

Climate change and crop yields in the Indian Cardamom Hills, 1978–2007 CE

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Received: 17 October 2008 / Accepted: 16 May 2011
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Abstract In this study we analyzed climate and crop yields data from Indian cardamom hills for the period 1978–2007 to investigate whether there were significant changes in weather elements, and if such changes have had significant impact on the production of spices and plantation crops. Spatial and temporal variations in air temperatures (maximum and minimum), rainfall and relative humidity are evident across stations. The mean air temperature increased significantly during the last 30 years; the greatest increase and the largest significant upward trend was observed in the daily temperature. The highest increase in minimum temperature was registered for June (0.37°C/18 years) at the Myladumpara station. December and January showed greater warming across the stations. Rainfall during the main monsoon months (June–September) showed a downward trend. Relative humidity showed increasing and decreasing trends, respectively, at the cardamom and tea growing tracts. The warming trend coupled with frequent wet and dry spells during the summer is likely to have a favorable effect on insect pests and disease causing organisms thereby pesticide consumption can go up both during excess rainfall and drought years. The incidence of many minor pest insects and disease pathogens has increased in the recent years of our study along with warming. Significant and slight increases in the yield of small cardamom (*Elettaria cardamomum* M.) and coffee (*Coffea arabica*), respectively, were noticed in the recent years.; however the improvement of yield in tea (*Thea sinensis*) and black pepper (*Piper nigrum* L.) has not been seen in our analysis.

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1 Introduction

Mountains represent unique areas for the detection of climate change and the assessment of climate-related impacts. One reason for this is that climate changes rapidly with height over relatively short horizontal distances (Whiteman 2000). A warming trend has been documented and reported at most locations around the world by the Intergovernmental Panel on Climate Change (Salinger 2005; IPCC 2007); The Working Group II of IPCC also examined the impact of climate change on natural and social systems in its 2007 assessment report and concluded that climate change will affect species and ecosystems in all parts of the world—such as rainforests, coral reefs, and Arctic ecosystems. Global temperatures have increased by approximately 0.4°C since 1980, with even larger increases observed in several montane regions including the Indian Cardamom Hills (IPCC 2001; Rosenzweig et al. 2001; Murugan et al. 2000), particularly during the boreal winter. The IPCC (2001) and Salinger (2005) have clearly observed that the temperature increases was the greatest during the 1990s and also suggested that global temperature increases are likely to persist in the 21st century and probably would be accompanied by changes in the precipitation pattern and amounts globally. Future climate change at regional and local scale is difficult to predict with a greater certainty due to the limited spatial and temporal resolutions of current climate models and the likely influence of unaccounted factors such as regional and local land use change (Pielke 2005).

Despite tremendous improvements in technology and crop yield potential, crop production remains highly dependent on climate because solar radiation, temperature and precipitation are the main drivers of crop growth, plant diseases; and pest infestations as well as supply of and demand for soil nutrients are also influenced by climate. Hence, Plant development, growth, yield and ultimately the production of crop species will respond to higher temperatures, altered precipitation and transpiration regimes, increased frequency of extreme temperature and precipitation events, weed and pest and pathogen pressure (Rosenzweig et al. 2001; IPCC 2001, 2007). Agricultural crop yields are likely to be affected by shifts in mean climatic conditions. Those shifts would entail warmer temperatures, changes in growing seasons, altered patterns of precipitation mainly in rain dependent regions. It is likely that warming has improved yields in some areas, reduced them in some others and had negligible impacts in still others (Lobell and Field 2007). Semi-arid and rain fed regions would be the most vulnerable to crop failures caused by small increase in warming and soil drying (McMichael 2001). Rates of yield increase in Europe have ranged from 0.8% (oats; *Avena sativa*) to 2.5% (triticale; *Triticum secale*) per year (Ewart et al. 2005). Monteith (1981) concluded that the two largest climatic causes of variation in yield were temperature and rainfall and their independent effects were three to four times larger than those caused by variation in how much light was incident on crops. However, climate sensitive shade loving crops like cardamom and vanilla have different responses to primary climatic elements (Murugan et al. 2007). Research on these crops has got fresh impetus by concerns that the security of global food production and quality may be affected at large and local spatial scales by future climate and weather changes. (Long et al. 2005). Therefore increased variation and changes in mean temperature and rainfall are expected to dominate future changes in climate.

Tropical ever green forests in Western Ghats that form a part of global biodiversity hot spots had been converted and used for plantation agriculture in India.

An example of such a system is the present Cardamom Hill reserves in the Western Ghats (Fig. 1), where cultivation of spices and plantation crops is being practiced since 1896 CE. Understanding the effect of climate change on ecosystems and species is an important goal of modern agroecological research. Relatively few studies have addressed the potential effects of increased variation in temperature or rainfall on the relationships within biotic communities (Stireman et al. 2005). Recent studies have focused on direct effects of climate change on herbivore life histories and subsequent population dynamics (e.g., predators and parasitoids). Importantly, herbivores often respond quickly and dramatically to climatic conditions that influence development (e.g., seasonal temperature change and timing of rainfall), leading to temporal variance in herbivore populations. The importance of pest insects and pathogens with climate change is understood qualitatively, but quantitative knowledge is lacking. Importantly, increased climate change extremes may promote plant disease and pest outbreaks in tropical montane agroecosystems than the plains of tropics (Deutsch et al. 2008); therefore pesticide consumption in mountain agroecosystems may go up under future warming.

