International Multidisciplinary Research Journal 2011, 1/6:03-12
ISSN: 2231-6302
Available Online: http://irjs.info/
IRMJ-Agriculture

Occurrence and activity of cardamom pests and honeybees as affected by pest management and climate change

***Murugan M.[1], Shetty P.K.[1], Hiremath M.B.[2], Ravi R.[3], Subbiah A.[4]**

[1]*School of Natural Sciences and Engineering, National Institute of Advanced Studies, Indian Institute of Science campus, Bangalore 560 012, India*
[2]*KLES Kidney Foundation, KLES Dr. Prabhakar Kore Hospital & MRC, Belgam, India*
[3]*Indian Institute of Science, Bangalore 560012, India*
[4]*Horticulture College and Research Institute, TNAU, Periyakulam, Tamilnadu 625604, India*

Abstract:
It has been conjectured that global warming will increase the prevalence of insect pests in most agroecosystems. The variability and possible trends in the occurrence and management of cardamom pests climatic variables and productivity were analyzed for cardamom agroforestry system. Analysis showed a general trend of decreasing temperature for temperature maximum since 2000. Year to year variation was noticeable for all parameters analyzed including relative humidity and soil temperatures (15 cm top soil layer) during 2000-2007. Contrary to the general agreement that recent warming had increased the prevalence of insect pests in majority of the agroecosystems, our results showed decreasing incidence of insect pests in cardamom agroforestry system because of calendar-based pesticide spraying. A decrease in natural enemy populations was observed. There has been an increase in number of pesticide sprays by at least one with the passage of each year. The reason for increased rounds of pesticides could be assigned to more prevalence and altered population dynamics of thrips and capsule borers during the study period. This situation has led to higher use of pesticides in cardamom agroecosystem.

Keywords: Climate Change; *Conogethes punctiferalis; Sciothrips cardamomi;* Pesticide Sprays; *Elettaria cardamomum*

INTRODUCTION

Crop protection and production in any agroecosystem depend on climate variability, and the dependency is high for tropical rainfed crop production systems. Global warming is expected to make regional and local climate more varied and unpredictable, which could affect relationships between plant eating insects and their natural enemies. Significant warming trends were observed at most of the investigated stations, and the changes in temperatures have shifted crop phenology and affected yields of crops (IPCC 2001; Salinger 2005; and Tao et al. 2006). Both beneficial insects and pests will react to warmer conditions, and a general increase in insect abundance is expected at mid and higher latitudes. In tropical climates, temperature change will affect both insect behaviour and their life cycle, with a strong influence on resulting population dynamics. Differing from temperate climates in northern latitudes, the main effects in tropical regions will concern changes in survival, generation numbers and distribution boundaries (Fuhrer 2003). Therefore a specific consideration concerns the fact that alternation of dry and wet season and season length affects prevalence of insect pests and diseases in tropics. Crop pests are extremely dependent on climatic conditions because several phases of a pest's life cycle strictly depend on the combination of two or more environmental variables. Any shift in optimal environmental variables for crops and pests may have different outcomes depending on the regions and crops (Olfert and Weiss 2006). The warming will extend the length of the potential growing season allowing early maturation and continuous flowering in perennial crops. Besides, climate warming at multiple scales can lead to structural changes in organs of crop plants particularly succulents. Therefore, enlarged organs and crop canopies can provide a humid microclimate conducive to increased fecundity, spread and severity of pest insets (Chakraborty 2005). Increased unpredictability and vulnerability, particularly rainfall and drought, should be exceptionally disruptive. Insects can often respond rapidly and dramatically to changes in climatic conditions that influence their development, for example, timing of rainfall and dates of seasonal temperatures changes (Stireman et al. 2005). Recent studies have considered possible changes in the

Received: May 23, 2011; Revised July 21, 2011; Accepted July 21, 2011.

*Corresponding Author, Tel: +91-4868236263
Email: muthupeyan@gmail.com

variability as well as the mean values of climatic variables in the middle and high altitudes of Western Ghats Cardamom Hills (Murugan et al. 2000; Murugan et al. 2007; Murugan et al. 2008).Temperature is one of the dominant factors affecting the growth rate and development of insect pests (Patterson et al. 1999; Bale et al. 2002). For example, the increase in Colorado potato beetle (*Leptinotarsa decemlineata* (Say)) population in many countries in Europe is related with the climate warming (an increase by 0.4 ºC between 1983 and 1984) during the month of May (Smatas et al. 2008; Baker et al. 1998; Hansen 2007; FAO 2008). Higher temperatures would favor growth of high altitude and temperate zone insects leading to faster development times and additional generations per year (Porter et al. 1991). Therefore, climate change in any agroecosystem will affect dynamics and interaction among species, and it will affect and change the pattern of pest damage and pest control strategies. Nowhere is the need for the application of sound ecological science more acute than in high energy input agriculture which is the world's largest industry, and with population growth leading to increasing requirements, there is a great need for a more productive agriculture that protects and promotes environmental integrity rather than degrades it (NRC 2003).

