MAUSAM, **68**, 2 (April 2017), 309-316

633.73 : 551.509.32 (540.69)

Coffee yield forecasting using climate indices based agrometeorological model in Kerala

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(*Received 22 December 2015, Accepted 3 August 2016*)

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सार – कॉफी के उत्पादन में जलवायु की महत्वपूर्ण भूमिका होती है। कॉफी के पुष्पन के समय प्रचुर मात्रा में और समय पर वर्षा का होना और कुछ अंतराल के बाद की वर्षा बेरि सेट तथा कॉफी के उत्पादन को प्रभावित करती है। आर्द्र उष्णकटिबंधीय जलवायु वाला भारत के केरल राज्य में अरेविका कॉफी की कटाई दिसम्बर-जनवरी के महीने में की जाती है और रोबस्टा कॉफी की कटाई जनवरी-फरवरी के दौरान की जाती है। इस शोध पत्र में कॉफी की इन दो प्रजातियों के उत्पादन के लिए पूर्वानुमान देने के लिए जनवरी से दिसम्बर तक मासिक जलवायविक परिवर्तिताओं का उपयोग करते हुए कृषि मौसम विज्ञान मॉडल विकसित करने के लिए केरल राज्य के वायान्द जिले में स्थित क्षेत्रीय कॉफी अनुसंधान केंद्र, चुंदाले में कॉफी उत्पादन के लिए 1991-92 से 2012-13 तक के दीर्घावधि डेटा तथा 1991 से 2012 तक के मौसम से संबंधित डेटा का उपयोग किया गया है। जलवायु सूचकांक और अरेबिका तथा रोबस्टा कॉफी की पैदावार के बीच एक सांख्यिकीय समाश्रयण मॉडल विकसित किया गया था और वर्ष 2013 एवं 2014 की पैदावार एवं जलवायु आँकड़ों को लेकर इस मॉडल को वैधीकृत किया गया है। इस मॉडल से यह पता चला है कि कृषि मौसम विज्ञान मॉडल पर आधारित जलवायु सूचकांक केरल में कॉफी की पैदावार का पूर्वानुमान देने में समर्थ है।

ABSTRACT. Climate plays important role in production of coffee. Adequate quantum and timely receipt of blossom rainfall for flowering and subsequent backing showers influence the berry set and yield of coffee. Harvesting of Arabica coffee in Kerala State with humid tropical climate in India is done by December-January and harvesting of Robusta coffee is taken up during January-February. In this paper, attempt was made to develop agrometeorological models to forecast the yield of these two varieties coffee by utilising monthly climate variables from January to December. Long term data from 1991-92 to 2012-13 on coffee yield and weather data from 1991-2012 recorded at Regional Coffee Research Station, Chundale located in Wayanad district of Kerala State was used to develop agrometeorological model. Statistical regression model between climate indices and yield of Arabica and Robusta coffee was developed and the model was validated using crop and climate data for 2013 and 2014. The model demonstrated that climate indices based agrometeological model is able to forecast the yield of coffee in Kerala.

Key words – Coffee yield, Climate indices, Statistical regression model.

1. Introduction

Climate variability influences the fluctuations in production of crops year to year. Advance forecasting of crops production prior to actual harvesting of crop would facilitate decision and policy making of food stock, price fixation, distribution and further import of food crops to meet the requirement of food security of the country. Adequate expertise is being developed during past few years under "Forecasting Agricultural output using Space, Agrometeorology and Land based observations (FASAL)" scheme, sponsored by Ministry of Agriculture in State Agricultural Universities and India Meteorological Department to develop in-season multiple stage crop yield forecasts by employing agrometeorological model and crop simulation models. Production forecasting of food, oilseeds, and sugarcane, potato and fibre crops are being done under FASAL. Recently, forecasting of horticultural crops *viz*., potato and onion is being taken up under CHAMAN (Coordinated Horticulture Assessment and Management using geoinformatics) project.

