African Journal of Agriculture and Utilisation of Natural Resources for Sustainable Development April, 2022
ISSN 2313-1306
Available Online at www.ajausud.org

Response of Tea (*Camellia sinensis*) to Rainfall and Temperature Patterns in Kenya

Langat, Joseph Kimutai

Department of Agricultural Sciences, Kisii University, P. O. Box 408–40200, KISII, Kenya; ORCiD ID: https://orcid.org/0000-0003-0587-8640.

E-mail address: drjosephlangat@kisiiuniversity.ac.ke or drjosephlangat@gmail.com

Tel: +254-722-305-965.

Abstract

Tea (*Camellia sinensis* [L.]) is cultivated in diverse climatic conditions, latitudes ranging from the equator to 33^{O}S (Natal, South Africa) and 49^{O}N (Georgia, USA), altitude varying between sea level (Bangladesh) to 2600 MASL (Mt. Kenya). The climates in these altitudes and latitudes range from Mediterranean to hot, humid tropics of Africa and Asia. Growth and productivity of tea are influenced by air temperature, soil temperature, soil moisture and solar radiation, all other factors not limiting. Seasonal differences in rainfall and temperature exist in the tea growing areas. This study was undertaken to investigate the response of tea genotypes to rainfall and temperature patterns in the Kenya's tea growing sites. A study was conducted in three sites (Kangaita (0^{O}30'S, 37^{O}16'E, 2100 m a.s.l.), Kipkebe (0^{O}17'S, 35^{O}3'E, 1740 m a.s.l.) and Timbilil (0^{O}22'S, 35^{O}21'E, 2200 m a.s.l.) with variations in weather conditions in Kenya using a split-plot design laid in RCBD to investigate the effect of temperature and rainfall to seasonal patterns among four tea clones (AHP-SC31/37, EPK-TN14-3, TRFK-301/5 and TRFK-31/8) of scientific and commercial importance to the country. Season 1 (mid-December to March) experienced clear skies, where highest temperature values and lowest rainfall amounts were realized. In season 2 (April to August), highest amount of rainfall and lowest temperature were measured. Moderate temperature and rainfall were recorded in season 3. Two-way ANOVA (P=0.05) for split-plot design indicated rainfall and temperature were significantly different between seasons and locations. This study conformed to the seasonal patterns experienced in the tea growing regions of Kenya.

Keywords: Rainfall, seasonal patterns, tea (*Camellia sinensis*), temperature, variability.

Introduction

Tea (*Camellia sinensis* (L.) O. Kuntze] (Theaceae) has over 700 useful chemicals to human health like flavanoides, amino acids, vitamins (C, E and K), caffeine and polysaccharides (Bhagat *et al.*, 2010). It is grown in latitudes ranging from the equator to 33^{O}S and 49^{O}N; between sea level to 2600 metres above sea level. The climates in these altitudes and latitudes range from Mediterranean to hot, humid tropics (Carr and Stephens, 1992). Tea is the second most popularly consumed traditional beverage worldwide after water, with a more significant role as a health drink (Hajiboland, 2017) arising from flavonoids, L-theananine, caffeine and non-proteinic amino acid that make up 25-35% tea fresh weight (Blumberg, 2013; Chaturvedula & Prakash, 2011). When consumed regularly in the right quantities, tea reduces lung cancer risk death caused by stroke lowers risks of developing Type-2 diabetes, cardiovascular disease, cognitive impairment, depressive symptoms, and reduced incidence of cold and flu symptoms (Bukowski & Percival, 2008; Da Silva Pinto, 2013; Arab *et al.*, 2013; Wang *et al.*, 2014). In 2020, tea production in Kenya reached the highest level of 570.5 thousand metric tons, the main producers made up of smallholder farmers, while the largest producing area being the West of the Rift.

Salient environmental components that influence growth and productivity of tea are air and soil temperature, soil water, solar radiation, sunshine hours and evaporation (Carr, 1972). Factors that limit tea yields are removal of young shoots, air temperature, soil temperature along with dry air, hail, day-length and soil temperature (Tanton, 1979; Tanton, 1982a, b; Carr & Stephens, 1992; Othieno *et al.*, 1992; Odhiambo *et al.*, 1993; Chen & Fong, 1994; Nixon *et al.*, 2001; Ngétich *et al.*, 2001). Generally, tea is cultivated commercially in many areas of the world with warm and moist climatic conditions.