Small cardamom (*Elettaria cardamomum* (L.) Maton; *Zingiberaceae*) is probably one of the oldest spices known to mankind. India is the largest consumer and second largest producer accounting for 40% (15 000 MT) of the world's production. The Indian cardamom hills (part of the Western Ghats) are considered to be the main centers of production contributing 70% of India's annual production. A total area of 86,000 ha has been allotted for exclusive cultivation of cardamom of which nearly 50% has been under intensive farming predominantly between 900 to 1600 m altitudes under wet tropical forest system. Cardamom farming is well organized under the Plantation Act. Cardamom is a high value (second costliest crop in the world after saffron) and high income crop, sensitive to both biotic and abiotic stresses. The shoot and capsule borer (*Conogethes* p*unctiferalis* (Guenee)) and thrips (*Sciothrips cardamomi* Ramakrishna) are the two major pests in cardamom. For the management of these pests, planters mainly depend on chemical insecticides. An array of chemicals against *S.cardamomi* (quinalphos, monocrotophos, methyl parathion, fenthion, dimethoate, phosalone and carbosulfan) and *C.functiferalis* (fenthion, monocrotophos, chlorpyrifos, triazophos, quinalphos, endosulfan and lambda cyhalothrin) on cardamom have been evaluated and found effective. The effect of these pesticides assumes a special significance in cardamom where pollination by bees is of tremendous importance. Production of this crop depends notably on climatic conditions, honey bee activity and management level, specifically of pests and soil fertility. Cardamom is a hermaphrodite crop pollinated by *Apis* species. Among the species, *Apis cerana indica*, *Apis dorsata* and *Apis florea* are the important ones contributing more than 95 % of cardamom pollination. Previously, solitary bees were dominating than social bees. The behavioral change of foraging activity of honey bees is mainly affected by climate (heat stress during day time temperature maxima) and pest management practices (use of toxic pesticides) (Stanely et al. 2009). Therefore, environmental alterations and intensive farming practices can lead to unsustainability of cardamom agroforestry system. Studies on the variation of season length in Western Ghats's high lands are scanty. Therefore, the purpose was to investigate and understand the effects of the farming system on the occurrence and prevalence of cardamom insect pests (*S. cardamomi* and *C. punctiferalis)* in farmers' field under changing climate and season length during the last two decades and the first decade of the 20th and 21st century, and to use this understanding for ecosystem management.

MATERIALS AND METHODS

Climate data and analysis

The location of the cardamom hills reserve along with vegetation map is shown in Fig. 1. The Cardamom Research Station (CRS), Pampadumpara (1978-2007) and the Indian Cardamom Research Institute (ICRI), Myladumpara (1990-2006) 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) supplied climate data on rainfall, air temperature and relative humidity representing tea growing areas of cardamom hills. The data were thoroughly checked before analysis. Soil temperature data used in this study were sourced from the daily weather records of the agro-meteorology station, Cardamom Research Station (CRS), Kerala Agricultural University, Pampadumpara and the forest department, Kerala. The agrometeorological station of CRS Pampadumpara is one of the representative stations for high altitude humid tropics. The data have been collected for the period 1986-2008. Data for a fixed number of years proceeding the years of 1990, 2000, 2004 and 2008 were averaged to monthly and seasonal values and expressed as the mean values for the periods ending in 1990, 2000, 2004 and 2008. These will henceforth be called the 1990, 2000, 2004 and 2008. The test employed here was the Seasonal Kendall test (ref), a generalization of the Mann-Kendall test. It is a nonparametric test that checks for monotonic trends of the data. For a complete description of the test refer to Hess et al. (2001).

The seasons can be defined as conventional (fixed) or 'floating'. In a fixed season, the starting dates and length of seasons remain the same for every year. In contrast, in a 'floating' season, the date of onset and duration of each season is allowed to change from year to year. Studies have shown that floating seasons reflect 'natural' seasons contained in the climate data better than fixed seasons, especially under changing climate conditions (Winkler et al. 1997; Anandhi et al. 2008). Therefore, in this study floating season is used to effectively capture the changes in the seasons.

The weather classification methods are used in this study to define floating meteorological season length, linked by grouping the monthly data sets of surface climate variables into a finite number of discrete weather types or 'seasons'. In this study, the hybrid approach, using K-means clustering (MacQueen 1967) was used since it had the advantages of both subjective and objective approaches. Hybrid techniques combine elements of empirical and automated procedures for grouping seasons, thereby avoiding time delay and enabling the production of easily reproducible and interpretable results.

The steps involved in the stratification into seasons are as follows:

Step 1: Selection of meteorological variables of interest for stratification.

Step 2: Standardization of meteorological variables to reduce systemic bias (if any) in the mean and variance of the variables. This step typically involves subtraction of mean and division by the standard deviation of the predictor for the period.

Step 3: Formation of feature vectors using standardized meteorological variables for each month. The feature vectors form the input to the K-means clustering algorithm, and the seasons its output.

Step 4: Partitioning of feature vectors into clusters, depicting seasons, by using K-means clustering. In this analysis, each feature vector (representing a month) of the data is treated as an object having a location in space. The feature vectors are partitioned into clusters so that the feature vectors within each cluster are as close to each other as possible in space, and are as far as possible in space from the feature vectors in the other clusters.

Step 5: The distance between feature vectors in space is estimated using Euclidian measure. Subsequently, each feature vector (representing a month) is assigned a label that denotes the cluster (season) to which it belongs.

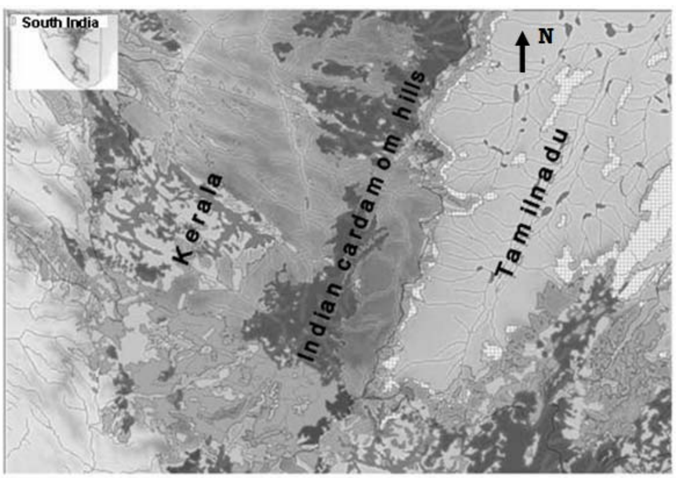

Fig. 1 Location map of cardamom hill reserves, Kerala
(9°15′N-10°0′N Lat. 76°45′E-77°25′E Long.)
(Source: French Institute Pondicherry, map no.6)