Like the Indian climate scenario, where rainfall decline and temperature increase were noticed since the last 50 years, the State of Kerala also experienced decline in annual and monsoon rainfall and increase in temperature. The mean annual maximum temperature over Kerala has risen by 0.8 ºC, the minimum temperature by 0.2 ºC and the average by 0.5 ºC between 1961 and 2003 (Rao, 1998). Climate change or variability lead to more frequent weather related disasters in the form of floods, droughts, landslides and sea level rise in a tiny State like

Kerala, which falls under the humid tropics. The climate projections across the high ranges of Kerala indicate that the southwest monsoon rainfall is likely to decline, and surface air temperature and its range are likely to increase. Under such circumstances, there is a threat to thermo sensitive crops like black pepper, cardamom, tea and coffee (Rao, 1998). Therefore, there is a need to formulate climate change risk management strategies to minimise the ill effects of climate change.

Weather continues to play important role in influencing yield of crops. Agrometeorological models or weather based statistical regression models utilise weather variables and crop yield to understand the variation in yield and correlation between yield and weather. The relationship between crop yield and weather parameters can be identified with the help of multiple regression models (Agrawal *et al*., 2001). Several models have been developed in India for field crops(Paul *et al.*, 2012; Tripathy *et al.*, 2012; Singh *et al.*, 2014; and Rajegowda *et al.*, 2014), but techniques for forecasting of plantation crops like coffee is limited in India. Presently, Coffee Board issues coffee production forecast by estimates at post blossom, post-monsoon and final estimates. Earlier crop estimates were fairly accurate due to availability of statistical data/information from estates and from other sources like merchants and processing factories. Currently, Board is purely depending on estimations through extension networks of the Board. Upto 2000-01 crop season, estimation was carried out by extension officers for their zones, which was then aggregated at zone, district and state level to arrive at crop estimates. These forecasts were mostly subjective. From 2001-02 seasons onwards, crop estimates are made more scientific using sampling methods. Crop forecasts under the new sampling methods were based on 889 randomly selected estates across different size categories of holdings in 43 coffee zones of traditional coffee growing areas. In order to achieve greater accuracy, the sample size is almost doubled to 1500 estates for the season 2002-03. This methodology involves a stratified multi stage random sampling technique with the size of the estates (holding size) in each zone as a first stratum, blocks within the estate as a second stratum and sections within blocks forming the third stratum of the sampling framework. However, considering the incremental accuracy *vis -a -vis* additional cost and man power requirements, the current sampling is restricted to the first stage sampling of estates. A total of 1500 estates were fixed as sample size. Due to inherent limitations in the system of agricultural statistics, in spite of established procedures and wide coverage, providing an objective assessment of crops at the pre-harvest stages with the desired spatial details are essential to identify problem areas. There was, therefore, need to enhance the capabilities of the system of crop forecasts and crop estimation with the help of technological advancements and the adoption of emerging methodologies (Ghosh *et al.*, 2014).

Statistical model developed between past climate and yield data can be used to determine the impact of climate on coffee berry production and also to forecast coffee berry yield. Agnihotri and Sridhara (2014) developed pre-harvest forecast models for *kharif* rice yield with good accuracy in coastal districts of Karnataka using basic weather variables. Kandiannan *et al.* (2011) studied crop weather relationship of perennial horticultural crop - black pepper and found that maximum relative humidity, rainfall, maximum and minimum temperature have more influence on black pepper yield. Attempt has been made in this paper to develop agrometeorological model with good accuracy for operational forecasting based on climate indices and to improve the current technique of forecasting the yield of coffee by crop estimates.

