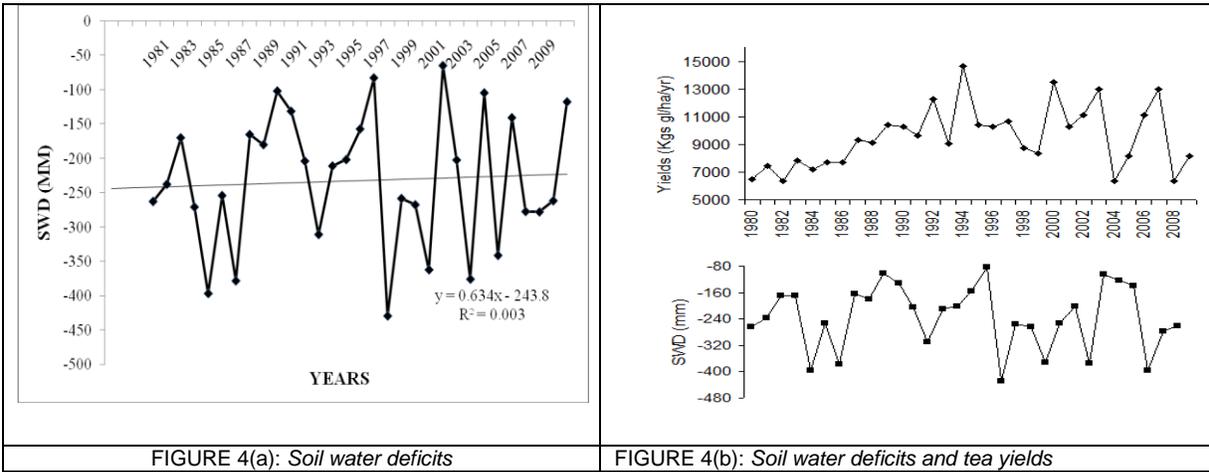


FIGURE 4(a): Soil water deficits

FIGURE 4(b): Soil water deficits and tea yields

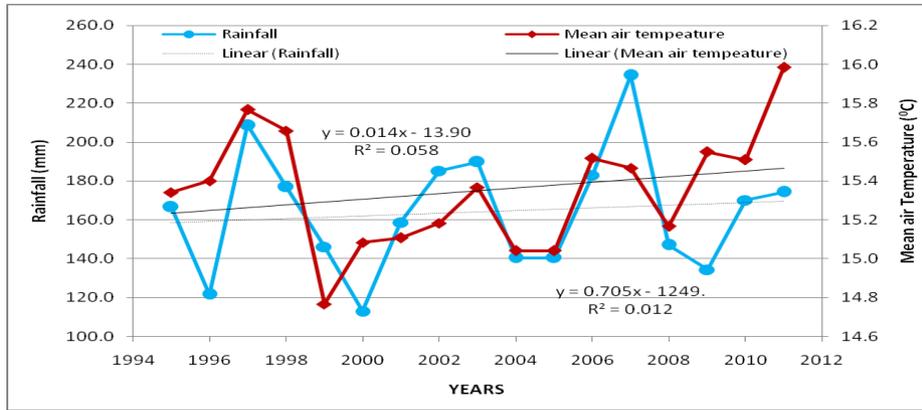


FIGURE 5: Mean air temperature in Kangaita Tea Estate (17 years)

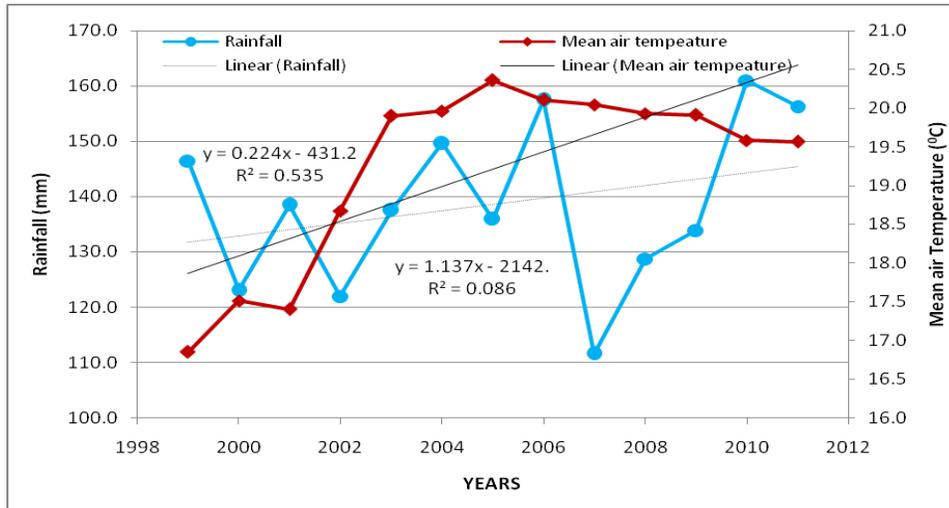


FIGURE 6: Mean air temperature in Sotik, Magura Tea Estate (12 years)