Insect pest population

The incidence data on cardamom thrips and capsule borers were collected by entomologists working on cardamom from the fixed plots of cardamom planters' on monthly intervals. Details on the total number of pesticide sprays were obtained from individual planter's (farmers) records and through interviews. Only the number of insecticides sprayed or applied was taken into consideration. Cardamom productivity data were collected from the publications of the Spices Board, the Ministry of Commerce, and the Government of India. The variability and possible trends in cardamom pests' occurrence and management, climatic variables and productivity, were analyzed for the period 2000-2007 using simple statistical methods. Observations on honeybee visits on small cardamom cv. Green Gold (*Njallani*) (2006-2007) were recorded under recommended pesticide spray in farmer's field**.** The experiment plants were sprayed with commonly available and prescribed (Spices Board, Government of India) pesticides for the management of shoot and capsule borer, thrips, leaf eating cater pillars and whiteflies infesting cardamom plants. To assess the level of pesticide residues of cardamom capsules, random samples from planters were taken and analyzed for various pesticide residue concentrations at the Pesticide Residue Laboratory, All India Co-ordinated Research Project on Pesticide Residues, College of Agriculture, Kerala Agricultural University, Thiruvananthapuram.

Experiment on honeybee activity and pesticide application

Treatment details of honeybee foraging experiment and recommended pesticides sprayed for major insect pest management in cardamom are as follows.

Treatment 1 (T1): Profenophos (35EC) @ 2.0 ml per litre of water

Treatment 2 (T2): Lambda Cyhalothrin (5EC) @ 0.60 ml per litre of water

Treatment 3 (T3): Triazophos (35EC) @ 2.0 ml per litre of water

Treatment 4 (T4): Imidacloprid (70% WS) ml per litre of water

Treatment 5 (T5): Monocrotophos (35 SL) @ 2.0 ml per litre of water

Treatment 6 (T6): Quinalphos (25EC) @ 2.0 ml per litre of water

The experiment was conducted at a planter's field in cardamom hills during peak flowering period (July 2008). Each treatment consisted of five yielding plants. All of the treatments were replicated thrice, and the total number of plants selected for this experiment was 90. The replications and well as treatments were randomized before the treatments were imposed on experimental plants. Observations on number of honey bee visits after each pesticide spray at hourly intervals were taken continuously for three days. The data were pooled and analyzed statistically.

RESULTS AND DISCUSSION

Climate change

The results obtained from analysis of data from 2000-2007 showed great variation and possible trends in all of the parameters studied (Table 1 and Fig. 2). A general trend of decreasing temperature was envisaged for temperature maximum. One of the possible reasons could be the extensive irrigation of estate plantations during summer season and the reduction of tree felling for the purpose of curing harvested cardamom all through the year. Year to year variation was noticeable in all the parameters analyzed including relative humidity and soil temperatures (15 cm top soil layer). Analysis of relative humidity and soil temperatures data showed no trends. The change and variability for temperature minimum and diurnal temperature were correspondingly positive and greater, but on comparing the rate of change between temperature minimum and maximum, it was disproportionate not symmetrical. Therefore such change in the cardamom agroecosystem could be related to the general warming trend experienced across the world (IPCC 2001). Although the rate of present warming reported in this study for Indian cardamom hills (0.5º C increases for 10 years) is unlikely (because of short term and insufficient data), the trend (increasing) is going to be the same. Modeling studies have also reported an increase of 0.5º C per decade and as much as 2º C per decade in hardest hit regions of the world (Schwartz and Randall 2003). The reason for climate warming in cardamom hills could be explained by frequent visits of long drought periods since 2000 (2002, 2003 and 2006), in some of these years there was no rainfall for 120 days starting from December up to March. The lowest rainfall of 63.2 inches was reported for the year 2003. The year 1959 which is considered the wettest year on record received a total of 130.5 inches rainfall. Long term analysis of temperature minimum for the Indian cardamom hills increased by 0.3 ºC for the year up to 2000 (rephrase, not clear) was reported by Murugan et al. (2000). In our observation, increased incidence of root grubs (*Basilepta fulvicorne*) in cardamom plantations was reported since 2000. The present level of warming coupled with elevated soil temperatures and prolonged drought could be the probable reason. Similar findings have been reported for non-thermoregulating pests such as caterpillars in tree species and species with subterranean pupal stage, like the cotton pest *Heliothis armigera* (Smatas, et al. 2008; Walker 1991). Also, the activity of *Heterorhabditis indicus,* an entomophilic nematode and biological agent of cardamom root grubs, was affected by enhanced soil temperature and reduced soil moisture level. Parasitization of cardamom shoot borer larvae by Ichneumon*ids* and other Dipterans were affected to a great extent due to year to year weather variability.

Table 1 Variability and trend analysis of climatic variables and pest incidence in cardamom agroforestry system, Indian cardamom hills during 2000-2007

Year	Tmax. ºC	Tmin. ºC	Diurnal temp.ºC	RH %	Thrips Incidence %	Borers Incidence %	Pesticide sprays, No.	Productivity Kg/ha
2000	27.2	14.9	12.3	68.4	10.2	8.0	7.5	214.0
2001	27.1	15.4	11.7	81.7	9.5	6.2	8.2	247.0
2002	27.8	15.7	12.2	81.4	8.8	8.2	8.5	272.0
2003	27.5	15.9	11.6	77.8	7.4	8.9	10.2	281.0
2004	26.7	16.9	9.8	80.6	2.3	9.0	10.7	285.0
2005	27.9	16.4	11.4	81.8	1.9	1.8	13.2	281.0
2006	27.2	15.7	11.5	77.1	0.8	4.9	14.1	287.0
2007	25.7	16.9	8.8	92.2	0.9	1.7	14.2	300.0
Mean	27.1	16.0	11.2	80.1	5.2	6.1	10.8	270.9
SD	0.7	0.7	1.2	6.6	4.1	3.0	2.7	27.6
Trend Slope	-0.1	0.2	-0.35	No trend	-1.6	-0.8	1.1	9.9