Rainfall is the most important climatic factor of any crop. Tea plant is affected by both excess and shortage of water. The growth, development and yield of tea depend on the soil moisture status. Minimum annual rainfall amounts of 1200 mm year^{-1}, well distributed throughout the year. Optimum soil and air temperature, sunshine hours and change of seasons influence tea performance significantly (Carr, 1972; Bhagat *et al.*, 2010; Hajiboland, 2017). Annual rainfall of 2500-3000 mm year^{-1} is considered optimal (Hajiboland, 2017). Even distribution of rainfall annually is more critical than the total precipitation received in Kenya, Sri Lanka and India (Waheed *et al.*, 2013).

Temperature influences the rate of photosynthesis, growth, dormancy and yield, and determines the natural distribution of plants, success and timing of agricultural crops (Lange *et al*., 1981). The ideal ambient temperature needed by tea crop is 18-25^{O}C. Seasonal temperature should not be less than about 13^{O}C (average for the coldest months), or higher than 30^{O}C (average for the warmest months) (Anonymous, 2005) as daytime maximum temperature in excess of 30^{O}C, and night minimum temperature less than 14^{O}C leads to a reduction in growth rate. The rate of net leaf photosynthesis and growth falls off quickly when temperature rises above 35^{O}C. For maximum tea output, optimum soil temperature of 20-25^{O}C is critical (Carr, 1972). Two to three leaves and a terminal bud are plucked after every 7-10-day cycle, leaving axils in the topmost leaves of remaining butts to develop and become the next crop. Hajiboland (2017) reported made tea yield of 6.5 t ha^{-1} $year^{-1}$ under favourable climatic and soil conditions with proper agronomic management.

There is compelling spatial and temporal variability in rainfall and temperature in the tea growing regions of Kenya, affecting its production potential significantly. The growing conditions of tea in various seasons are described by Stephens *et al.* (1992) and Ngétich *et al.* (1995) as: (1) the main dry-warm season running from mid-December to the end of March; (2) a cool-wet season from April to August; and (3) a warm-wet or warm dry season from September to mid-December. It is well established that the growth of tea is affected by differences in weather patterns (Kamau, 2008).

Weather is bound to change. The current study of the 3-seasonal pattern conformity theory was carried out not to disapprove, but to provide further information on weather patterns in tea growing areas of Kenya that may not have been explored by earlier authors. It is against this background that the three tea seasons as suggested by Ngétich *et al.* (1995) and Stephens *et al*. (1992) were tested in the trial done between 2007 and 2013. The current study was, therefore, undertaken to investigate the response of tea (*Camellia sinensis*) to rainfall and temperature patterns in three tea growing sites in Kenyan

Materials and Methods

This experiment was done in three sites differing in altitude and climatic conditions in Kenya: Kipkebe (0^{O} 17’ S, 35^{O} 3’ E & 1740 m a.s.l) and Kangaita (0^{O} 30’ S, 37^{O} 16’ E & 2100 m a.s.l) and Timbilil - 0^{O}22’S, 35^{O}21’E, 2200 m a.s.l which was a reference site. The study was set up in a split-plot design for sites, established in an existing experiment, set out in 1998 in a randomized complete block design (RCBD). It investigated the effect of temperature and rainfall to seasonal patterns among four tea (*Camellia sinensis*) clones of scientific and commercial importance to the country. This experiment had two factors: sites (environment-E) (whole or main-plot factor) and genotypes (G) (split-plot factor). The treatments were 4 tea clones: EPK TN 14-3, TRFK 301/5, AHP SC 31/37 and TRFK 31/8. Clone TRFK 31/8 was used as control because it is grown by the majority of smallholder farmers in the region.