Mean Air Temperature and rainfall Kangaita Tea Estate

Results indicated that the Kangaita Tea Estate appears to be experiencing an increasing temperature trend with a rise of about $0.01^{\circ}\text{C}\text{y}^{-1}$ ($r^2=0.058$) from 1995 to 2010 although not significant (Figure 5). Temperature extremes are thought to affect production more than mean air temperature. Rainfall distribution and patterns have changed at Kangaita Tea Estate from 1958 to 2010. Although annual variation of rainfall does not relate with time (yrs) but its distribution have not been evaluated (Figure 5).

Mean air Temperature and rainfall Sotik - Magura Tea Estate

Results indicated that the Magura Tea Estate in Sotik experienced an increasing temperature trend with a rise of about $0.22^{\circ}\text{C}\text{y}^{-1}$ ($r^2=0.535$) from 1999 to 2011 (Figure 6). Although annual variation of rainfall does not relate with time (yrs), it shows that rainfall has been increasing but its distribution is key to tea production (Figure 6).

Effects of climatic parameters on Tea Production

Timbilil Tea Estate tea production data has been used to demonstrate how weather parameters affect tea yields in Kenya. This model was used because tea production in Kenya has a monthly trend that is similar to tea production at Timbilil Tea estate (Figure 7) with the national production generally having lower monthly yields ($\text{kg mt.}\text{ha}^{-1}$). The lower monthly average at the national level is likely to be as a consequence of different farm management practices. Poor farm management practices have been known to affect output. The national tea production includes tea yields both from smallholder farmers and the large scale growers. The effect of climate variability at the Timbilil Tea Estate on tea production can therefore be taken to represent the nation-wide effect of climate change on tea production.

Based on this assertion, Timbilil Tea Estate in Kericho (2178m a.s.l.) yield data was correlated with weather data for the site to determine the most important weather variable in determining tea yields. Other sites used for comparison are Magura Tea Estate in Sotik (1740m a.s.l.) and Kangaita Tea Estate in Kirinyaga (2020m a.s.l.).

Temperature at Timbilil Tea Estate

The monthly mean air temperature varied significantly ($P\leq 0.05$, $n=360$) over the study period of 30 years (since 1982 to 2011) with a mean of 17.0°C . The coldest month was July (15.3°C) and the warmest was March (17.3°C) (Figure 8).

Tea does well in warm temperatures only if soil moisture is not inhibitive. The case of Timbilil Tea Estate illustrates a significant ($P\leq 0.05$, $n=270$, $r^2=0.928$) positive relationship between mean air temperature and tea yields ($319 \text{ kg ha}^{-1}\text{m}^{-10}\text{C}^{-1}$) for the last two quarters of the year which usually has adequate soil moisture (Figure 9).

However, Ng'etich, 1995 noted tea response to temperature varies with clones. AHP S15/10 and BBK 35 being highly responsive while clones EPK TN14-3 and TRFK 6/8 were not responsive. Additionally, it was found that shoot extension rates varied with clones and seasons. Shoots initiated during the cool, wet periods had the lowest extension rates reaching $0.05 \text{ mm mm}^{-1}\text{d}^{-1}$ while the largest relative shoot extension rates were found in shoots growing during the warm wet period (0.06 to $0.09 \text{ mm mm}^{-1}\text{d}^{-1}$).

Additionally, Timbilil Tea Estate illustrates a significant ($P\leq 0.05$, $n=270$, $r^2=0.778$) positive relationship between minimum temperature and tea yields ($378 \text{ kg ha}^{-1}\text{m}^{-10}\text{C}^{-1}$) for the last two quarters of the year which has an adequate soil moisture (Figure 10).

Temperature at Magura Tea Estate

The case of Magura Tea Estate illustrates a significant ($P\leq 0.05$, $n=117$, $r^2=0.559$) polynomial relationship between mean air temperature and tea yields ($220.0 \text{ kg ha}^{-1}\text{m}^{-10}\text{C}^{-1}$) for the last two quarters of the year which usually has adequate soil moisture (Figure 11). This indicates that response of tea production to temperature increases also with the rise in temperature to an optimum of about 19.2°C then tea yields are depressed due to temperature stress. The Magura Tea Estate is the warmest area of the three tea growing areas under study with a mean air temperature of 19.2°C .