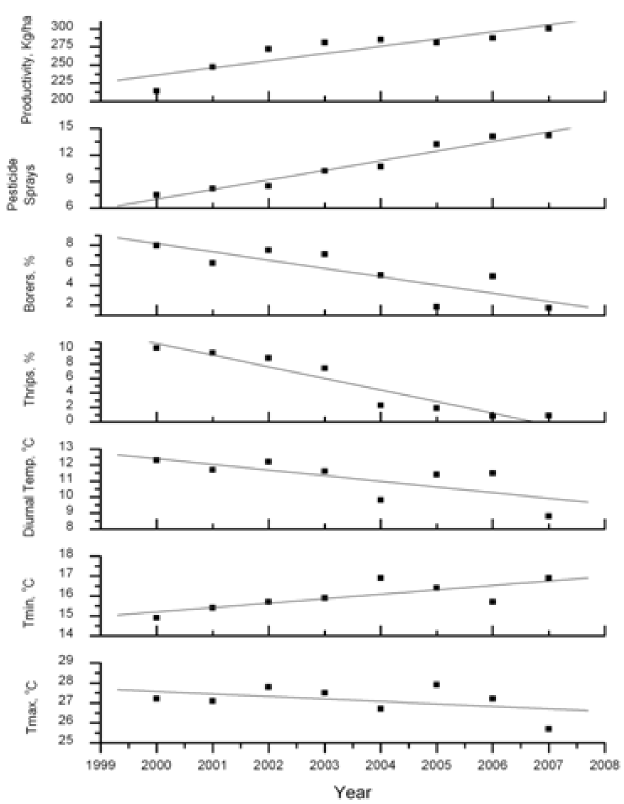

Fig. 2 Trend slopes of climatic variables, pest incidence, pesticide application and productivity of cardamom in Indian cardamom hills during 2000-2007.

Soil temperature

Soil temperature data are far more important for understanding various processes like soil nutrient dynamics and soil microbial communities and their activities. Surprisingly, soil temperature data and information are very scarce worldwide. Long term soil temperature research in India is very scanty. Similarly, published literature is hardly available. Temporal variations in soil temperatures at different depths are presented in Table 3 (3a, 3b and 3c) and Fig.6 (6a and 6b). For measurements of soil temperature at depths 5cm and 10 cm, the Seasonal Kendall test found a significant upward trend (both with $p < 0.05$). The test statistic was 45 and 46, respectively, out of a maximum possible value of 72. At 15 cm depth, a weaker upward trend was found, but with a less significant p value ($p > 0.05$). The statistic was 12 out of a maximum possible value of 72. Significant soil temperature increase was noticed after 2000 at 5 and 10 cm depths. Summer months have reported greater soil warming than winter month's at all soil depths. Such significant warming of soil during the period after 2000 occured mainly because the first decade of this century experienced many warmest years (2002, 2004 and 2006). Such phenomenal increase in soil temperature observed in cardamom hills can be related to recent accelerated warming coupled with severe forest degradation. Elsewhere, observation and findings on soil temperature variations for similar tropical mountain ecosystems have been reported (Lal and Cummings 1979). The deforestation in cardamom hills has reached its maximum. One of the observations to prove the extent of degradation of forests in cardamom estates is the shape of rainforest trees; in plantations the shape of all tress has been changed (to inverted "T" shaped trees) from the original shape which is inverted "J" shaped. The intensity of shade lopping and selective tree felling in plantations is maximum during these years and the amount of forest biomass removed is high. It is important that the rate of deforestation has been at a much faster rate in the cardamom hills compared with similar locations in Kerala. For instance, 85% of the cardamom hills were under thick forest cover in 1905 which came down to 65 and 40% correspondingly by 1973 and 2000 (Sivanandan et al 1973; Murugan et al. 2008). The soil warming in cardamom hills will have several consequences specifically on the soil organic matter turn over and nutrient dynamics as well as the soil microbial communities' composition and function (Waldrop et al. 2002).

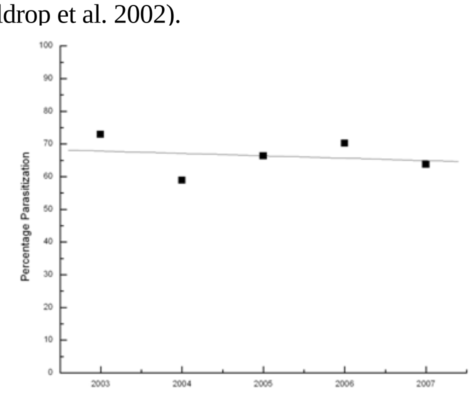

Fig.3 Natural parasitization percentage of cardamom shoot and capsule borer (*Conogethes punctiferalis*) by dipterans and ichneumonids. The points are the mean values of 12 months and the line indicates the linear fit.

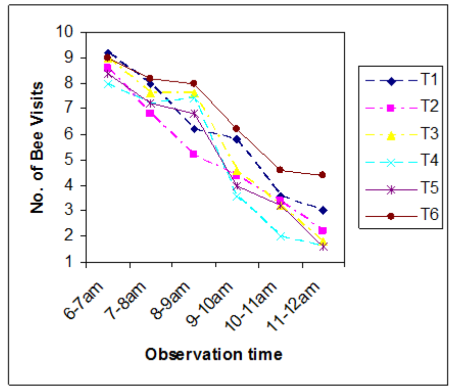

Fig. 4 Number of honeybee visits as affected by pesticide treatments

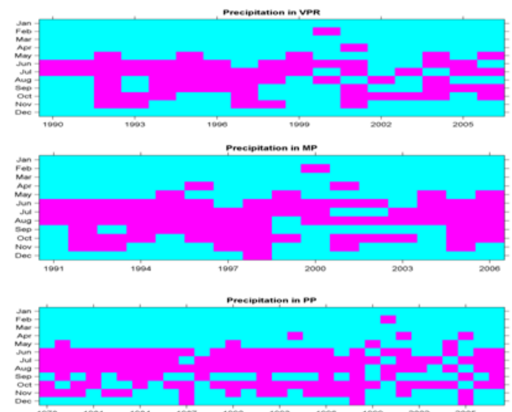

Fig. 5 a. Typical results of classification into wet and dry seasons performed using cluster analysis on precipitation from three gauging stations located at Pampadumpara (PP), Myladumpara (MP) and Vandiperiyar (VPR) in Indian cardamom hills. A month in a year in the cluster depicting the rainy season, is represented by ' ', similar symbol in ' ' color represents the month in the cluster depicting the dry season. Rainy season is shown in pink color ( ), whereas dry season is represented in cyan color ( )