2. Data and methodology

2.1. *Study area*

The study was conducted in Regional Coffee Research Station, Chundale, located in Wayanad district of Kerala state to assess the influence of climate on yield of Arabica and Robusta coffee and to develop yield forecasting model. Yield data of coffee for 24 years from 1991-92 to 2014-15 were collected from experimental plots of coffee. The data on climate parameters particularly maximum and minimum temperature (°C), relative humidity (%) and rainfall (mm) were recorded from agrometeorology observatory installed in the station during the study period. Due to short daily range of relative humidity, mean relative humidity was used in the study instead of maximum and minimum relative humidity. Daily weather data was used to compute the monthly averages of maximum and minimum temperature and relative humidity and total monthly rainfall from January to December. Planting of coffee is during September-October and fruiting of new plantation starts from 4^{th} year after planting. Coffee being perennial crop, climate data from January to December was used to compute climate indices. Phenological stages of coffee are budding stage (October- December), flowering stage (February-March), fruit set (April-May), fruit dropping (July-August), ripening stage (December-January) and harvesting stage (January- February).

2.2. *Detrending analysis*

Detrending analysis was done by regressing yield as dependent variable and year starting from 1 to 22 for yield

TABLE 1

Weight factor (simple correlation coefficient) for Arabica coffee

Climate parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax	0.62**	0.58**	0.34	0.10	-0.27	-0.11	-0.13	-0.26	0.08	-0.05	0.00	0.31
Tmin	0.07	0.18	0.36	0.10	0.03	0.24	0.29	0.17	0.06	0.02	-0.13	-0.18
Rain	-0.25	0.13	-0.09	0.23	0.13	0.13	-0.23	-0.16	-0.28	-0.09	-0.13	-0.38
RH	0.05	0.42	0.36	0.29	0.35	0.39	0.32	0.26	0.10	0.30	0.19	-0.05
Tmax*Tmin	0.36	0.46*	0.49*	0.12	-0.25	0.02	0.04	-0.13	0.10	-0.02	-0.09	0.03
Tmax*Rain	-0.25	0.14	-0.09	0.25	0.11	0.13	-0.25	-0.18	-0.28	-0.09	-0.13	-0.37
Tmax*RH	0.46*	0.61**	0.44	0.28	0.17	0.12	0.04	-0.03	0.13	0.26	0.20	0.23
Tmin*Rain	-0.26	0.15	-0.07	0.23	0.13	0.16	-0.21	-0.14	-0.27	-0.09	-0.14	-0.41
Tmin*RH	0.05	0.37	0.47*	0.29	0.37	0.43*	0.39	0.32	0.10	0.23	0.08	-0.17
Rain*RH	-0.26	0.14	-0.07	0.27	0.16	0.18	-0.21	-0.13	-0.27	-0.06	-0.12	-0.40

*correlations are significant at 0.05 level, **correlations are significant at 0.01 level

from 1991-92 to 2012-13 as independent variable (time). Similar to weather, technological development such as introduction of new varieties, improved irrigation facilities, fertilizer and pesticide usage has also responsible for variations in yield from year to year. Significant F value is taken as a factor to determine the influence of technology on yield of coffee. If value of significant F is <0.05, there is technological trend and if F is >0.05, it is inferred that there is no influence of technological trend on coffee yield over years.

2.3. *Crop weather model*

Fisher (1924) studied the gradual change of the effect of weather variables on crop yield development during the growing season with special statistical tool - ‘orthogonal polynomial technique’. He assumed that the effects of change in weather variables in successive weeks would not be an abrupt or erratic change but an order one that follows some mathematical law. Several workers have studied the crop-weather relationship by using Fisher’s technique. Hendricks and Scholl (1943) have modified the Fisher’s method. They assumed that a second-degree polynomial in a week number was sufficiently flexible to express the effects in successive weeks. Based on this, Hendricks and Scholl suggested,

$$Y = A_0 + a_0 \sum_{W=1}^{n} X_w + a_1 \sum_{w=1}^{n} w X_w + a_2 \sum_{w=1}^{n} w_2 X_w + e$$

where, X_w denotes value of weather variable under study in wth week, n is the number of weeks in the crop season and A_0, a_0, a_1 and a_2 are the model parameters. This model was extended to study combined effects of weather variables and an additional variate T representing the year for time trend.