Temperature at Kangaita Tea Estate

The Kangaita Tea Estate results illustrated a significant ($P\leq 0.05$, $n=96$, $r^2=0.647$) positive relationship between mean air temperature and tea yields ($309.5 \text{ kg ha}^{-1}\text{m}^{-10}\text{C}^{-1}$) for the last two quarters of the year which usually has adequate soil moisture (Figure 12). This indicates that the response of tea production to temperature increase in cold areas is higher compared to tea production response to temperature in warm areas. Kangaita Tea Estate is the coldest area of the three tea growing areas under study with a mean air temperature of 15.3°C .

It is important to note that temperature plays a vital role in tea production. From the study, it is shown that the warmer areas (Magura Tea Estate) recorded the highest monthly tea production consistently over the years with an annual mean of 295 kg mt./ha followed by Timbilil Tea Estate with 213 kg mt./ha and finally Kangaita Tea Estate recording 176 kg mt./ha (Figure 13).

Radiation at Timbilil Tea Estate

Mean monthly radiation of $19.09 \text{ MJm}^{-2} \text{ d}^{-1}$ was recorded during the study period of two seasons when soil moisture was not limiting (April to December). The peak was in December which is usually a very productive month (Figure 14). The monthly radiation varied significantly over the study period ($P\leq 0.05$, $n=270$) with a tea yield increase of $81.06 \text{ kg ha}^{-1}\text{MJ}^{-1}\text{m}^2 \text{ d}$ ($r^2=0.355$). Radiation is also positively related with temperature $0.236^{\circ}\text{C MJ}^{-1}\text{m}^2 \text{ d}$ ($r^2=0.365$) (Figure 15). Generally, the months with high radiation also record higher mean air temperatures (Figure 16).

Rainfall at Timbilil Tea Estate

Monthly rainfall totals varied significantly during the study period with an average of 174 mm at the Timbilil Tea Estate. The peak was in the second quarter of the year between April and June with average of 234 mm , and the first quarter had the lowest rainfall average of 116 mm . The study period showed a weak negative linear relationship between tea yields and rainfall $1.4 \text{ kg ha}^{-1} \text{ mm}^{-1}$ ($r^2=0.024$), which is not significant ($P\leq 0.05$, $n=120$) (Figure 17).

However, lagged correlations both Kendall's tau b and Spearman's rho Correlation Coefficients (Table 1) indicated that monthly rainfall significantly increased monthly tea production in the subsequent months during the first quarter of

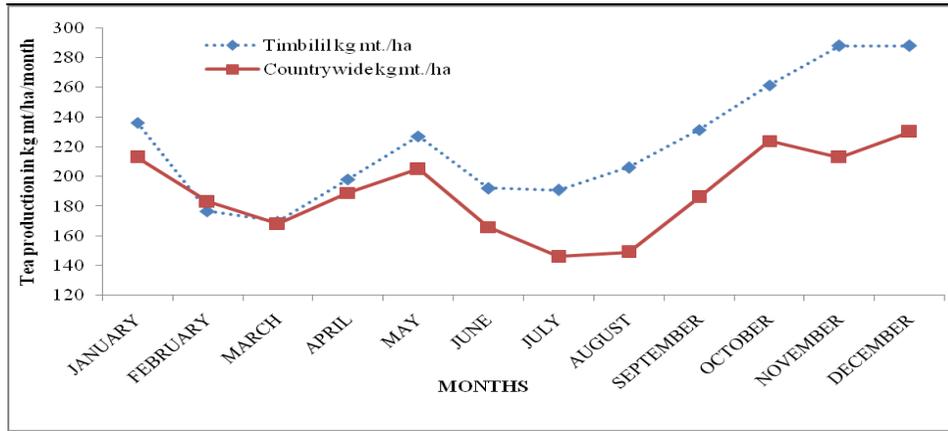


FIGURE 7: Timbilil Tea Estate and Kenya's monthly tea production in kg green leaf