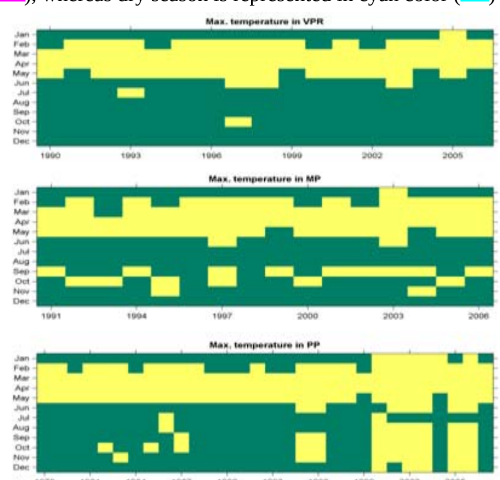

Fig. 5b.Typical results of classification into warm and cold seasons performed using cluster analysis on maximum temperature from three gauging stations located at Pampadumpara (PP), Myladumpara (MP) and Vandiperiyar (VPR) in Indian cardamom hills. A month in a year in the cluster depicting the warm, is represented by ' ', similar symbol in ' ' color represents the month in the cluster depicting the cool season. Warm season is shown in yellow color ( ), whereas cool season is represented in green color ( ).

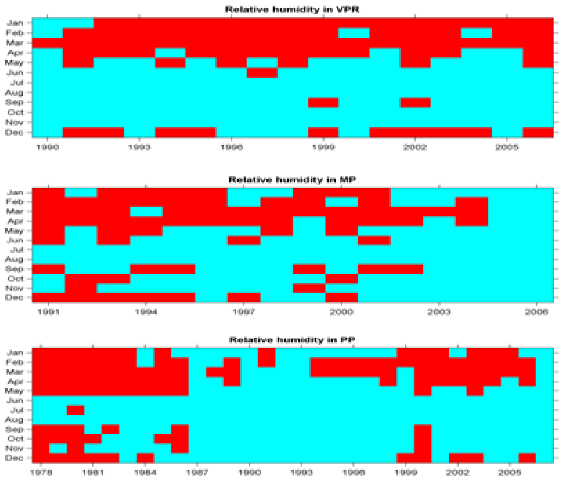

Fig. 5 c. Typical results of classification into wet and dry seasons performed using cluster analysis on relative humidity from three gauging stations located at Pampadumpara (PP), Myladumpara (MP) and Vandiperiyar (VPR) in Indian cardamom hills. A month in a year in the cluster depicting the dry season, is represented by ' ', similar symbol in ' ' color represents the month in the cluster depicting the wet season. Dry season is shown in red color ( ), whereas wet season is represented in cyan color ( )

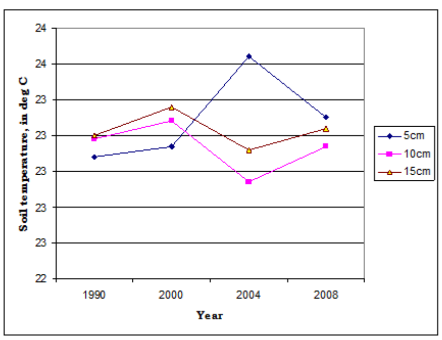

Fig. 6a Soil temperature variations observed at 5 cm, 10 cm and 15 cm soil depths during monsoon months (June-December)

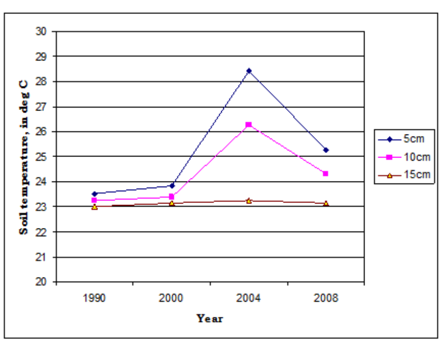

Fig. 6b Soil temperature variations observed at 5cm, 10cm and 15cm soil depths during summer months (January-May)

Variation in season length

Depending on the application, seasons are defined in a number of ways, such as astronomical seasons, meteorological seasons (Argiriou et al. 2004) and standard seasons. In this study seasons are divided based on meteorological variables, namely, rainfall and temperature, as they affect agriculture and irrigation of the region and also they are commonly used in climate change impact studies. The results of the season stratification of the study area are shown in Fig. (5a-c). Monsoon rains have become spells and erratic. The spells were more frequent in cardamom growing regions Pampadumpara (PP) and Myladumpara (MP) than that of tea growing region (Vandiperiyar). Significant upward trends of air temperature for all the seasons and months were noticed. The atmosphere was always warmer in all the months in cardamom areas compared to tea growing areas. As far as relative humidity was concerned, cardamom growing regions (PP and MP) had registered higher relative humidity values when compared with tea growing areas (VP) of cardamom hills. The higher relative humidity in cardamom areas is mainly due to constant irrigation given to cardamom plantations. Since the change in climate variables and season length can directly influence the occurrence and frequency of insect pests and plant pathogens, the pattern of pesticide consumption can change considerably. Therefore, the increase in pesticide consumption under changing climatic conditions will not only increase the variable cost of production of cardamom, but also the environmental cost significantly.

