

[Research]

Yield of small cardamom (*Elettaria cardamomum* M) variety PV1 as influenced by levels of nutrients and neem cake under rain fed condition in southern western ghats, India.

M. Murugan^{1,2*}, S. Backiyarani², A. Josephraj Kumar², M.B. Hiremath¹ and P.K. Shetty¹

1- National Institute of Advanced Studies, Indian Institute of Science campus, Bangalore-560012, India.

2- Cardamom Research Station, (Kerala Agricultural University), Pampadumpara 685 556, India.

*Corresponding author's Email: muthupeyan@yahoo.co.in

ABSTRACT

This paper seeks to understand the influence of different levels of fertilizer nutrients on annual yield of cardamom in Cardamom Hill Reserves (CHR) under rain fed situation. Field experiment conducted at CRS, Pampadumpara during 1994-2002 on nutrient levels with sources revealed that increasing the levels of nitrogen, phosphorus and potassium had increased the yields of cardamom up to 125: 125: 200 kg ha⁻¹. Application of fertilizer nutrients at the present level of recommendation (75: 75: 150 kg NPK ha⁻¹ yr⁻¹) in the form of urea, single super phosphate and muriate of potash along with 0.5 kg neem cake per plant had not increased the yield significantly over the control. Application of fertilizer nutrients at the rate of 125: 125: 200 kg ha⁻¹ yr⁻¹ in two splits (just before and after summer monsoon) increased the yield significantly under Pampadumpara rainfall climatology. Among N, P and K, it appears that K is the most important as indicated by a larger absolute value than that of N and P. Therefore application of fertilizer K is a must to increase the cardamom yield in CHR system. However, rainfall during summer months and number of rainy days had pronounced effect on the production of cardamom. Among rainy seasons (SWM, NEM and SR), SR played significant role in increasing the cardamom yield. Higher than the average SR (366mm) followed by SWM (1162mm) found to influence the yield significantly. The reason for the higher yield by summer rainfall could be due to increased growing season soil moisture which is essential for the growth and panicle initiation and subsequent development of flowers and capsule setting. The recent all India droughts have very little influence on the rainfall climatology of cardamom hill reserves during the period of South West monsoon and therefore the yield was not affected by all India droughts but the summer months' rainfall and its distribution.

Key words: Cardamom, neemcake, nutrient levels, rainfall, tropical evergreen forest, yield.

INTRODUCTION

The establishment of relations between climate variability and crop yield values is vital because of the economic importance of crops and interest in the future of agriculture under possible climate change in the twenty - first century. Cardamom is highly responsive to added nutrients and much sensitive to weather and climate. The uniqueness of cardamom in tropical rainforest and climate vagaries particularly rainfall make this an interesting one. Small Cardamom (*Elettaria cardamomum* Maton) is cultivated as an under storey crop in the tropical ever green forests of western Ghats of South India in the altitude ranging from 500-1500m above MSL with an average annual rainfall between 1500 (Karunapuram-

Anniarthozhu) to 6000mm (Elappara and Eravikulam-Idamalakkudi) and annual lowest and highest temperature varying from 10° to 36°C. India is the second largest producer of cardamom in the world and the major part of the production is consumed with in the country. The contribution of Kerala to India's total production is about 60 per cent. The cardamom hills have highly variable weather and climate from year to year. There is remarkable fluctuation in rainfall from severe drought to heavy rainfall. As a result high rainfall amounts can sometimes be detrimental to cardamom. In Idukki district, it is cultivated in and around cardamom hills, which were legally allotted for exclusive cultivation of cardamom. PV1 (Pampadumpara Variety 1) variety is also

popular among the planters in Sivagiri and Palni hills of Tamil Nadu. The cured capsules of cardamom are used in flavoring foods and beverages. However the value added products of this produce such as essential oil and oleoresin have been used in the perfumery and *ayurvedic* preparations. Despite the hurdle in the export of cardamom during the immediate past ten years, the internal market or demand has increased greatly. Most of the soils in the cardamom growing tracts in the cardamom hills are acidic owing to its local rainfall situations. The predominant soil orders under which the soils are grouped were Ultisols, Oxisols and Inceptisols. Leaching of soil nutrients in cardamom plantations is very common due to high rainfall and undulating topography and the combination of these with the thick vegetation have resulted in the development of nutrient limited acidic soils. Kaolinitic Alfisols, Ultisols and Oxisols dominate upland soil types in tropical regions with low effective cation exchange capacity *i.e.* less than 12meq/100g of clay (Sanchez 1976, Moench 1991, Juo and Wilding 1996). Cardamom being a perennial crop, continuous intensive cultivation in such nutrient poor soils has led to depletion of nutrients in the soil resulting in poor growth and reduced yields.