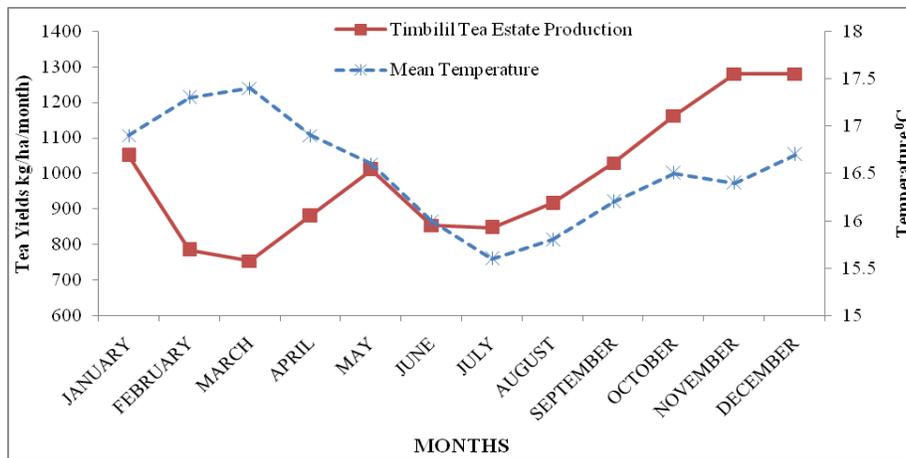


Figure 8: Monthly mean air temperature and tea yields at Timbilil Tea Estate

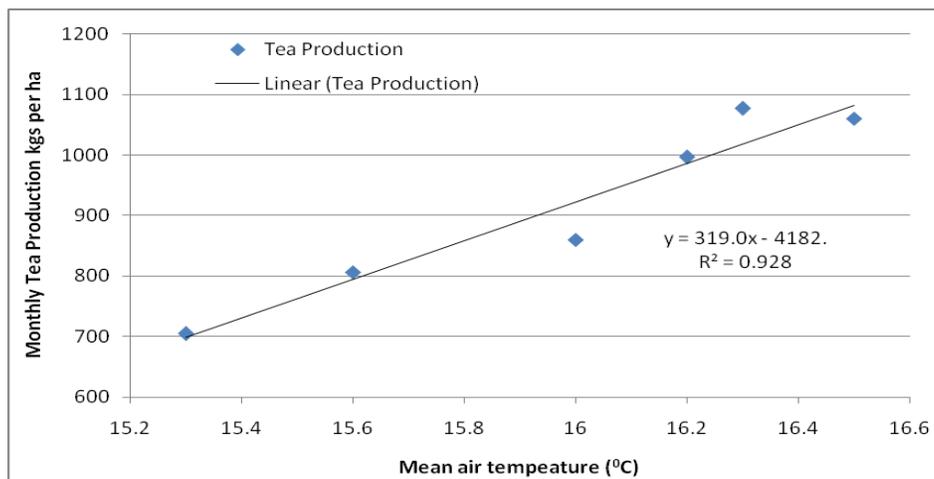


Figure 9: Relationship of tea production and mean air temperature when soil moisture is not limiting at Timbilil Tea Estate (July to December).

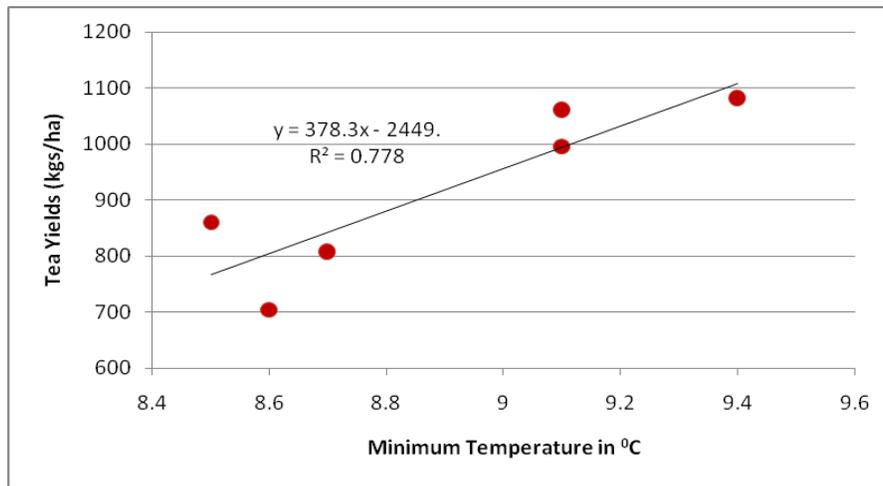


Figure 10: Relationship of tea production and minimum temperature when soil moisture is not limiting at Timbilil Tea Estate (July to December).