The yield and quality of food crops is central to the well being of humans and is directly influenced by climate and weather change. In contrast to high latitudes, crop production is predicted to decline across the tropics even under moderate climate change (1.4°C increase in 2040). There has been recent developments in our understanding of the physiology of cardamom and their sensitivity to weather and climate (Murugan et al. 2009) in Indian Cardamom Hills. Climate and weather variation can substantially influence the development and distribution of pest insects and disease causing organisms across cardamom agroecosystem. Climatic variability

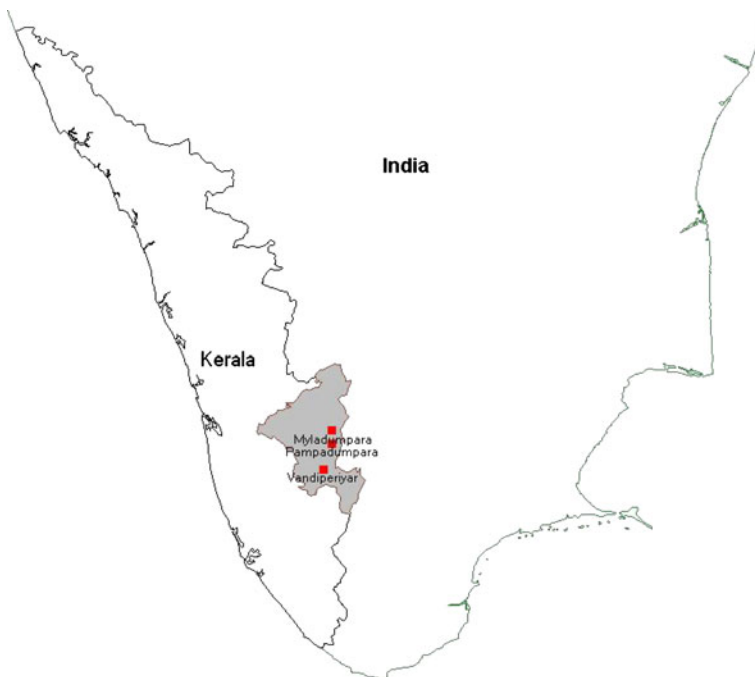


Fig. 1 Location of agrometeorological stations in the Indian Cardamom Hills

or more accurately the variability of the weather, since crop growth and development respond to local weather and not the general climate, variability at a range of spatial and temporal scales is now a key concern in studies of impact of ecosystems in general and agroecosystem in particular (Rosenzweig et al. 2001). Different crops will have different weather sensitivities that will need to be taken into account when considering the changes. For example seasonal rainfall variability is a major cause of variation in crop yields and quality in case of perennial spice crops like cardamom and black pepper. In order to provide useful information on agricultural climate change impacts more comprehensive estimates of physical and biological uncertainty are required, to date no published information is available on this aspect for tropical hill agroecosystems in India.

Cardamom is a climate sensitive grown as rain fed tropical understory crop in cardamom hills since 19th century CE (Murugan et al. 2007). India is the second largest producer in the world after Guatemala, and consumes 90% of its production internally. Relationships between weather and yield have been widely studied, often to identify critical climate factors for crops, mostly in USA and a few developed countries. The potential impacts of climate change on natural and managed ecosystems are of concern and have been extensively evaluated by simulation models (Tao et al. 2000; Parry et al. 2004), but few studies have examined how climate change has actually affected crop growth and development in the field. Such observational evidence of climate change can provide more accurate and valuable information which could be helpful in improving models, and, consequently, have important implications for predicting and testing the impact of future climate change (Tao et al. 2006). One of the simplest ways to evaluate how climate change can variability affect crop yields is through historical records (Thompson 1975, 1986; Changnon and Winstanley 2000). The climate and weather of Cardamom Hills are rapidly changing; therefore our objective was to show whether there were significant time trends in changes of the climate variables across Indian Cardamom Hills and whether these changes have had significant impacts on the production of cardamom, tea, black pepper and coffee which are high value crops as far as India is concerned.

2 Study area and methods

2.1 Indian Cardamom Hills (9°15'–10°0'N, 76°45'–77°25'E)

The central portion of the Western Ghats in Kerala is called the Cardamom Hills (Fig. 1). It is mostly a 700–1000 m high plateau. The northern edge of the Cardamom Hills abuts onto the High Ranges. This part is higher and more undulating but the rest of the Cardamom Hill tract is very gentle and undulated plateau. Majority of it is in Kerala excepting the spur hill called the High Wavies (*Meghamalai*, one of the few remaining montane cloud forests in India) in the southeast corner, which is in Tamil Nadu. Most of the western boundary of the Cardamom Hills is sharply set off from the narrow Kerala plains by steep scarp faces. The upper reaches of the eastern slopes have heavy moist forest vegetation and the lower reaches are drier. The 777 km² Periyar Tiger Reserve is located mostly within this southern most part of the Cardamom Hills. The main segment of Cardamom Hills extends towards east from the Periyar River Channel as a fairly smooth plateau. The main Periyar River,

part of it now submerged under the Idukki reservoir, drains the Cardamom Hills. The northern boundary of the Cardamom Hills is the high Munnar saddle running east to Chokkanad Mala and further on to the Kolukkumala (2400 m asl) on the eastern edge of the Ghats. The Cardamom Hills have had forests of exceptional biodiversity value and they were the vital catchment forests of the rivers Periyar, Mullayar, Vaigai and Kottagudi.

The study area encompasses the entire Cardamom Hills of about 3200 km² in the states of Kerala and Tamil Nadu. About half a dozen peaks in this mountainous region rise to an elevation range of 1600–2400 m asl. The regional climate is characterized as humid tropics with cool summer with abundant rainfall, which is relatively uniformly distributed across seasons. Climate at any individual location within this region is strongly influenced by elevation; annual minimum and maximum temperatures ranges from 13–33°C at Pampadumpara (1100 m) 12–24°C at Bodimettu and Kolukkumalai peak (>2375 m). The mean annual rainfall ranges from 1400 mm to 5000 mm depending on the elevation and geographical location (high rainfall on the windward side and low to moderate rainfall amounts on the leeward side). The location details of the sites are given in Table 1.