Pests, pest management practices and productivity

The percentage incidence of cardamom thrips and capsule borers decreased drastically during the period 2000-2007 (Table 1) and followed a definite negative trend (Fig. 2). Oppositely, there was a remarkable increase in number of pesticide sprays between 2000 (7.5 rounds) and 2007(14.2 rounds). The increase in pesticide sprays was observed with increase in years and the trend was positive. Contrary to the general findings and agreement that recent warming has increased the prevalence of insect pests in majority of the agroecosystems, our results showed decreasing incidence of insect pests in cardamom agroforestry systems. The obvious reason for declining trends is that the number of insecticide sprays increased considerably which suppressed the population of thrips and borers effectively in the planters' estates. There has been an increase in the number of pesticide sprays by at least one with the passage of each year. The reason for increased rounds of pesticides could be assigned to more prevalence and altered population dynamics of thrips and capsule borers during the study period. This could be caused by recent climate warming reported in this study. Worldwide at least five years have registered very high temperatures since 2000 than those of previous years. This has led to higher use of pesticides in cardamom agroecosystem including quinalphos, **m**onocrotophos, triazophos, chlorpyrifos, imidacloprid, lambdacyhalothrin, profenophos, endosulfan, Carbofuran, fenthoate and phorate.

In recent years, cardamom borers have become a menace to planters who had to increase the number of insecticide sprays. The temporal trend of the natural parasitization percentage of cardamom shoot and capsule borers by dipterans and ichneumonids is on the decrease (Fig.3). This could be a clear case of the negative impact of pesticides on the activities of natural enemies of cardamom agroecosystem. The declining trend of natural enemies would lead to consumption of more pesticides; many studies have suggested that the more diverse the agroecosystems and the longer the diversity remains undisturbed, the more internal links develop to promote greater insect stability. And any changes on the levels of plant and crop diversity in such systems (monocrop cardamom system) can lead to disruptions of natural pest control mechanisms, potentially making farmers more dependent on pesticides (Altieri and Nicholls 1999).

The trend analysis of cardamom productivity is very positive (Fig. 2), and the increase was significant for later years in our study period (Table 1). There are two possible reasons for increased cardamom production: 1) Cardamom thrips and borers are the most destructive pests and a yield loss up to 60% is experienced if populations are not controlled with chemicals (Murugan et al. 2002, 2005). Currently these pests are under control, and yield loss is minimum. So far biological management of these perennial pests in cardamom has not been standardized and available, consequently, chemical management is preferred.

2) Monoculture cardamom agroforestry system has a peculiarity of having only one variety (*Njallani*) under majority of the area (nearly 80%) which is very much adapted to warm environment and chemical inputs. All the morphological and yield attributing parameters, including enlarged organ of economic importance (capsules), were greater for the *Njallani* (Backiyarani et al. 2006).

Table 2 Number of visits by bees on hourly basis as affected by pesticides in cardamom

Time of observation	T1	T2	T3	T4	T5	T6	Average	SD	CV
6-7am	9.2	8.6	9	8	8.4	9	8.7	0.45	5.19
7-8am	8	6.8	7.6	7.2	7.2	8.2	7.5	0.53	7.10
8-9am	6.2	5.2	7.6	7.4	6.8	8	6.86	1.03	15.04
9-10am	5.8	4.4	4.6	3.6	4	6.2	4.76	1.02	21.46
10-11am	3.6	3.4	3.2	2	3.2	4.6	3.33	0.83	25.07
11-12am	3	2.2	1.8	1.6	1.6	4.4	2.43	1.09	45.14
Total	35.8	30.6	33.8	29.8	31.2	40.4	33.6	4.00	11.92

Table 3a Monthly and seasonal soil temperatures (˚C) (cumulative average) recorded at 5 cm depth at CRS Pampadumpara from 1990-2008

Month	1990	2000	2004	2008
January	23.3	23.6	32.3	26.4
February	28.8	29	34.3	30.7
March	29.3	30.6	37.1	32.3
April	29.4	29.5	36.6	31.8
May	25.8	27.9	31.6	28.4
June	23.8	23	26.9	24.6
July	22.2	23.5	25.5	23.7
August	22.3	22.4	28.7	24.5
September	24.7	25.9	32.3	27.6
October	24	24	28.6	25.5
November	23.2	23.4	27.5	24.7
December	24.6	24.7	29.5	26.3
Season				
Jan-May (mean)	27.3	28.1	34.4	29.9
Jun-Dec (mean)	23.5	23.8	28.4	25.3
Difference	3.8	4.3	6.0	4.6

Table 3b. Monthly and seasonal soil temperatures (˚C) (cumulative average) recorded at 10 cm depth at CRS Pampadumpara from 1990-2008

Month	1990	2000	2004	2008
January	22.9	23.1	28.2	24.7
February	28.8	29	30.5	29.4
March	27.8	29.2	33.4	30.1
April	29.0	29.1	34.0	30.7
May	27.5	27.8	30.5	28.6
June	22.8	22.8	25.7	23.8
July	23.3	23.3	24.3	23.6
August	21.7	21.8	24.9	22.8
September	25.3	25.4	29.7	26.8
October	23.4	23.6	26.9	24.6
November	23.2	23.4	25.6	24.1
December	23.1	23.4	26.7	24.4
Season				
Jan-May (mean)	27.2	27.6	31.3	28.7
Jun-Dec(mean)	23.3	23.4	26.3	24.3
Difference	3.9	4.2	5.0	4.4

Table 3c. Monthly and seasonal soil temperatures (˚C) (cumulative average) recorded at 15 cm depth at CRS Pampadumpara from 1990-2008

Month	1990	2000	2004	2008
January	23.4	23.4	23.8	23.5
February	26.9	27.3	26.2	26.8
March	28.4	28.5	30.2	29.0
April	28.2	28.2	28.8	28.4
May	27.2	27.2	27.4	27.3
June	22.5	22.5	25.7	23.6
July	22.7	22.7	21.5	22.3
August	21.8	21.8	21.7	21.8
September	25.1	25.2	25.5	25.3
October	23.3	23.5	23.8	23.5
November	23.0	23.2	22.2	22.8
December	22.8	23.1	22.4	22.8
Season	1990	2000	2004	2008
Jan-May (mean)	26.8	26.9	27.3	27.0
Jun-Dec(mean)	23.0	23.1	23.3	23.2
Difference	3.8	3.8	4.0	3.8