(a) Air temperature measurements

Dry-bulb thermometer, housed in a screen to effectively shield it from direct solar radiation and precipitation, was mounted on a moveable wooden stand within a stand of about 1.5m height over a neat short grass surface in each site. To reflect as much direct radiation as possible, the whole structure was painted white, with sloping roof covered with aluminium. The sites where the stands were set at large open areas with free air circulation and no buildings, trees or other obstructions in the vicinity as recommended by Mwebesa (1970). The dry-bulb thermometers were used to measure daily maximum and minimum temperatures at research sites.

(b) Rainfall measurements

Rain gauge recommended by Kenya Meteorology Department was used to measure the amount of rainfall at 0900 hours daily. Water that collected in the glass bottle, graduated in millimeters, was poured into a measuring cylinder. When 0.05mm or less was measured, the rainfall was recorded as trace. While taking readings, the measuring cylinder was held horizontal to the eye level to guard against parallax error.

Data analysis

Genotype by environment interaction (G×E) analysis was done using split plot design following the model:

X_{jklm} = *ì + xj + ßk +åjk + ôij + ëil + åjklm* (1)

Where: *Xjklm* = plot observation; *ì* = mean of observation; *xj* = main treatment effect (genotypes); *ßk* = block/ replication effect (A, B, C); *åjk* = error (1); *ôij* = sub-treatment effect (environmental factors -E, i.e. rainfall, seasons and temperature); *ëil* = interaction between main treatment (G) and the sub-treatment (E); *åjklm* = error (2).

Two-way ANOVA (p=0.05) for split plot design (GenStat, 2012 and Stern *et al*., 2001) was used to determine significance of rainfall and temperature between and within seasons and genotypes, and across locations and years. Pearson correlation was used to compare the relative strength of parameters and determine significance and interrelationships (SPSS, 2011 and Pallant, 2011).

Results and Discussions

(a) Temperature

The highest daily mean maximum temperature recorded in 2007 was in Timbilil in March (25.7^{O}C) (Table 3-1), while in 2008 and 2009, the highest was 25.7^{O}C in January (Timbilil) and 27.4^{O}C in March (Timbilil) respectively. In all the 3 years, the highest daily mean maximum temperature was either in January or March (Table 1). Although Timbilil recorded the highest daily mean maximum temperature, the highest overall daily mean temperature over the same period was in March (20.8^{O}C) at Kipkebe.

(b) Rainfall

At Kangaita, peak rainfall amounts were recorded in the months of April (382 mm in 2007), May (497 mm in 2007 and 305 mm in 2009), August (243 mm in 2007) (all in S2), and October (384 mm in 2008 and 489 mm in 2009) (S3). The pattern was replicated at Kipkebe where 211 mm was recorded in July 2008. The 3-year means for the months of January to March for Kangaita was 88 mm, 89 mm in Kipkebe and 113 mm at Timbilil (Table 1). The driest month at Timbilil was January where a 3-year mean of 91 mm was measured. The 3-year rainfall summary gave peak precipitation in May (345 mm in S2) and October (353 mm in S3) at Kangaita (Figure 2). Kipkebe also had duo peaks: 166 mm in April (S2) and 171 mm (S3) in September, while the highest rainfall measurements were recorded at Timbilil in 3 peaks: 235 mm in April (S2), 261 mm in September and 251 mm in October, both of these months in S3. It was noted that S1 was the driest, while S2 the wettest. S3 was moderately wet/ dry.

The 3-year overall daily mean air temperature depicted the peak in the month of March in all the three trial sites, where 16.8^{O}C was recorded in Kangaita, while Kipkebe registered 20.8^{O}C and Timbilil 17.1^{O}C (Table 1 and Figure 1). The mean temperature for season 1 in the 3 sites was the highest compared to seasons 2 and 3.