2.2 Data sources and site description

Climate data were obtained from various governmental (agricultural university station, forest department observatory, commodity board research stations) and non governmental organizations (planters association research station; Table 1). The Cardamom Research Station (CRS), Pampadumpara (1978–2007 CE) and the Indian Cardamom Research Institute (ICRI), Myladumpara (1990–2006 CE) provided rainfall and air temperature as well as relative humidity data representing cardamom growing tracts. United Planters Association of South India (UPASI) at Vandiperiyar (1990–2007 CE) supplied climate data on rainfall and air temperature as well as relative humidity representing tea growing areas of cardamom hills. The data were thoroughly checked before analysis.

Agronomic practices of these crops have not been changed much and were more or less uniform through the time. For e.g. shade regulation, application and doses

Table 1 Details of meteorological stations in the study area

Name of the station	Geographical location	Major land use pattern since 1970s
Cardamom Research Station (KAU), Pampadumpara Kerala (1978–2007)	9° 46' 25.19" N 77° 08' 44.16" E 3539 msl Wind side for SWM	Cardamom, black pepper, coffee and tea with semi protected tropical humid forest system
Indian Cardamom Research Institute, Spices Board (SB), Myladumpara Kerala (1990–2007)	9° 51' 59.49" N 77° 08' 59.95" E 3346 msl Wind side for both SWM and NEM	Cardamom, black pepper, coffee and tea and with semi protected tropical humid forest system
Regional Tea Research Station, United Planters Association of South India (UPASI), Vandiperiyar Kerala (1990–2007)	9° 35' 01.48" N 77° 04' 59.44" E 2774 msl Wind side for SWM	Tea, black pepper, cardamom and coffee with tropical humid forest and mountain grass system

of fertilizers and manures, pest insects and disease management and soil and water conservation measures were being same to all most all plantations. One of the prime reasons is that, farmers in the Cardamom Hills can't change cropping system and pattern as rules do not permit other crops to be brought in except tea, coffee, vanilla and black pepper, that require similar climatic condition as that of cardamom. Another reason is that cardamom and tea as well as coffee plantations are highly organized sectors in many aspects therefore only a little change is expected in their practices. In case of cardamom (main crop), 85% of the farmers' area is occupied by the variety called "Njallani". The productivity trend of the crops from 1990–2007 has been shown in Fig. 2. However, recent climate change has caused some changes in management practices like irrigation during the summer of drought years. This change in crop management is therefore definitely climate driven in the cardamom ecosystem.

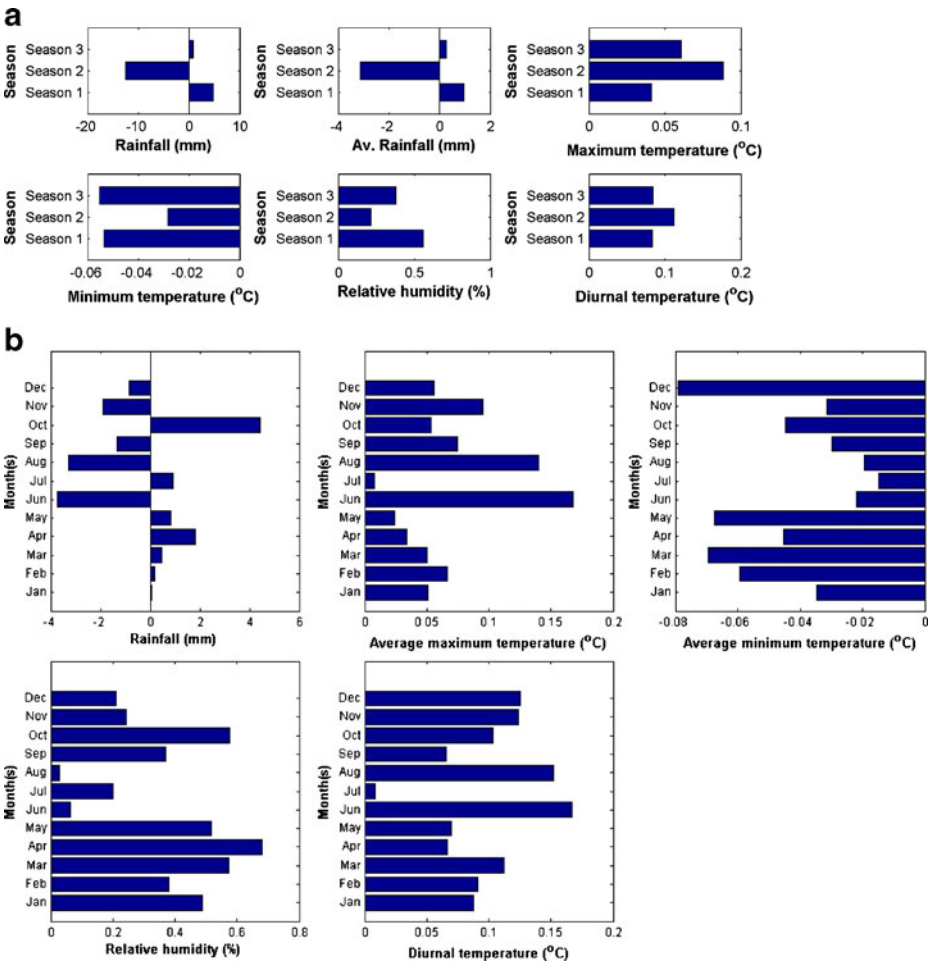


Fig. 2 a. Sen slopes of trends in the seasonal variation of climatic variables at Pampadumpara (1978–2007 CE) b. Sen slopes of trends in the mean monthly climatic variables at Pampadumpara (1978–2007 CE)