Effect of pesticide spray on honeybee visits

The results on the number of visits by honeybees as affected by different pesticides are presented in Table 2 and Fig. 4. Overall the bee visits decreased as the time progressed. The honey bee visits (foraging activity) was maximum (8.7) between 6 and 7 am followed by 7-8 am. The number of visits was the lowest during noon (11-12) in all of the treatments. The decreasing trend of foraging activity was common irrespective of the treatment. One of the reasons could be the warming of the atmosphere and consequent increase in the air temperature. As the atmosphere warms up, the honeybee activity decreased, and the reasons for this reduced activity after the noon could be explained by the combined effect of atmospheric warming and the types of pesticides sprayed. Among the treatments, the number of visits was maximum for T6 (quinalphos) and decreased in the order of T1 (profenophos)>T3 (triazophos)>T5(monocrotophos)>T2 (lambdacyhalothrin)>T4 (imidacloprid).The low bee activity in cardamom plants sprayed with insecticides such as imidacloprid, lambdacyhalothrin and monocrotophos could be attributed to the higher bee toxicity of these insecticides even at sub-lethal doses. Yet, the mechanism and physiological basis of this in honeybees is not fully understood. Therefore, avoiding spraying of insecticides toxic to bees during blooming season of cardamom is recommended; however, safer insecticides like quinalphos and profenofos can be used to manage the problems of insect pests during peak flowering season. Cardamom is 100 per cent cross pollinated crop by honey bees. Due to habitat destruction (forest degradation) and modification, the population of native bees that pollinate cardamom has been reduced. Currently, managed colonies of introduced species in private plantations are very common and susceptible to these toxic insecticides, which can impair memory and brain metabolism in honeybees (Decourtye et al. 2004). In future, due to expected climatic change in the highly disturbed cardamom agroforestry system, the number of sprays and concentrations of pesticides can go up, and this would further aggravate the process of honeybee colony destruction because honeybees are exposed to pesticides both in the field and hive (Bonmatin et al. 2005; Kievitis 2007). To maintain honeybee colonies in monoculture cardamom plantations as well as to reduce the risk of pest management in that ecosystem, tandem use of selective insecticides and natural enemies is imperative (Gentz et al. 2009).

CONCLUSIONS

The combined influence of significant increase in maximum temperature and short lived wet and dry spells observed during the first monsoon period have increased sucking pests and root feeding grubs in cardamom plantations which has led to higher levels of pesticide consumption. Discontinuous rainfall during the summer monsoon has given opportunity for planters to take up spraying chemical pesticides, particularly insecticides and fungicides. Also in recent years after 2000, the frequent occurrence of wet and dry spells during the winter monsoon and summer rainfall period have more pesticide sprays, specifically soil insecticides like chlorpyriphos and phorate. No pesticide spray has been recommended during the Indian summer and winter monsoon period (KAU, 2006). However planters now resort to at least 7-8 rounds of pesticide application. Therefore we can infer directly that climate variability and change have increased the quantum of pesticides used in cardamom agroecosystem. This is mainly attributable to some of the minor pests that have become quite serious (e.g., *Basilepta fulvicorne*) in the past decade. Repeated and calendar based application of pesticides for every 22-35 days could result in development of pesticide resistance which in turn increase the quantity of pesticides to be used to control these major pests. Most planters go for chemical control of pest insects and diseases rather than integrated pest management (IPM).The practices of intensive pesticide application have suppressed the population of natural enemies and other ecosystem service providers. Therefore, the ecosystem service provided by the honey bees will be affected more seriously under intensive cardamom farming as well as future climate change. Considering these, future research should aim and focus on reducing the level of pesticide consumption and risk as well as monitoring and regulation of pests and pesticide residues which are the major concerns of agricultural and environmental sustainability of cardamom agroecosystem.

ACKNOWLEDGEMENTS

The funding for this study in the form of NIAS senior research fellowship is thankfully acknowledged. The authors thank the Associate Professor and Head, Cardamom Research Station, Kerala Agricultural University, Pampadumpara and the Director, Indian Cardamom Research Institute, Myladumpara, Spices Board, Ministry of Commerce, Government of India for providing data. The authors also thank several cardamom planters who helped us carry out this research. Dr.Mukund Vasudevan and Kishore Butt of JNCASR and NIAS respectively are thanked for their help. The authors also thank the anonymous reviewers for their valuable suggestions and comments on the previous version of this manuscript.

REFERENCES

Altieri MA, Nicholls CI (1999) Biodiversity, ecosystem function and insect pest management in agroecosystems. In: Collins and Qualset (eds) Biodiversity in agroecosystems. CRC Press, Boca Raton, FL. pp69-84

Anandhi A, Srinivas VV, Kumar ND, Nanjundaiah RS (2008) Role of predictors in downscaling surface temperature to river basin in India for IPCC SRES scenarios using support vector machine. Int J Climatol 29: 583-603

Argiriou AA, Pavlos A, Kalsomines P, Lykoudis SP (2004) On the methods of the delimitation of seasons. Water, Air & Soil Poll 4(5): 65-74

Backiyarani S, Josephrajkumar A, Sainamolekurian P, Murugan M, Sivakumar G (2006) A bold capsule cardamom [*Elettaria cardamomum* (L.) Maton] variety PV-2- suitable for Cardamom Hill Reserves of Kerala. Indian J Gen Pl Breed 66(3): 267-268

Bale JS, Masters GJ, Hodkinson ID, Awmack C, Bezemer JM, Brown VK, Butterfield J, Buse A, Coulson JC, Farrar J, Good JEG, Harrington R, Hartley S, Hefinjones J, Lindroth RL, Press MC, Symmioudis I, Watt AD, Wittaker JB (2002) Herbivory in global climate research: direct effect of rising temperature on insects herbivores. Global Change Biol 8**:** 1-16