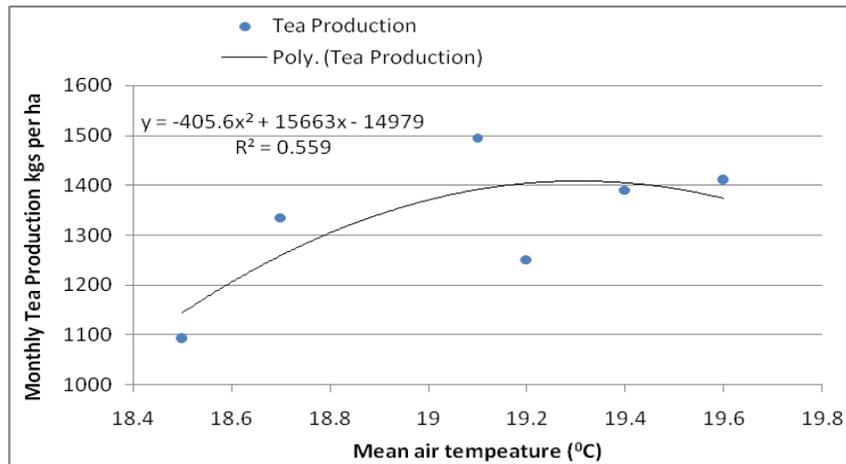


Figure 11: Relationship of tea production and mean air temperature when soil moisture is not limiting at Magura Tea Estate (July to December).

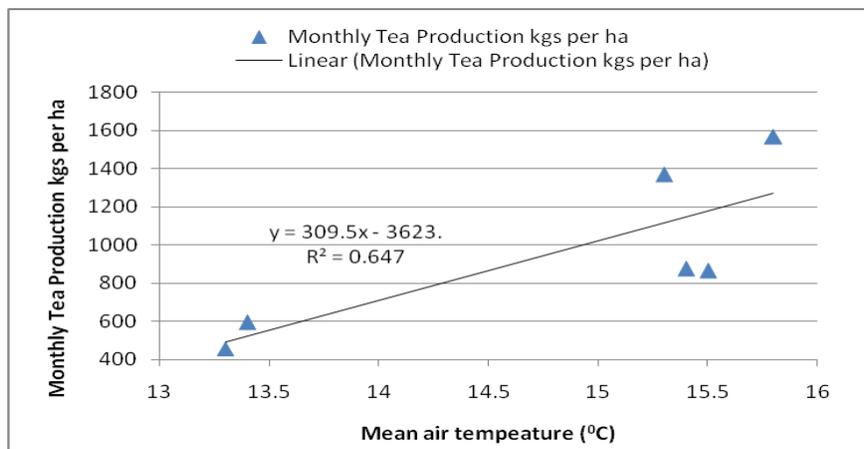


Figure 12: Relationship of tea production and mean air temperature when soil moisture is not limiting at Kangaita Tea Estate (July to December).

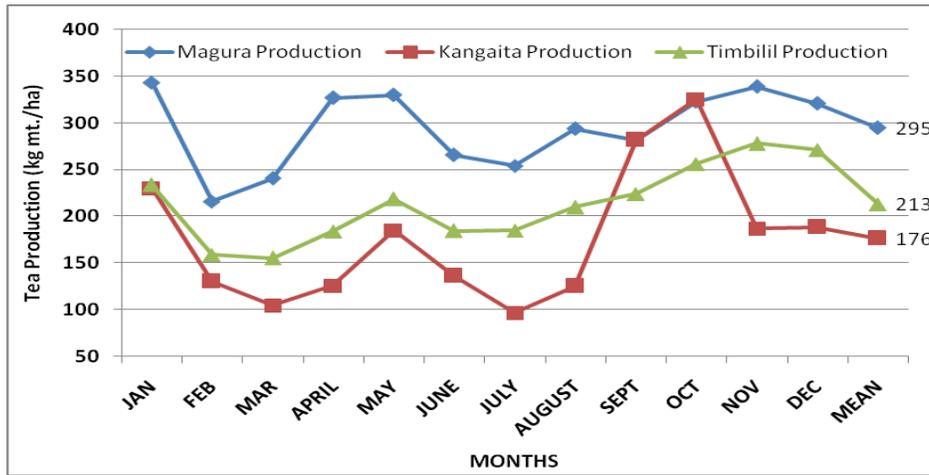


FIGURE 13: Mean Monthly tea production in kg mt./ ha at Magura, Kangaita and Timbilil Tea Estates (20 years)