2.3 Data analysis

Daily rainfall amounts were summed up to obtain monthly, seasonal and annual values. Daily climatic variables namely, maximum and minimum temperature, relative humidity amounts was averaged up to obtain the mean monthly, mean seasonal and mean annual values. Diurnal temperature was estimated by subtracting the minimum from the maximum temperature. Six types of statistics were used on these climatic variables and reported here: (1) Arithmetic mean of climatic variables at annual, seasonal (season 1 represents January to May; season 2 comprises June to September and season 3 pertains to October–December) and monthly time-scales. (2) Temporal trends were evaluated at annual, seasonal and monthly time scales using the Mann–Kendall method (3) The slope of each trend was identified by the Sen slope method as a median of all pair wise slopes (3) Variation in daily temperature range (4) Significant trends were identified at annual, seasonal and monthly scales in using a two tailed Z-test. (5) The LOESS procedure was used to reduce the noise inherent in the climate data to allow quantitative visual examination of temporal changes in these data. (6) The climatology of climate variables using box plots.

Temporal trends were evaluated using the non-parametric Mann–Kendall test. The advantage of using non-parametric test over parametric test is that it is more suitable for non-normally distributed and censored data which are frequently encountered in meteorological time series (Yue et al. 2002). The Mann–Kendall test reliably identifies monotonic linear and non-linear trends with outliers (Helsel and Hirsch 1992).

One of the difficulties encountered in the interpretation of the climate data is the quantification of trends (e.g., calculation of slope). To quantify the slope we used Sen's non-parametric estimator of slope (Sen 1968; Thiel 1950). This method estimates the slope of each trend was identified by Sen Slope method as a median of all pair wise slopes. The significant of the test were evaluated using two tailed Z-Test. The significant level was varied form 1 to 10.

In addition, LOESS (Locally weighted scatter plot smooth; Cleveland and Devlin 1988) procedure was used to reduce the noise inherent in climate data to allow qualitative visual examinations of temporal changes in these data. The LOESS uses a least square regression approach to consider the user defined proportion of the data to weigh each regression point. A p value of <0.05 was used to indicate statistical significance, using a two tailed Z test.

Box and Whisker plots were prepared to indicate the degree of dispersion and skewness in the data, and identify outliers. Whisker plot is the convenient way of graphically depicting groups of numerical data through their five number summaries that are the smallest of the observations, lower quartile (Q1, 5%), median (Q2), upper quartile (Q3, 95%) and the largest of the observations. The span of the box represents the interquartile range of the observed climate variable. The whiskers extend from the box to 5 and 95% quantiles on the lower and the upper side of the box, correspondingly.

3 Results

In this section, trend results are presented for: (1) annual, seasonal and monthly mean, maximum and minimum air temperature (calculated from daily values), and

diurnal temperature worked out from daily temperature range (2) annual, seasonal and monthly rainfall, and (3) annual, seasonal and monthly relative humidity.

3.1 Air temperature

3.1.1 Air temperature maximum ($^{\circ}\text{C}$)

Increasing annual mean maximum air temperature trends were noticed across stations but significant increase was found only for Pampadumpara and Myladumpara. In all three seasons, seasonal mean air temperature increased in these two stations (Figs. 2a and 3a). The season 1 reported slightly down trend at Myladumpara. Increasing trends at Myladumpara were significant on the monthly scale but not on a seasonal scale. The positive trends were significant for January, and December months. Significant decline was observed for April at Myladumpara station ($0.17^{\circ}\text{C}/18$ years). Among months, the increase was greatest in June at Pampadumpara that displayed increasing trends for all months. In this station, the increase was maximum in January. However, the up trend was significant for three months for Pampadumpara (June, August and November) and two months at Myladumpara (January and December; Figs. 2b and 3b). Decrease in average maximum air temperature was observed at Vandiperiyar station for four months namely March, April, May and September. The dispersion within month was larger in Myladumpara than those of other two stations. The range of this variable in the months of June, July and August was comparable for Pampadumpara and Vandiperiyar stations (Figs. 2b and 4b).

3.1.2 Air temperature minimum ($^{\circ}\text{C}$)

Both positive and negative trends were reported among the stations examined. Decreasing annual mean minimum temperature trends were noticed at the Pampadumpara station in two seasons (season 1 and 3) and the trend was found to be significant (Fig. 2a). Seasonal scale minimum air temperature at Pampadumpara declined while other two stations reported both upward and downward trends. At Myladumpara station, all the three seasons experienced positive trends, of which season 1 and 2 recorded significant changes. Similarly, season 1 and 3 of Vandiperiyar observatory recorded positive trends; however, season 2 registered decreasing values. The mean minimum air temperature showed downward trends for all the months at Pampadumpara showing the highest decrease for December. At Myladumpara, the trend was positive and June reported the highest increase of $>0.37^{\circ}\text{C}/18$ years of passage. Mixed response was envisaged at Vandiperiyar where higher positive trends were noticed for January, February and March (Fig. 4b). The over all spread within month was uneven and greater across stations.