Table 1: The 3-year mean monthly rainfall (mm) and daily mean air temperature measurements (^{O}C) for Kangaita, Kipkebe and Timbilil (January 2007 to December 2009)

Month	Monthly means 3-year rainfall (mm)			Daily means of 3-year $T^{O}C$ (^{O}C)		
	Kangaita	Kipkebe	Timbilil	Kangaita	Kipkebe	Timbilil
Jan.	72	105	91	15.9	20.4	17.0
Feb.	80	60	92	16.0	20.6	16.5
Mar.	112	103	157	16.8	20.8	17.1
Total S1	**264**	**268**	**340**	**48.7**	**61.8**	**50.6**
% $site^{-1}$	**14.2%**	**18.4%**	**16.2%**	**26.4%**	**25.8%**	**25.9%**
Mean in S1	**88**	**89**	**113**	**16.2**	**20.6**	**16.9**
Apr.	316	166	235	16.1	20.1	16.6
May	345	129	219	16.0	19.9	16.2
June	100	120	176	14.7	19.5	15.8
July	69	133	191	13.5	19.3	15.3
Aug.	137	163	223	13.2	19.0	15.8
Total S2	**967**	**711**	**1044**	**73.5**	**97.8**	**79.7**
% $site^{-1}$	**52.0%**	**48.7%**	**49.6%**	**39.8%**	**40.9%**	**40.8%**
Mean in S2	**193**	**142**	**209**	**14.7**	**19.6**	**15.9**
Sept.	60	171	261	15.4	19.7	16.0
Oct.	353	95	251	16.0	20.5	16.2
Nov.	125	103	109	15.6	19.7	16.4
Dec.	89	111	99	15.6	19.9	16.6
Total S3	**627**	**480**	**720**	**62.6**	**79.8**	**65.2**
% $site^{-1}$	**33.7%**	**32.9%**	**34.2%**	**39.8%**	**33.3%**	**33.4%**
Mean in S3	**157**	**120**	**180**	**15.7**	**20.0**	**16.3**
Grand total	**1858**	**1459**	**2104**	**184.8**	**239.4**	**195.5**
Grand mean	**155**	**122**	**175**	**15.4**	**20.0**	**16.3**

The outcome of this study agrees with findings of Stephens *et al.* (1992) & Ngétich *et al.* (1995) that S1 (mid-December and March) experiences the highest temperatures on average during the year. Likewise, the lowest mean temperature was experienced in the month of August at Kangaita (13.2^{O}C) and Kipkebe (19.0^{O}C), while 15.3^{O}C was measured as the lowest in Timbilil in July, and is illustrated as a trough in Figure 1.

Further temperature analysis of S2 (April to August) showed it is the least compared to the other two seasons. S2 is described by authors as '*cool*' (Stephens *et al.*, 1992 & Ngétich *et al.*, 1995), hence lowest annual mean temperatures recorded in this study was expected during this period in the three sites.

Between September and mid-December (S3), moderately high temperatures in October at Kangaita (16.0^{O}C), Kipkebe (20.5^{O}C) and Timbilil (16.2^{O}C) were recorded. Computation of the 3-year data for the site means as shown in Table 1 revealed the lowest mean temperature was at Kangaita (15.4^{O}C), while Kipkebe's measurement was the highest (20.0^{O}C). Timbilil's mean daily temperature between January 2007 and December 2009 was 16.3^{O}C. It is evident from these finding that temperature at Kangaita, Kipkebe and Timbilil sites follow the weather seasonal pattern described by Stephens *et al.* (1992) and Ngétich *et al.* (1995).