Barker RHA, MacLeod A, Cannon RJC (1998) Predicting the impact of non-indigenous pest on the UK potato crop under global climate change: reviewing the evidence for the Colorado beetle, *Leptinotarsa decemlineata*, Brighton Crop Protection Conference, 16-19 November, Brighton UK, 979-984

Bonmatin JM, Marchand PA, Charvet R, Moineau I, Bengsch ER, Colin ME (2005) Quantification of imidacloprid uptake in maize crops. J Agric Food Chem 53:5336-5341

Chakraborty S (2005) Potential impact of climate change on plant-pathogen interactions. Aust Pl Pathol 34**:** 443-448

Decourtye AC, Armongaud R, Renou J, Devillers S (2004) Imidacloprid impairs memory and brain metabolism in honey bees (*Apis mellifera* L). Pestic Biochem Phys 78:83-92

Gentz MC, Mordoch G, King GF (2009) Tandem use of insecticides and natural enemies for effective and reduced risk pest management. Biological Control doi: 10.1016/j biocontrol 2009.7.012

Food and Agricultural Organization of the United Nations (FAO) (2008) Climate-related transboundary pests and diseases, Rome, 1-14

Fuhrer J (2003) Agroecosystem response to combinations of elevated CO_2, ozone and global climate change. Agric Ecosy Environ 97: 1-20

Hansen LM (2007) Will climate change give rise to increasing pest problem in agricultural crops, Trends and perspectives in Agriculture, NJF 23rd Congress: 26-29, June, Copenhagen, p.17

Hess A, Iyer H, Malon W (2001) Linear trend analysis: a comparison of methods. Atmos Environ 35:5211-5222

Intergovernmental Panel on Climate Change (IPPC) Climate change (2001) Synthesis Report In: Watson R. T. (ed) Cambridge University Press, Cambridge, UK, 147 pp. and appendices

Kerala Agricultural University (KAU) (2006) Packages of Practices of Cardamom. KAU Press, Thrissur, Kerala, India.

Kievitis J (2007) Bee gone: Colony collapse disorder. Pesticide News 76:3-5

Lal R Cummings DJ (1979) Clearing a tropical forest: Effects on soil microclimate. Field Crop Res 2:91-107

Mac Queen JB (1967) Some methods for classification and analysis of multivariate observations. In: 5th Berkeley symposium on mathematical statistics and probability. Berkeley, UC Press, 1:281-297

Murugan M, Miniraj M, Carmelranijoseph M (2000) Changes in climatic elements and their impact on production of cardamom (*Elettaria cardamomum* M.) in the cardamom hills of Kerala, India. J. Spices Aromatic Crops 9 (2): 157-160

Murugan M, Josephrajkumar A, Kurian SP, Backiyarani S (2002) Essential oil of cardamom (*Elettaria cardamomum* M.) – Effect of infestation by thrips (*Sciothrips cardamomi* Ramk.). Indian Perfumer 46(4):321-323

Murugan M, Josephrajkumar A, Sheeba B, Vasanthakumar K, Ambikadevi D (2005) Essential oil profile of elite small cardamom (*Elettaria cardamomum* M.) accessions and their interaction with thrips (*Sciothrips cardamomi* Ramk.) infestation. Indian Perfumer 49(2): 219-223

Murugan M, Mukund V, Ramesh R, Hiremath MB, Josephrajkumar A, Shetty PK (2008) Centennial rainfall variation in semi arid and tropical humid environments in the cardamom hill slopes, southern Western Ghats, India. Caspian J Environ Sci 6(2): 31-39

Murugan M, Backiyarani S, Josephrajkumar A, Hiremath MB, Shetty PK (2007) Yield of small cardamom (*Elettaria cardamomum* Maton) variety PV-1 as influenced by levels of nutrients and neem cake under rain fed condition in southern Western Ghats, India. Caspian J Environ. Sci 5(2): 19-25

Olfert O, Weiss RM (2006) Impact of climate change on potential distributions and relative abundance of *Oulema melanopus*, *Meligethes viridescens* and *Ceutorhynchus obstrictus* in Canada. Agric Ecosyst Environ 113: 295-301

Patterson DT, Westbrook JK, Joice RJV, Lingren PD, Rogasik J (1999) Weeds, insects, and diseases. Clim Change 43: 711-727

Porter JH, Parry ML, Carter, TR (1991) The potential effect of climate changes on agricultural insect pests. Agric For Meteorol 57: 221-240

Salinger MJ (2005) Climate variability and change: Past, Present and Future- an overview. Clim Change 70 9-29

Smatas R, Semaskiene R, Lazauskas S (2008) The impact of climate conditions on the occurrence of the Colorado potato beetle (*LEPTINOTARSA DECEMLINEATA*), Zemdirbyste-Agric 95(3):235-241

Stanley J, Pretha G, Chandrasekhar S, Kuttalam S (2009) Honey bees of cardamom ecosystem and selective toxicity of diafenthiuron to four different species in the laboratory. J Apicultural Res 48(2):91-98

Stireman JO, Dyer LA, Jenzen DH, Singer MS, Lill JT, Marquis RJ, Ricklefs RE, Gentry GL, Hallwachs W, Cole PD, Barone J.A, Greeney HF, Cannahs H, Barbosa P, Morais HC, Diniz IR (2005) Climatic variability and parasitism of caterpillars: Implications of global warming. Proc Nat Acad Sci 102(48): 17384-17387

Waldrop MP, Balser TC, Firestone MK (2002) Linking microbial community composition to function in a tropical soil. Soil Biol Biochem 32(13):1837-1846

Walker BH (1991) Ecological consequences of atmospheric and climate warming. Clim Change 18: 301-316

Winkler JA, Palutikof JP, Andresen JA, Goodess CM (1997) The simulation of daily temperature series from GCM output: Part II. Sensitivity analysis of empirical transfer function methodology. J Climate 10: 2514-2535