3.1.3 Diurnal temperature ($^{\circ}\text{C}$)

Increase in diurnal temperature was reported for Pampadumpara station but Myladumpara displayed the opposite way. At Vandiperiyar station, increasing trend was noticed only for season 1 and 2. For season 3, the change was opposite (Figs. 2a, 3a and 4a). Considering the seasonal trends across stations, Pampadumpara reported a significant drift. In the case of Myladumpara, all the three seasons had a significant reduction in diurnal temperature (Fig. 3b). Monthly scale change occurred at a

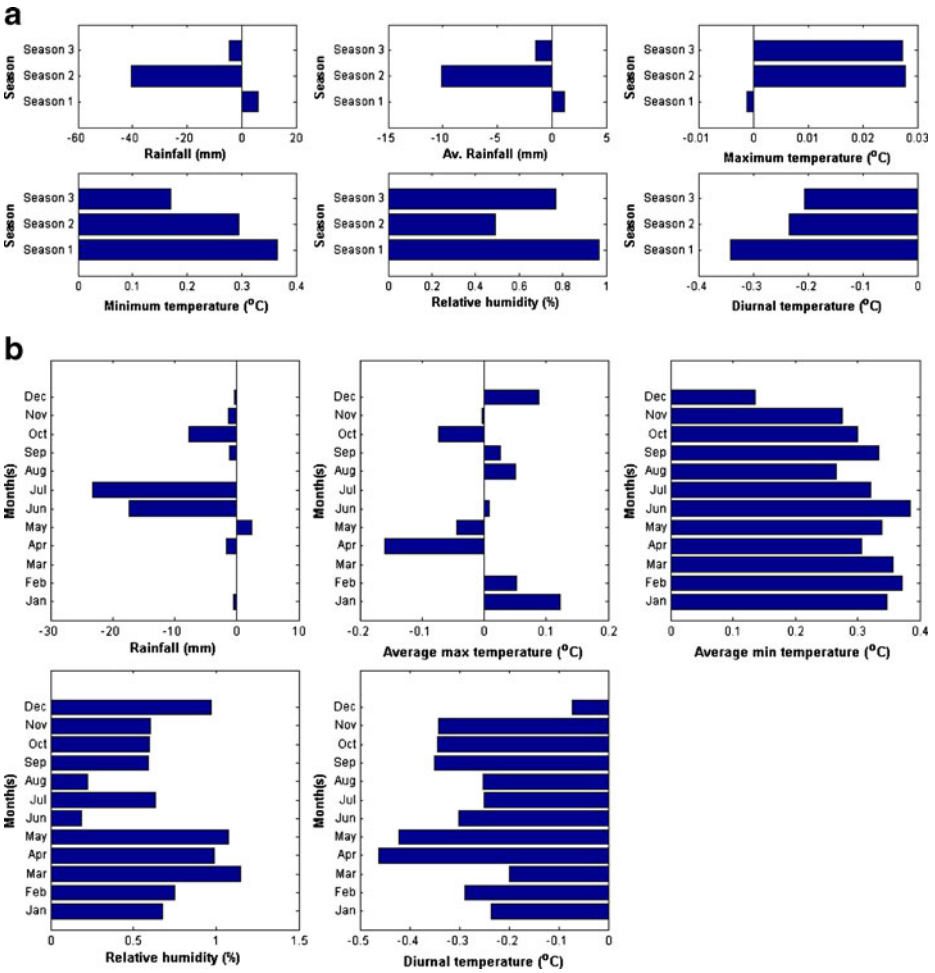


Fig. 3 a. Sen slopes of trends in the seasonal variation of climatic variables at Myladumpara (1990–2007 CE) b. Sen slopes of trends in the mean monthly climatic variables at Myladumpara (1990–2007 CE)

significant level across stations. At Pampadumpara, all monsoon months and April showed significant up trends. The decrease in diurnal temperature was higher for April followed by May at Myladumpara. Except January, other months had decreased diurnal temperature values; March registered reduced diurnal temperature at Vandiperiyar. Significant increase was noticed for August (Fig. 4b). Among months and stations; the dispersal of diurnal temperature was considerable.

3.2 Rainfall (mm)

Annual rainfall trends were inconsistent across all stations. Pampadumpara and Myladumpara station experienced increasing trends for the seasons 1 and 3. Across seasons, season 2 registered decreasing values. Among the stations, the highest