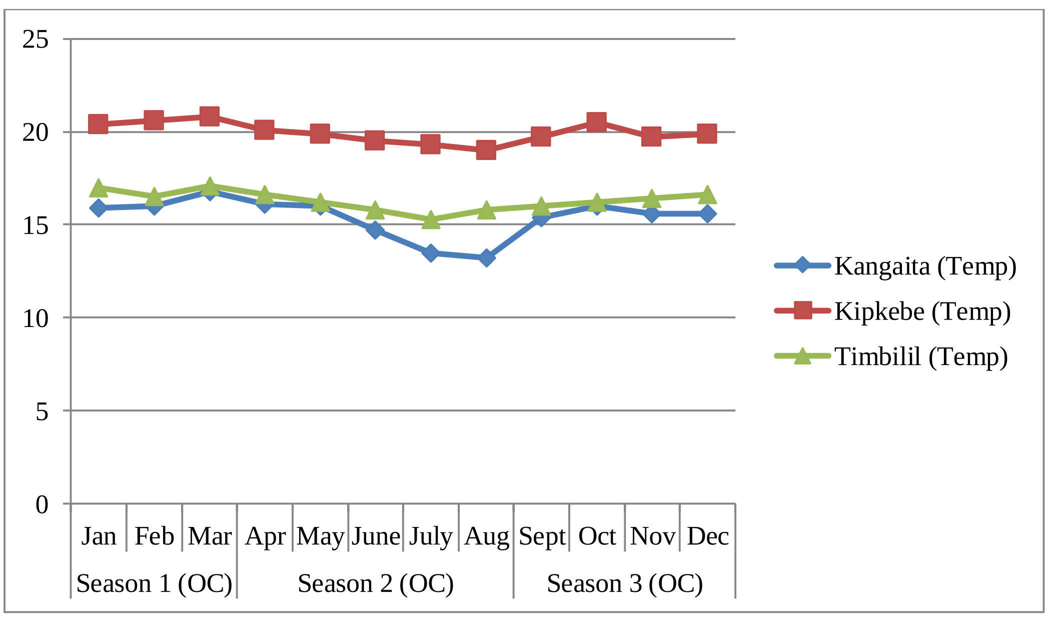

Figure 1: Monthly mean temperature categorized into 3 seasons, 2007-2009.

Pearson correlation analysis of temperature across the 3 locations

Table 2 presents the results of correlation significance between temperature across the three locations (Kangaita, Kipkebe and Timbilil).

Table 2: Temperature correlation in the 3 sites.

Parameter interactions	Kangaita	Kipkebe	Timbilil
Kangaita	1	0.887**	0.829**
Kipkebe	0.887**	1	0.797**
Timbilil	0.829**	0.797**	1

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

Temperature correlation between sites was significant at the 0.01 level. Temperature difference between Timbilil and Kipkebe was closer compared to Kipkebe and Kangaita.

Temperature across the locations was found to be statistically different from each other with (p < 0.001. Use of Genstat (2012) analysis showed that temperature at Kipkebe was significantly different from that of both Timbilil and Kangaita (Table 3).

(c) Temperature across locations

Table 3: ANOVA of temperature across the locations (Variate: Temperature).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Season stratum	2	26.0298	13.0149	27.24	
Location	2	416.5785	208.2893	435.91	<0.001**
Residual	103	49.2158	0.4778		
Total	107	491.8241			

** Statistical significant difference exists at <0.001.

Key: d.f. = degrees of freedom; s.s.= sum of squares; m.s.= mean of squares; v.r.= variance ratio; F pr.= the probability value corresponding to a v.r., on the assumption that this has Fisher-Snedecor (F) distribution.