Hendricks and Scholl model has been further modified at Indian Agricultural Statistics Research Institute (IASRI), where, the effects of changes in weather variables on yield in the wth week were expressed as second degree polynomial in respective correlation coefficients between yield and weather variables (Agrawal *et al.*, 1980, 1983; Jain *et al*., 1980; Agrawal and Jain 1982). The relationship was, thus, explained in a better way as weather in different weeks receives appropriate weightage. Agrawal *et al.* (1986) further modified this model considering that the impact exerted by changes in weather variables in wth week on yield is a linear function of respective correlation coefficients between yield and weather variables. The significant effect of trend on yield was also removed while calculating correlation coefficients of yield with weather variables to be used as weights. The studies on effects of second degree terms of weather variables showed that (*i*) the models using correlation coefficients based on yield adjusted for trend effect were better than the ones using simple correlations and (*ii*) inclusion of quadratic terms of weather variables and also the second power of correlation coefficients did not improve the model. Full crop season data considering different climate variables simultaneously have been used to develop the forecast model in following finally recommended form.

$$Y = A_0 + \sum_{i=1}^{p} \sum_{j=0}^{1} a_{ij} Z_{ij} + \sum_{i=i'-1}^{p} \sum_{j=0}^{1} a_{ii'j} + cT + e$$

TABLE 2

Weight factor (simple correlation coefficient) for Robusta coffee

Climate parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax	0.04	0.35	0.11	0.36	-0.12	0.19	0.19	0.32	0.24	0.15	0.13	-0.15
Tmin	0.34	0.26	0.35	0.22	0.28	0.33	0.25	0.22	0.30	0.29	0.37	-0.06
Rain	-0.25	0.28	0.37	-0.08	0.37	-0.02	-0.37	-0.12	-0.14	-0.01	-0.02	-0.02
RH	-0.11	-0.17	-0.16	-0.10	-0.07	0.01	0.13	0.24	-0.02	0.11	-0.17	0.07
Tmax*Tmin	0.34	0.44*	0.35	0.36	0.02	0.26	0.27	0.33	0.35	0.25	0.33	-0.13
Tmax*Rain	-0.24	0.30	0.38	-0.04	0.36	0.01	-0.32	-0.07	-0.13	0.01	-0.01	-0.02
Tmax*RH	-0.09	0.01	-0.10	0.06	-0.14	0.15	0.24	0.41	0.10	0.20	-0.11	-0.03
Tmin*Rain	-0.25	0.30	0.37	-0.07	0.38	0.02	-0.35	-0.10	-0.12	0.01	0.01	-0.02
Tmin*RH	0.18	0.06	0.06	-0.02	0.03	0.20	0.24	0.32	0.10	0.20	0.06	-0.02
Rain*RH	-0.24	0.28	0.37	-0.10	0.37	-0.01	-0.36	-0.09	-0.12	0.01	-0.02	-0.04

*correlations are significant at 0.05 level; **correlations are significant at 0.01 level

TABLE 3

Correlation coefficient of climate indices with coffee yield

Climate parameters	*Simple indice	Correlation coefficient		**Weighted indice	Correlation coefficient	
		Arabica	Robusta		Arabica	Robusta
Maximum temperature(Tmax)	z_{10}	0.28	0.33	z_{11}	0.69**	0.51*
Minimum temperature(Tmin)	z_{20}	0.15	0.38	z_{21}	0.40	0.46*
Rainfall(RF)	z_{30}	-0.22	-0.19	z_{31}	0.47*	0.54*
Relative Humidity(RH)	z_{40}	0.33	-0.06	z_{41}	0.43	0.33
Tmax*Tmin	z_{120}	0.22	0.44	z_{121}	0.55*	0.55*
Tmax*Rain	z_{130}	-0.23	-0.11	z_{131}	0.47*	0.54*
Tmax*RH	z_{140}	0.40	0.06	z_{141}	0.52*	0.39
Tmin*Rain	z_{230}	-0.18	-0.13	z_{231}	0.46*	0.54*
Tmin*RH	z_{240}	0.32	0.14	z_{241}	0.49*	0.26
Rain*RH	z_{250}	-0.16	-0.18	z_{251}	0.48*	0.52*