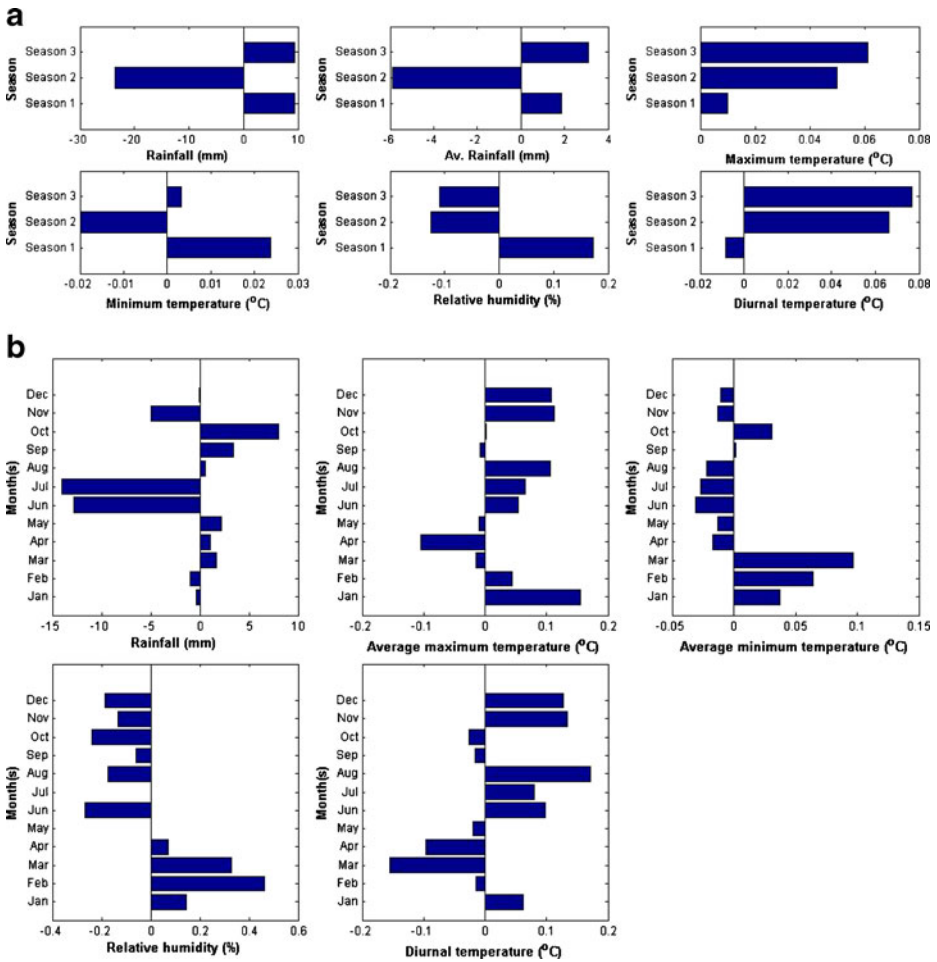


Fig. 4 a. Sen slopes of trends in the seasonal variation of climatic variables at Vandiperiyar (1990–2007 CE) b. Sen slopes of trends in the mean monthly climatic variables at Vandiperiyar (1990–2007 CE)

decrease in rainfall recorded for Myladumpara (>40 mm in the season) followed by Vandiperiyar (20 mm) and Pampadumpara (>10 mm; Figs. 2a, 3a and 4a). Except July and October, rest of the months in season 1 and 2 registered declining trends (Fig. 2b) in Pampadumpara. Up trends in rainfall for the months of March, April May, August, September and October were noticed at Vandiperiyar station (Fig. 4b). Similar trends of increase in rainfall for March, April and May was also observed for Pampadumpara also. In contrast, decreased rainfall of >10 and 20 mm respectively for June and July was experienced (Figs. 3b and 4b) at Myladumpara and Vandiperiyar respectively. At Myladumpara, rainfall in May increased slightly while other months reported decreasing values. No significant increasing or decreasing trends are reported across station. Rainfall variability within month especially June, July, September and October was noticeable (Figs. 2b, 3b and 4b) among stations.

3.3 Relative humidity (%)

As showed in Figs. 2a and 3a, relative humidity increased both at Myladumpara and Pampadumpara stations during the study period. At Vandiperiyar, it decreased in seasons 2 and 3 and increased during the season 1. At Myladumpara and Pampadumpara, the relative humidity increased significantly especially in seasons 2 and 3 (Figs. 2a and 3a).. More than 1% increase in relative humidity was recorded at the Myladumpara station in season 1. Vandiperiyar station reported insignificant trends. Relative humidity increased by 1% at the Myladumpara station during March, May and December. June and August had the least variation both at Myladumpara and Pampadumpara. Monsoon months (June to December) except July showed decreasing trends at Vandiperiyar (Fig. 4b).

4 Discussion

The temporal trends in air temperature minimum and maximum, rainfall and relative humidity are compared in this section to those of previous studies of tropical mountain areas. Implications for spices and plantation crops management in the Cardamom Hills are also discussed. Detectable trends in monthly and seasonal scale of climatic variables were noticed for all three stations studied. Maximum air temperature increased in all seasons across stations except in season 1 at Myladumpara. Pampadumpara and Myladumpara stations have reported decreasing and increasing trends, respectively, in minimum air temperature during the study period. At the Vandiperiyar station, season 2 exhibited a declining trend but the other two seasons registered upward trends. This clearly shows the peculiarity of tropical montane weather which needs deeper understanding of mountain top environment and its ecosystem change. The mixed trends reported here on surface air temperature have resulted in similar trends of seasonal diurnal temperature range across three stations. The increase in diurnal temperature range reported for Pampadumpara and Vandiperiyar stations is in contrast with other observations (Easterling et al. 1997; Forster and Solomon 2003) elsewhere. Therefore, the explicit spatial and temporal changes in temperature characterized by marked asymmetry between maxima and minima are presumed to cause significant changes in crop development and production (Rosenzweig et al. 2001; Tao et al. 2004; Tao et al. 2006; Porter and Semenov 2005). The productivity trend of cardamom, black pepper, tea and coffee in Cardamom Hills from 1990 is shown in Fig. 5 and Table 2. Many fold increase in cardamom productivity was noticed irrespective of varieties used. The latest variety *Njallani* responded more than the previous cultivated types and PV-1. There was slight increase in the productivity of coffee also, therefore under a warming trend these two crops respond positively. However, the other two crops (*viz.*, black pepper and tea) did not increase their yield for the same period, therefore had failed to respond positively. But the yield productivity of these two crops has been stagnant during our study period. One can not rule out the possible influence of crop management practices on enhancing the productivity of these crops in the recent decades. It is clearer that these crops were being grown in the Cardamom Hills with uniform agricultural practices for the entire period of this study. Under such condition cardamom and coffee had reported continuous higher yields; this