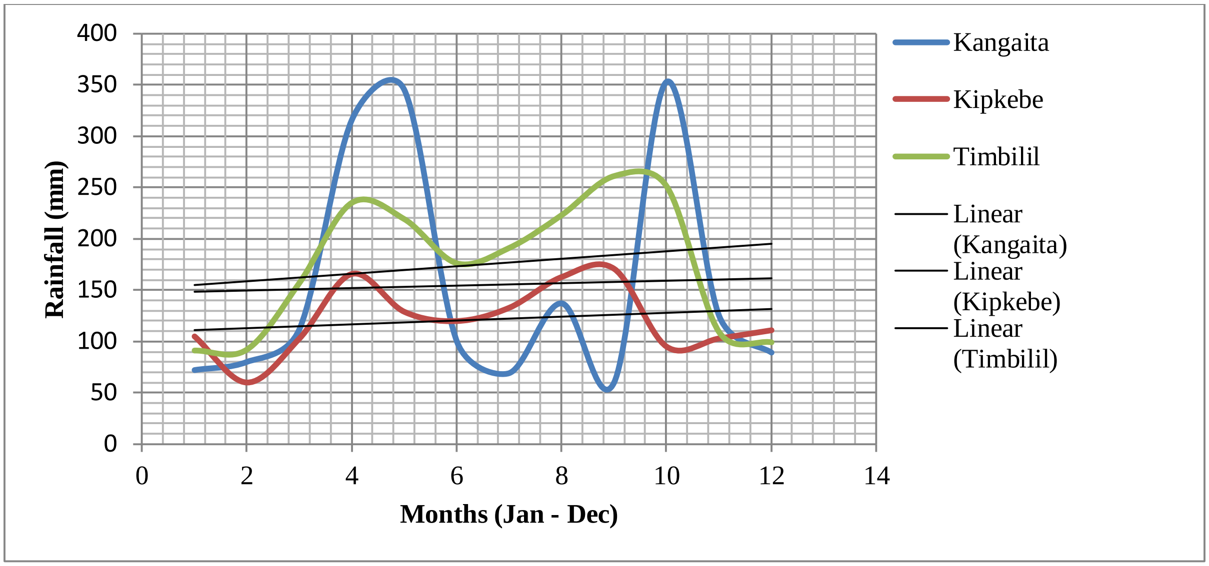

Figure 2: Response of rainfall to seasonal patterns in the 3 trial sites, 2007-2009.

Analysis of rainfall across seasons and locations

Table 4 presents the results **of** rainfall analysis across seasons and locations using data generated from January 2007 to December 2009. S1 constituted rainfall data recorded from January to March, S2 from April to August, while S3 was precipitation received from September to December.

Table 4: ANOVA of rainfall across the 3 locations and seasons (Variate: Rainfall).

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Location	2	51259	25630	2.94	
Season	2	109312	54656	6.27	0.003**
Season. Location	4	16294	4074	0.46	0.767
Residual	103	898323	8722		
Total	**107**	**058895**			

** The mean difference is significant at 0.05 level.

The rainfall was significantly different between seasons (p = 0.003). Rainfall data subjected to multiple comparison tests between seasons revealed that significance came from the difference between S1 and S2. There was no difference though of rainfall between locations (p = 0.767).

Conclusion

Temperature and rainfall at Kangaita, Kipkebe and Timbilil trial sites follow the weather seasonal pattern described by Stephens *et al.* (1992) and Ngétich *et al.* (1995).

The current study concluded that there exists considerable spatial and temporal differences in temperature and rainfall across varied locations, attributed to the tea (*Camellia sinensis*) growing highlands of Kenya.

Acknowledgments

The author would like to thank Prof.. Wilson Ngétich and Prof. Caleb Othieno, experts of tea and soil science, University of Eldoret, Kenya, and Prof. Patrick Mathenge- an expert in the field of crop science based in Karatina University, Kenya for their invaluable input in guiding the study.

References

Anonymous (2005). http://www.krishiworld.com/html/plantcrops.html. pages?

Arab, L., Khan, F. & Lam, H. (2013). Tea consumption and cardiovascular disease risk. American Journal of Clinical Nutrition 98(6): 1651–1659. DOI: 10.3945/ajcn.113.059345. Epub 2013 Oct 30. pages

Bhagat, R. M., Baruah. R. D. & Safique, S. (2010). Climate and tea [*Camellia sinensis* (L.) O. Kuntze] production with special reference to North Eastern India: A review. Journal of Environmental Research and Development 4(4): 1017-1028.

Blumberg, J. B. (2013). Introduction to the proceedings of the fifth international scientific symposium on tea and human health. American Journal of Clinical Nutrition 98(6**)**: 1607–1610. DOI: 10.3945/ajcn.113.060186.

Bukowski, J. F. and Percival, S. S. (2008). L-theanine intervention enhances human gammadelta T lymphocyte function: Review article. Nutritional Reviews PubMed, 66: 96–102. DOI: 10.1111/j.1753-4887.2007.00013.x.

Carr, M. K. V. (1972). The climatic requirements of the tea plant: A review. Experimental Agriculture 8: 1-14. DOI: 10.1017/S0014479700023449.

Carr, M. K. V. and Stephens, W. (1992). Climate, weather and yield of tea in "*Tea: Cultivation to consumption*". (Eds. K. C. Willson and M. N. Clifford), London: Chapman and Hall.

Chaturvedula, V. S. P. and Prakash, I. (2011). The aroma, taste, colour and bioactive constituents of tea. Journal of Medicinal Plants Research 5(11): 2110–2124. http://www.academicjournals.org/JMPR.