*Simple indice is sum of climate parameter from January to December; **Weighted indice is sum product of climate parameter and weight factor from January to December

where,

$$Z_{ij} = \sum_{w=1}^{m} r_{iw}^{j} X_{iw} \text{ and } Z_{ii'j} = \sum_{w=1}^{m} r_{ii'w}^{j} X_{iw} X_{ii'w}$$

where, $X_{iw}/X_{ii'w}$ is the value of i^{th}/i'^{th} climate variable under study in w^{th} week, $r_{iw}/r_{ii'w}$ is correlation coefficient of yield (adjusted for trend effect, if present) with i^{th} climate variable/ product of i^{th} and i'^{th} climate variables in w^{th} week, m is week of forecast and p is number of climate variables used. Two climate indices were developed for each climate variable, *i.e*., simple as well as weighted accumulation of monthly climate variable, weights being correlation coefficients of climate variable in respective weeks with yield (adjusted for trend effect, if present). Similarly, indices were also generated for interaction of climate variables, using monthly products of climate variables taking two at a time. Combination of climate variables for climate indices, thus, generated are presented in Table 3. Climate variables used for this model are maximum temperature (Tmax), minimum temperature (Tmin), rainfall (RF) and relative humidity. Stepwise regression technique was used to select the important climate indices. The yield data for the period 1991-2012 was used in developing the forecast model and the remaining 2 years from 2013-2014 was used for the validation of the model.

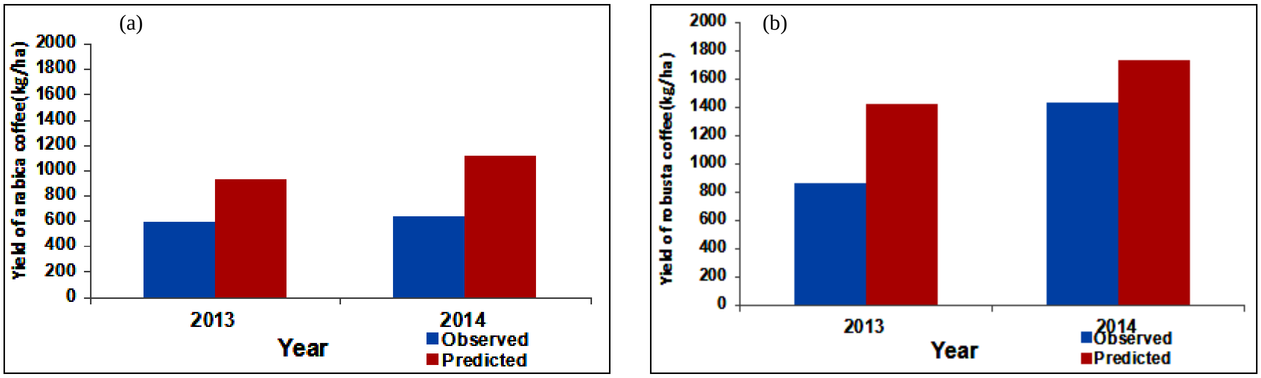
3. Results and discussion

3.1. *Technological trend*

Detrending analysis of yield of Arabica and Robusta coffee indicated that both the species are not influenced by technological inputs over years. Since significance F is greater than 0.05 and multiple correlation coefficient(R) and coefficient of determination (R^2) are less, there is no technological trend and therefore, actual yield has to be correlated with climate indices.