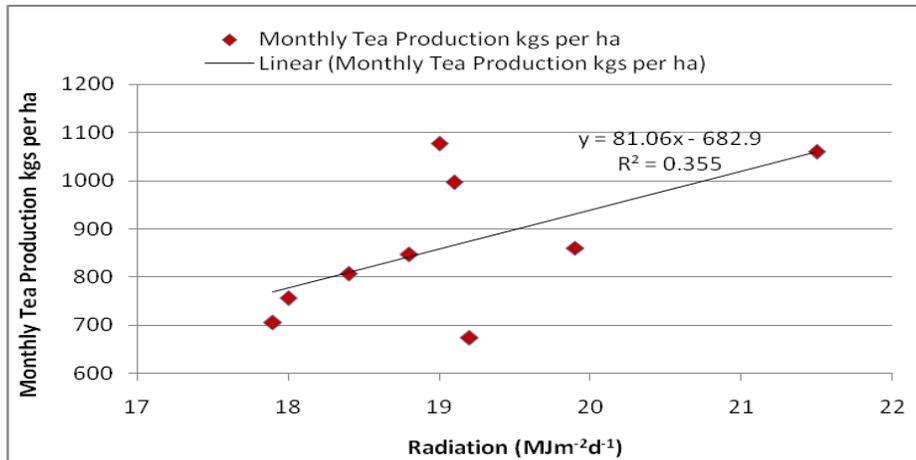


FIGURE 14: Monthly radiation and tea production at Timbilil Tea Estate

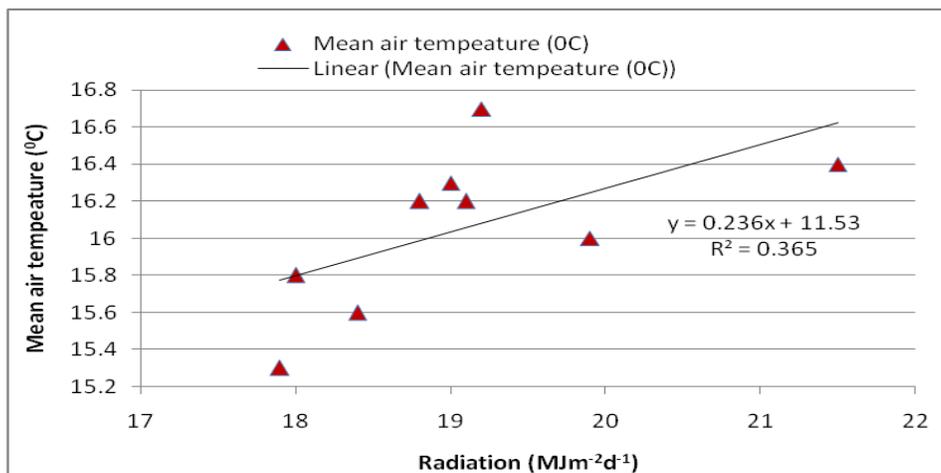


FIGURE 15: Monthly radiation and mean air temperature at Timbilil Tea Estate

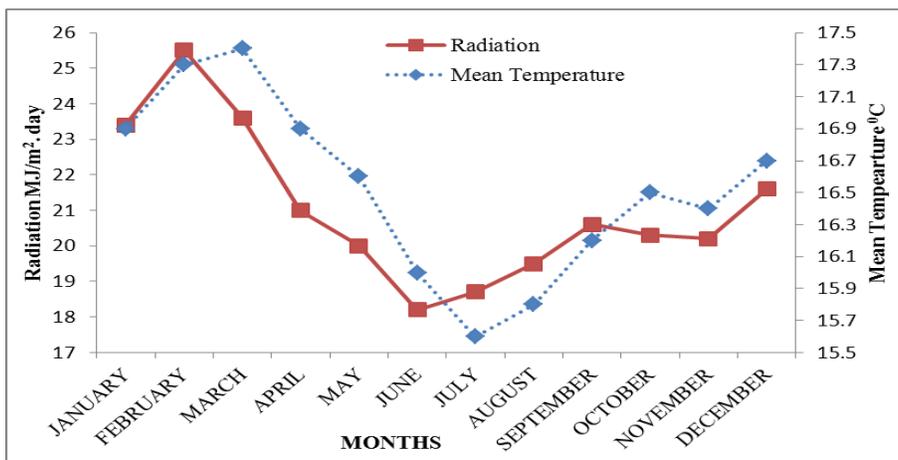


FIGURE 16: Monthly radiation and mean air temperatures at Timbilil Tea Estate

Table 1: Timbilil Rainfall and tea production lagged correlations (January to March)

		Temperature	Rainfall	SWD	Tea Production
Kendall's tau b	Temperature	1.000			
	Rainfall	-.145*	1.000		
	SWD	.253**	-.694**	1.000	
	Tea Production	-.139	.325**	-.374**	1.000
Spearman's rho	Temperature	1.000			
	Rainfall	-.213*	1.000		
	SWD	.358**	-.808**	1.000	
	Tea Production	-.195	.479**	-.526**	1.000