Chen, H. and Fong, C. H. (1994). Drought damages and related factors in tea (*Camellia sinensis*) in Taiwan. Chinese Journal of Agrometeorology 1: 133-141.

Da Silva Pinto, M. (2013). Tea: A new perspective on health benefits. Food Research International 53(2): 558–567. DOI: 10.1016/j.foodress.2013.01.038.

GenStat (2012). GenStat for Windows 10th Edition. VSN International, 5 The Waterhouse, Waterhouse Street, Hemel Hempstead, Hertfordshire HP1 1ES, UK.

Hajiboland, R. (2017). Environmental and nutritional requirements for tea cultivation. Folia Horticulturae 29(2): 199-220. DOI: 10.1515/fhort-2017-0019.

Kamau, D. M. (2008). Productivity and resource use in ageing tea plantations. PhD thesis, Wageningen University, Wageningen, The Netherlands, pp. 40.

Lange, O.L., Nobel, P. S., Osmond, C. B. & Zeigler, H. (1981). Physical Plant Physiology. I. Response to the Physical Environment. Springer-Verlag, Berlin. 10-105. DOI: 10.1007/978-3-642-68090-8.

Mwebesa, M. M. N. (1970). East African observer's handbook. East African Meteorological department. A handbook of standard procedures for surface weather observing and recording of climatological data. 1st ed. p. 110-133.

Ngétich, W. K., Stephens, W. & Othieno, C. O. (1995). Clonal tea response to altitude in Kericho. II. Weather, climate analysis and soil water deficits. Tea 16(2): 86-98.

Ngétich, W. K., Stephens, W. and Othieno, C. O. (2001). Response of tea to environment in Kenya. 3. Yield and yield distribution. Experimental Agriculture 37: 361-372.

Nixon, D. J., Burgess, P. J., Sanga, B. N. K. and Carr, M. K. V. (2001). A comparison of the responses of mature and young clonal tea to drought. Experimental Agriculture 37: 391-402.

Odhiambo, H. O., Nyabundi, J. O., & Chweya, J. (1993). Effects of soil moisture and vapour pressure deficits on shoot growth and yield of tea in the Kenyan highlands. Experimental Agriculture 29, 341-350.

Othieno, C. O., Stephens, W. & Carr, M. K. V. (1992). Yield variability at the Tea Research Foundation of Kenya. Agricultural and Forest Meteorology 61: 237-252. Elsevier Science Publishers B. V., Amsterdam.

Pallant, J. (2011). *SPSS survival manual.* A step by step guide to data analysis using the SPSS programme. 4th edition.

SPSS Statistics 17.0 (2011). www.spss.com. SPPS Incorporation.

Stephens, W., Othieno, C. O. & Carr, M. K. V. (1992). Climate and weather variability at the Tea Research Foundation of Kenya. Agricultural and Forest Meteorology 61: 219-235.

Stern, R., Arnold, G., Coe, R. and Buysse, W. (2001). Using GenStat for Windows in Agriculture and Experimental Biology, 5th Edition. ICRAF Nairobi, Kenya. 204 pp.

Tanton, T. W. (1979). Some factors limiting yield of tea (*Camellia sinensis*). Experimental Agriculture 15: 187-191.

Tanton, T. W. (1982a). Environmental factors affecting yield of tea (*Camellia sinensis*). I. Effects of air temperature. Experimental Agriculture 18: 47-52.

Tanton, T. W. (1982b). Environmental factors affecting yield of tea (*Camellia sinensis)*. II. Effects of soil temperature, day-length and dry air. Experimental Agriculture 18: 53-63.

Waheed, A., Hamid, 1, F. S., Ahmad, H., Aslam, S., Ahmad, N. & Akbar, A. (2013). Different climatic data observation and its effect on tea crop. Journal of Material and Environmental Science 4 (2): 299-308.

Wang, L., Zhang, X., Liu, J., Shen, L. & Li, Z. (2014). Tea consumption and lung cancer risk: A meta-analysis of case-control and cohort studies. Nutrition 30(10): 1122–1127. DOI: 10.10.1016/j.nut.2014.02.023. Epub 2014 Mar 12.