3.2. *Correlation of Arabica coffee yield with climate parameters*

Correlation coefficients worked out between yield of coffee and different climate parameters (Tables 2 and 3).



Figs. 1(a&b). Observed and predicted yield of (a) Arabica and (b) Robusta coffee

Simple correlation between yield and climate parameters indicated that climate parameters had differently influenced the yield of coffee. In the present study, yield of Arabica have positive correlation with maximum temperature during January, February and March which corresponds to harvesting, flowering and fruit setting of coffee. Correlations are significant (p = 0.01) during January and February. Correlations are negative between maximum temperature during May to August and yield which are non-significant. Minimum temperatures have positive correlation with yield of Arabica coffee in most of the months which are not significant. High correlation between minimum temperature and yield of Arabica coffee was observed during March (0.36) followed by July (0.29). Rainfall during April and May (month during which backing showers occurs to augment fruit set) have non significant positive correlation with yield of Arabica coffee and have negative correlation in remaining months. Mean relative humidity during all the months have positive correlation with yield of Arabica coffee with highest correlation (0.42) during February. Product of maximum and minimum temperature have positive correlation with yield of Arabica coffee during January to April with significant correlations (p = 0.05) during February and March. Product of maximum temperature and relative humidity have positive correlation with yield of Arabica coffee in all the months except August with significant correlations during January (p = 0.05) and February (p = 0.01). Product of minimum temperature and relative humidity have positive correlation with yield of Arabica coffee in most of the months with significant correlations during March and June (p=0.05). Products of maximum temperature and rainfall, minimum temperature and rainfall and rainfall and relative humidity have no significant correlations with yield of Arabica coffee.

Correlation coefficient between climate indices and yield of Arabica coffee is provided in Table 3. Yield of Arabica coffee have significant (p = 0.01) positive correlation with sum product of maximum temperature and weight factor. Also, yield of Arabica coffee have significant positive correlation (p = 0.05) with sum product of rainfall and weight factor. Yield of Arabica coffee have similar significant positive correlation with combinations of climate parameters. Sum product of maximum temperature x minimum temperature, maximum temperature x rainfall, maximum temperature x relative humidity, minimum temperature x rainfall, minimum temperature x relative humidity and rainfall x relative humidity and weight factor have significant positive correlation with yield of Arabica coffee. Yield of Arabica coffee have non significant correlation with rest of the climate indices. All the unweighted climate indices have non significant correlation with yield of Arabica coffee.

3.3. *Correlation of Robusta coffee yield with climate parameters*

Yield of Robusta coffee have non significant positive correlation with maximum temperature during all the months except May and December which have non significant negative correlation. Higher correlation (>0.30) observed during February, April and August months. Minimum temperatures have positive correlation with yield of Robusta coffee during all the months except December which are not significant. Correlation coefficients range from 0.22 to 0.37 during January to November. Rainfall during February, March and May during which flowering and early fruiting in Robusta coffee have non significant positive correlation with yield of Robusta coffee and have negative correlation in remaining months. Mean relative humidity has no significant correlation with yield of Robusta coffee and the highest correlation (0.24) observed during July. Product of maximum and minimum temperature have positive correlation with yield of Robusta coffee during January to November with significant correlation (p = 0.05) during February (0.44). Product of maximum temperature and rainfall have non significant positive correlation with yield of Robusta coffee during February, March and May and non significant negative correlation during January (-0.24) and July (-0.32). Products of maximum temperature and relative humidity have non significant positive correlation with yield of Robusta coffee in most of the months and the highest correlation (0.41) was observed during August. Product of minimum temperature and rainfall, minimum temperature and relative humidity and rainfall and relative humidity has no significant correlations with yield of Robusta coffee.