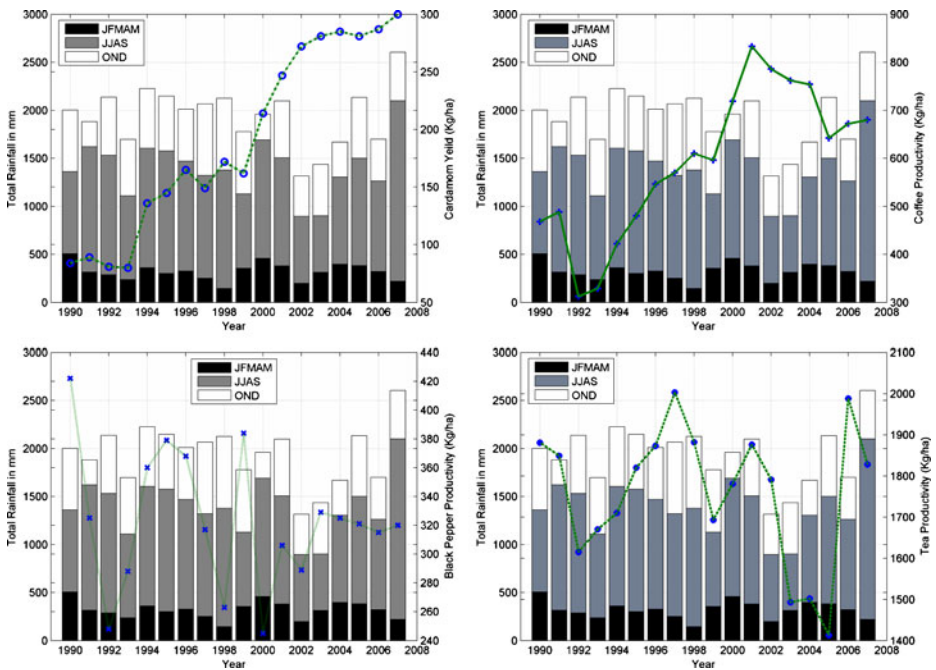


Fig. 5 Relationship between productivity and rainfall (1990–2007 CE)

means the climatic elements had directly or indirectly influenced the yields of cardamom and coffee. Many studies have shown that the primary climatic elements (temperature and rainfall) have a profound influence on the phenology of crop plants. In the case of cardamom, the seasonal flowering habit has changed; that means cardamom used to flower only during June to December up to early 1990s, and now cardamom has been flowering throughout the year. Therefore the number of harvests has been increased from five to nine per year. This has resulted in manifold increase in productivity of cardamom. Application of higher levels of fertilizers and manures can increase the yield of crops but not the number of harvests of crops. In cardamom in recent years (since the late 1990s) more harvests indicate the impact of recent weather and climate change on cardamom phenology. Other crops (coffee and black pepper) flower once in a year. Therefore this study highlights the need for further investigations on physiological process and mechanisms governing growth and yield of these commercial crops which are of national and international importance through models and controlled climate studies. Many controlled experiments on gradual temperature changes from 1982 to 1998 have caused measurable impacts on the yields of corn and soybeans in the United States (Lobell and Asner 2003) but in the Philippines rice grain yield was found to decline by 10% for every 1°C increase in the growing season minimum temperature in the dry season (January–April) from 1992–2003 CE (Peng et al. 2004). In Germany, a shift in phenology of fruit trees and field crops due to the increase in temperature from 1961–2000 CE has been observed, but the changes in the development were still moderate so no strong impact on yield formation process have been noticed on these crops (Chmielewski et al. 2004).

Table 2 Observed Productivity of cardamom, tea, black pepper and coffee in cardamom hills, Kerala from 1990–2007

Year	Cardamom Kg ha ⁻¹	Tea Kg ha ⁻¹	Black pepper Kg ha ⁻¹	Coffee Kg ha ⁻¹
1990	84	1881	422	468
1991	89	1849	325	488
1992	81	1615	248	312
1993	80	1670	288	329
1994	136	1710	360	422
1995	145	1820	379	480
1996	165	1873	368	546
1997	149	2003	317	570
1998	172	1882	263	610
1999	162	1693	384	596
2000	214	1781	245	719
2001	247	1876	306	833
2002	272	1791	289	786
2003	281	1493	329	762
2004	285	1502	325	754
2005	281	1413	321	642
2006	287	1988	315	672
2007	300	1828	320	680

Both Pampadumpara and Myladumpara displayed increase in relative humidity up to nearly 0.5% and 1% correspondingly during the study period; at the Vandiperiyar station season 1 reported a slight increase while the rest of the seasons recorded a decline. The reason for the increase in relative humidity in cardamom tracts of Pampadumpara and Myladumpara could be attributed to large scale irrigation, which has been playing significant role. Tea growing tract of Vandiperiyar has not been irrigated regularly. There has been large spatial and temporal variations in the rainfall distribution. Huge reduction in season 2 at all the three stations has been reported with a maximum reduction at the Myladumpara station up to nearly 40 mm during the study period. This means that the south-west monsoon circulation is getting weakened. The south-west monsoon circulation, which brings about considerable amount of annual rainfall, gets a forced ascent and the windward slopes of Cardamom Hills experience good rainfall. Although all the three stations are located at windward slopes, rainfall is not uniformly distributed and this showed the complex relationship between topography and rainfall in the Cardamom Hills. It is reported that the energy level of Low Level Jet during the south-west monsoon period was the deciding factor for the variation in annual rainfall in Kerala (Krishnamurthy 1985; Joseph et al. 1994). Most of the north-east monsoon is closely associated with the westward passage of storms and depressions, which are the remnants of low pressure systems that move into the Bay of Bengal (Das 1995). The Cardamom Hill slopes of lower elevation (Pampadumpara and Vandiperiyar) get good rain during the north-east monsoon period. The spatial and temporal variability of rainfall in Cardamom Hills is therefore attributable to the topographic factors like exposure of the stations to the prevailing wind, elevation, orientation and scale and slope of mountain (Basist and Bell 1994). In this study, we found annual total and seasonal distribution of rainfall, which are important as the primary source of soil moisture, is probably the most important factor determining the yield productivity of cardamom,