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

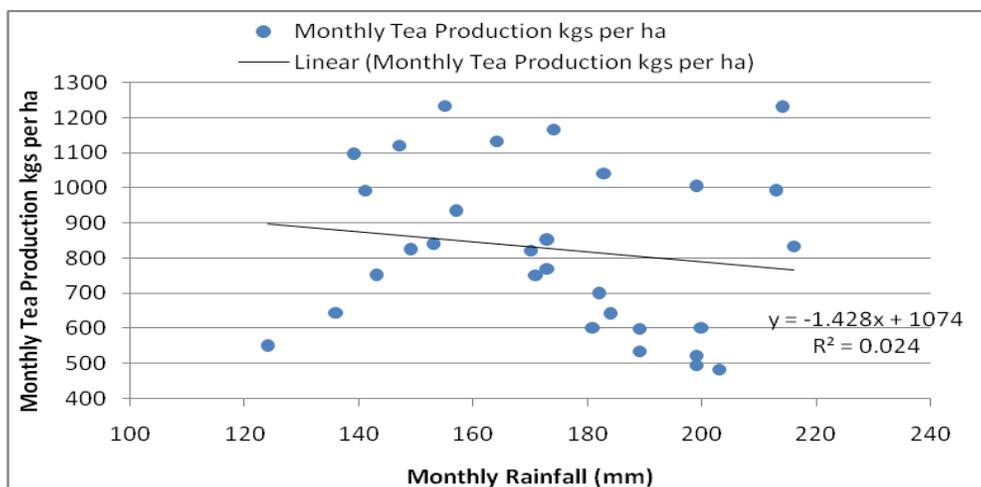


FIGURE 17: Monthly rainfall and tea production at Timbilil Tea Estate (30 years)

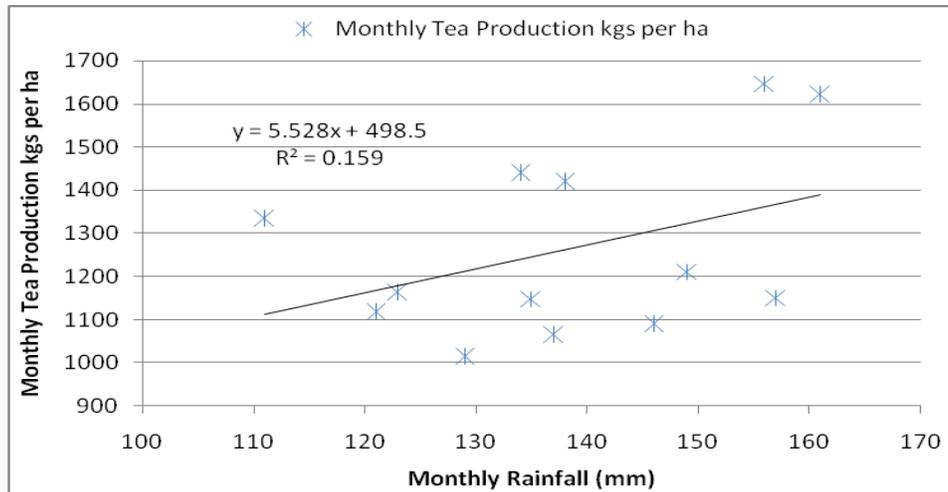


FIGURE 18: Monthly rainfall and tea production at Magura Tea Estate (13 years)

Table 2: Magura Rainfall and tea production lagged correlations (January to March)

		Temperature	Rainfall	Tea Production
Kendall's tau b	Temperature	1.000		
	Rainfall	.011	1.000	
	Tea Production	-.003	.480**	1.000
Spearman's rho	Temperature	1.000		
	Rainfall	.027	1.000	
	Tea Production	-.027	.674**	1.000

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

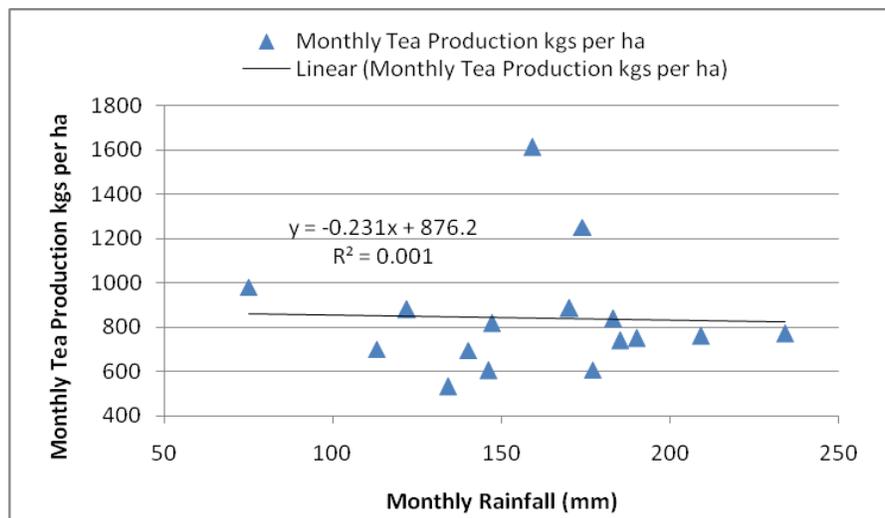


FIGURE 19: Monthly rainfall and tea production at Kangaita Tea Estate (16 years)