Correlation coefficient of climate indices with yield of Robusta coffee is provided in Table 3. Yield of Robusta coffee have significant (p = 0.05) positive correlation with sum product of maximum temperature and weight factor, minimum temperature and weight factor and rainfall and weight factor. Yield of Robusta coffee have similar significant positive correlation with combinations of climate parameters. Sum product of maximum temperature x minimum temperature, maximum temperature x rainfall, minimum temperature x rainfall and rainfall x relative humidity and weight factor have significant positive correlation. Yield of Robusta coffee have non significant correlation with rest of the climate indices. All the unweighted climate indices have non significant correlation with yield of Robusta coffee.

3.4. *Physical significance of correlation between yield and climate*

In the present study, maximum temperatures during January and February have significant positive correlation with yield of Arabica coffee and similarly maximum temperatures during February and April have high positive correlation with yield of Robusta coffee. This indicates that maximum temperature during flowering and early fruit set of coffee is significant climate parameter determine the yield of coffee. Alègre (1959) reported that the optimum mean annual temperature range for Arabica coffee is 18-21 ºC and above 23 ºC, development and ripening of fruits are accelerated, often leading to loss of quality(Camargo,1985). However, Gopakumar (2011) observed poor coffee yield is noticed when the maximum temperature go beyond 26.9 ºC. Relatively high temperature during blossoming, especially if associated with a prolonged dry season, may cause abortion of flowers (Camargo, 1985). Selected cultivars under intensive management conditions have allowed Arabica coffee plantations to be spread to marginal regions with average temperatures as high as 24-25 ºC, with satisfactory yields, as in northeastern Brazil (Da Matta and Ramalho, 2006). On the other hand, in regions with a mean annual temperature below 17-18 ºC, growth is largely depressed. Relative humidity have positive correlation with yield of Arabica coffee and negative correlation with yield of Robusta though the correlations are not significant. Jayakumar *et al*. (2013) reported that whenever relative humidity exceeds 84%, Arabica and Robusta coffee yields were high in Wayanad. Air humidity has a significant impact on the vegetative growth of the coffee tree. Robusta successfully grows under high air humidity, while on contrast, Arabica coffee requires a less humid atmosphere (Haarer, 1958; Coste, 1992). Rainfall has positive non significant correlation with yield of Arabica and Robusta coffee during flowering fruit set of coffee and negative correlation with yield of both species of coffee during remaining periods. The optimum annual rainfall requirement for Arabica coffee range from 1200 to 1800 mm (Alègre, 1959) and a similar range required for Robusta, although it adapts better than Arabica during intensive rainfall exceeding 2000 mm (Coste, 1992). For both species, a short dry spell, lasting two to four months, corresponding to the quiescent growth phase, is important to stimulate flowering (Haarer, 1958). Abundant rainfall throughout the year is often responsible for scattered harvest and low yields. Lack of a dry period can also limit coffee cultivation in lowland tropical regions (Maestri and Barros, 1977). Generally between February 15th and March 15th flower buds will develop and ready for blooming in Robusta coffee. In Robusta, if blossom shower is not received in time or in deficient quantity, then flower buds turn pinkish and fall. Robusta plants are very sensitive and easily respond to rain. It requires timely blossom and backing shower. If, Robusta coffee plants do not receive blossom shower by March 15th, there will be a considerable loss of crop. Sunil and Devadas (2004) observed that rains during February and April were favourable for coffee. Due to positive correlation of maximum temperature, rainfall and relative humidity, combinations of these parameters exhibited positive correlation with yield of Arabica coffee. Positive correlation of maximum temperature, minimum temperature and rainfall with yield of Robusta coffee have resulted positive correlation of yield of Robusta coffee with combinations of maximum temperature, minimum temperature and rainfall.