black pepper and coffee. Seasonal variation in rainfall played a major role in the reduction in the yields of these crops (Figs. 2a, 3a and 4b). In the 30 year climate normal period (1978–2007), their could have been an increase of CO₂ by 45–50 ppm in the atmosphere therefore the fertilization effect of CO₂ on the yields of these crops could be between 4.5 and 5% only. On comparison of this fertilization effect of CO₂ with the yield realised in the farmers field of these crops is not greater. Therefore, the climate effect could have played significant role in the crop yield change (DaMatta et al. 2006; IPCC 2007).

4.1 Climate trends and change on the pest insects and disease intensity of crops

Climate variability can affect agricultural pests as well. The spatial and temporal distribution and proliferation of pests is determined, to a large extent, by climate, because temperature, light and water are the major factors controlling the growth and development of pests (Rosenzweig et al. 2001). Until 1990 CE cardamom planters in the Cardamom Hills used to spray 7–8 rounds of pesticides to manage few insect pests (*Sciothrips cardamomi* and *Conogethes punctiferalis*) and disease problems (*Phytohthora* sp.). Since 2000 CE, the number of pesticide sprays has been significantly increased, and at present, 15–18 rounds of pesticide sprays have been given to the majority of the plantations for controlling pest attacks. This means the frequency of insect pest and disease incidence in the cardamom plantation has increased substantially. However, the results of the fixed plot surveillance and survey for major insect pests and diseases in the Cardamom Hills since 1995 CE showed no great increase in the frequency of cardamom damage by major insect pests like thrips and borers; this clearly indicates the involvement of more number of insect pests and diseases in damaging the crops. The observation of once minor pests (root grubs and white flies) becoming major ones causing economic damage (*Basilepta fulvicorne*, *Kanakarajiella cardamomi* etc.) in the recent past can be ascribed to the sudden increase in the number of sprays of pesticides. The present practice of calendar based spray of pesticides (15–18 rounds) had resulted in the reduced population of natural enemies of stem and capsule borer (most serious pest) mainly ichneumonids (*Agripon* sp and *Temeluchus* sp) and dipterans (not identified, looks like mosquito and house flies). Highest larval–pupal parasitisation was noticed in December and February for ichneumonids, while it was least for dipterans (under laboratory observation). The total parasitism has been reduced from 72.44% to 61.9%. However, no trend could be observed for parasitisation among individual species on the borers. Therefore, climatic variability in cardamom hills can impair larval–pupal–parasitoid interaction in the future also; hence conservation of these parasitoids in cardamom ecosystem is therefore important. Stireman et al. (2005) predicted an increase in the frequency and intensity of herbivore outbreaks through a disruption of enemy–herbivore dynamics as climates become more variable. Out break of root grubs (*Basilepta fulvicorne*) has been frequent after 2000 in which period, four out of eight years have registered below average rainfall coupled with very high variability in soil and air temperature. Cardamom being sensitive to drought and excess wet years, both root grubs and rot diseases dominated in the recent period (2000–2007). In case of black pepper and coffee, out break of anthracnose and coffee locust became a menace during the same study period, and which is primarily due to weather elements change and human induced forest disturbances like loss

of alternate hosts by shade lopping and deforestation. The reason for the increased activity of insect pests in the Cardamom Hills could be related to large thermal safety margin (temperature difference between physiological thermal optimum of insects and the climatological temperature of the insect's habitat) of these pest insects; oppositely and interestingly, the activity of many agricultural insect pests in tropical plains under global mean warming is expected to decline (Deutsch et al. 2008). Cluster analysis of climatic elements for Pampadumpara station revealed increased frequency of break period during monsoon seasons (wet and dry spells). This situation might favour the development of dry rot during dry spell and wet rot during wet spell. Such situations necessitated the use of pesticides to manage these rot disease in cardamom, other wise the crop loss would reach up to 70% (DaMatta et al. 2006).

5 Conclusions

Trends in weather elements, as well as their impacts on the development and production of plantation crops have become significant in the Cardamom Hills. The observed increases in temperature coupled with change in rainfall pattern in this tropical high altitude forest ecosystem probably necessitate more pesticide application. The existing practice of pesticide application (15–18 sprays of pesticide per year may not yield marketable produce) can have significant economic cost for planters and environmental cost for the society. The sensitivity of these crops and their varieties to climate change can also be influenced by agronomic practices such as shade lopping suggesting potential role of management for adaptation. Although changes in weather pattern are almost certainly happening, we have not yet understood how these changes will affect these crops, insects, diseases, and relationships among them. Therefore future studies must focus on these lines using statistical and simulation models in order to achieve both agricultural and environmental sustainability of Indian cardamom hills.

Acknowledgements The funding for this study in the form of NIAS senior research fellowship by the Department Science and Technology and Indian Space Research Organization, Government of India is thankfully acknowledged. The Associate Professor and Head, Cardamom Research Station, Kerala University, Pampadumpara and the Director, Indian Cardamom Research Institute, Ministry of Commerce, Government of India, Myladumpara as well as the Senior Scientist, Regional Tea Research Station, United Planters Association of South India, Vandiperiyar, Kerala are sincerely thanked. Many thanks to Indian Council of Agricultural Research, New Delhi. Our sincere thanks to Prof. R. Ramesh, Physical Research laboratory, Ahemedabad, for constructive comments on the earlier version of this manuscript.

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