Table 3: Kangaita Rainfall and tea production lagged correlations (January to March)

		Temperature	Rainfall	Tea Production
Kendall's tau b	Temperature	1.000		
	Rainfall	.011	1.000	
	Tea Production	.016	.436**	1.000
Spearman's rho	Temperature	1.000		
	Rainfall	.014	1.000	
	Tea Production	.010	.645**	1.000

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

the year (January to March). This illustrates that the negative relationship in Figure 17 below was actually due to the slow physiological response of tea plant to moisture conditions. The results further indicated a negative relationship between rainfall and temperature. Most importantly is the obvious negative relationship between Soil Water Deficits (SWD) and rainfall which was significant. SWD is one of the main abiotic stresses affecting tea production during the dry spells. Because almost all tea gardens in Kenya are ruined, this is a very important component dependent entirely on rainfall.

Rainfall at Magura Tea Estate

Monthly rainfall totals varied significantly during the study period with an average of 138mm at the Magura Tea Estate. The peak was in the second quarter of the year between April and June with 261mm, and the first quarter had the lowest rainfall amount of 118mm. Although the study period suggested a weak positive relationship between tea yields and rainfall $5.5 \text{ kg ha}^{-1} \text{ mm}^{-1}$ ($r^2=0.159$), it was not significant ($P \leq 0.05$, $n=52$) (Figure 18). This positive relationship is due to warm temperatures in the area.

Additionally, lagged correlations both Kendall's tau b and Spearman's rho Correlation Coefficients was conducted to verify this relationship. The findings (Table 2) indicated that rainfall significantly increased tea production in the subsequent months during the first quarter of the year (January to March). This illustrates further that the weak positive relationship in Figure 18 above was actually due to the slow physiological response of tea plant to moisture conditions. It also emphasizes that tea in warm areas respond much faster to availability than those in cold areas. Nevertheless, there was no relationship between the independent variables in Magura.

Rainfall at Kangaita Tea Estate

Monthly rainfall totals varied significantly ($P \leq 0.05$, $n=192$) during the study period with an average of 164mm at Kangaita Tea Estate. The peak was in the second quarter of the year between April and June with 268mm, and the first quarter had the lowest rainfall amount of 82mm.

Although the study period suggested a weak negative relationship between tea yields and rainfall $0.231 \text{ kg ha}^{-1} \text{ mm}^{-1}$ ($r^2=0.001$), it was not significant ($P \leq 0.05$, $n=192$) (Figure 19). This negative relationship is due to low temperatures, which accompany rainy seasons coupled with generally cold weather conditions in the area, therefore lower crop yields due to cold stress.

Lagged correlations of both Kendall's tau b and Spearman's rho Correlation Coefficients were conducted to

verify this relationship. The findings (Table 3) indicated that rainfall significantly increased tea production in the subsequent months during the first quarter of the year (January to March). The weak negative relationship in Figure 19 above can be attributed to the slow physiological response of tea plant to moisture conditions. There was no relationship between rainfall and temperature in this region.

CONCLUSION

Climate change is due to persistent increase in temperatures over a long period of time. Depending on proximities, it can either increase or reduce the amount of rainfall received in an area. Temperature variability is evident from the study and it has the greatest impact on tea productivity. From the results, it is noted that a positive correlation exists between air temperatures and tea yields when soil moisture is adequate. However, there is a limit to this. An extreme temperature either cold or hot suppresses tea production and is seen as a major threat to tea production. Further studies, especially in a controlled environment to model the effect of increased temperature and in the presence of increased CO_2 as this will be the case in relation to climate change ought to be carried out.

It is evident that temperature coupled with radiation is key weather parameters that affect tea production, particularly when soil moisture is not limiting. From lagged correlations, rainfall increased tea production significantly. This also ascertains the rainfall and especially its distribution is critical for sustainable tea production. In cases where the rainfall distribution is unpredictable as is expected with climate change, other sources of moisture should be considered for instance use of irrigation. For this to happen, cost benefit analyses of the available irrigation technologies should be carried out.

ACKNOWLEDGEMENT

The authors acknowledge and thank the continued support of FAO, through the Director of Trade and Markets Division, which funded the project and the Tea Research Foundation of Kenya (TRFK) through the Managing Director because this work benefited from the collaboration between the two institutions. The TRFK staff who assisted in data collection and collating are also appreciated.

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