3.5. *Statistical model*

The multiple regression equation which describes the average relationship between the yield of Arabica coffee and significant climatic parameters is derived and expressed as below:

$$Y = -5550.024 + (116.434*z_{11}) + (1.085*z_{241}) - (0.482*z_{141}) \quad R^2 = 0.783*, \quad R = 0.885*$$

where, Y= Yield of Arabica coffee, z_{11}= sum product of maximum temperature and weight factor from January-December, z_{241} = sum product of minimum temperature x relative humidity and weight factor from January-December and z_{141} = sum product of maximum temperature x relative humidity and weight factor from January-December. The multiple correlation coefficients were significant. Standard error of the estimate is 157.63. *F* value for this equation is significant (probability of F≤0.05). The results of *t*-test shows that the generated climate variables z_{11}, z_{241} and z_{141} were found to be significant and explain the differences in the yield of Arabica coffee with an R^2 value of 0.783 which is significant at 5% level of significance.

Similarly, the multiple regression equation which describe the average relationship between the yield of Robusta coffee and significant climatic parameters is derived and expressed as below:

$$Y = -1184.394 + (1.669*z_{121}) + (0.045*z_{131})$$

$$R^2 = 0.529^*, R = 0.727^*$$

where, Y = Yield of Robusta coffee, z_{121}= sum product of maximum temperature x minimum temperature and weight factor from January-December and z_{131} = sum product of maximum temperature x rainfall and weight factor from January-December. The multiple correlation coefficients were significant. Standard error of the estimate is 205.10. *F* value for this equation is significant (probability of $F \leq 0.05$). The results of t-test shows that the generated climate variables z_{121} and z_{131} were found to be significant and explain the differences in the yield of Robusta coffee with an R^2 value of 0.529 which is significant at 5% level of significance.

In step wise regression analysis, it was found that climate indices involving maximum temperature, minimum temperature and relative humidity are identified as predictors of Arabica coffee yield. Similarly, climate indices involving maximum temperature, minimum temperature and rainfall are the predictors of Robusta coffee yield. The forecasting models could able to explain the inter annual variation in the coffee yield to an extent of 78 and 53% for Arabica coffee and Robusta coffee respectively. Coffee yield forecasts along with observed yield in 2013 and 2014 are presented in Figs. 1(a&b). Forecasting model could predict Robusta coffee better in year 2014. Yield forecasting models for both the species of coffee over estimated the yield of Arabica and Robusta coffee in 2013 and 2014. Hence, the climate indices based agrometeorological model developed could be used to forecast Robusta coffee yield in Wayanad.

4. Conclusions

Kerala is second major coffee producing State in India after Karnataka. In Wayanad district of Kerala, more than 80 per cent of Robusta coffee is produced and area of Arabica coffee is comparatively less in Kerala. Production forecasting of this important plantation crop in major coffee producing States is in need to make policy in pricing and export of coffee. Area estimation and yield forecasting are essential components of production forecasting of coffee. Different approaches namely crop weather models and crop simulation models are widely used for forecasting of yield of crops worldwide. Crop simulation models are available for several food, oilseed and commercial crops. Development of crop weather models by statistical regression techniques is the alternate method for forecasting of coffee yield in India due to non availability of simulation model for coffee. Modified Hendricks and Scholl model which takes account of climate parameters in successive months is used to develop agrometeorological model for forecasting of Arabica and Robusta coffee in Wayanad. The following conclusions are drawn from the study.

(*i*) There is no technological trend in yield of Arabica and Robusta coffee from 1991 to 2012 in Wayanad, Kerala.

(*ii*) Climate is found to be responsible for year to year variation in yield of coffee due to absence of technological trend.

(*iii*) Different climate indices derived based on maximum temperature, minimum temperature, rainfall and relative humidity and their combinations have positive correlation with yield of coffee.

(*iv*) Models developed for forecasting of Arabica and Robusta coffee in Kerala have good coefficient of determination and could predict the yield of Robusta coffee closer to observed yield during 2014. Model developed for Arabica coffee have high error percent during 2013 and 2014.

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