In the humid zone, major upland soils are strongly weathered, Kaolinitic Ultisols and Oxisols. Both Ultisols and Oxisols are acidic, and thus contain very low levels of mineral nutrients (Van Wembeke, 1991). Balanced fertilization would really mean rational use of fertilizers for supply of nutrients to the crop in such a manner that would ensure among others maintaining soil productivity and sustain high commensurate with the biological potential of the crop variety under the unique soil, climate and agro ecological set up (Goswami, 1998; Swaroop and Ganeshamurthy 1998).

Cardamom is a cross-pollinated crop and therefore variation is huge among the varieties and cultivars. The variety PV 1, which is a drought tolerant variety, was very popular among the planters in Kerala until the middle of the 1990s. Even now this variety is very famous among the planters of Karnataka and Tamil Nadu considering its drought tolerance, quality (Essential oil) as well as higher yield potential under average management condition. The chemical profile of elite as well as *kattalam* cardamom types was studied by Murugan *et al.* (2005). Increasing input of fertilizers has significantly contributed to the increase of crop yields (Murayama, 1982; Lui, 1999). One of the

main reasons for the low yield of this variety is that planters do not apply recommended levels of fertilizer nutrients to this variety. To realize the yield potential of the variety nutrients must be given in recommended quantity and balanced proportion. The response of cardamom cultivars and varieties to levels of nutrients varies widely according to soil and climatic condition and yield level. The climatic condition of cardamom hills is fast changing and with in a passage of 10 years there were three drought years and therefore occurrence of drought is frequent. The change in climatic elements and their impact on production was discussed by Murugan *et al.* (2000).

The yield of cardamom has been affected by climatic and non-climatic factors. Non-climatic factors that affect yield include soil fertility, insect pests and diseases, weed pressures etc. Several non-climatic factors act in concert with climatic factors to affect the cardamom yield. For example alternate, hot and dry, humid and wet weather conditions can favour root grubs and white flies. Considering the importance of PV 1 variety particularly the drought tolerance in the changing climatic scenario this study was undertaken to know the response of PV 1 variety to varying levels of N P and K along with neem cake under rain fed condition and the results were presented in this paper. Such studies on the yield-nutrient-climate (rainfall) relations have positive implications for agro ecosystem management.

MATERIALS AND METHODS

The field experiment was conducted at Cardamom Research Station, Pampadumpara from 1994-2002. The soil of the experimental site was loam with a pH of 5.2 and electrical conductivity of 0.05 m mhos cm⁻¹. The organic carbon content that is an index of available nitrogen was 1.26 %. The available P₂O₅ and K₂O were 1.45 and 11.5 mg per 100g of soil respectively. The concentration of DTPA extractable micronutrients (µg g⁻¹) at the experimental site was in the order of Fe (68), Mn (17.58) Cu (0.32) Zn (0.80) and Mo (0.05). The cation exchange capacity of the soil was 7.07 cmol (P⁺) kg⁻¹. The experiment was laid out in randomized block design with four replications during 1993-1994. Six clumps of PV 1 variety were planted in each treatment with spacing of 2.5 x 2.5m apart. Intercultural operations were carried out as per the KAU package of practices. Matured capsules from the experimental plants were harvested and cured. The data on yield and biometric characters were recorded

regularly till the completion of experiment in 2002. The treatment details are:

- T₁ : NPK@ 0:0:0 Kg ha⁻¹ Yr⁻¹
 T₂ : NPK@ 75:75:150 Kg ha⁻¹ yr⁻¹
 T₃ : NPK@ 100:100:175 Kg ha⁻¹ yr⁻¹
 T₄ : NPK@ 125:125:200 Kg ha⁻¹ yr⁻¹
 T₅ : NPK@ 150:150:225 Kg ha⁻¹ yr⁻¹
 T₆ : NPK@ 75:75:150 Kg ha⁻¹ + 0.5kg neemcake plant⁻¹ yr⁻¹

The fertilizer nutrients as per above treatments were mixed and applied right at the base of each plant from the start of the experiment. The fertilizer nutrients and neemcake were applied in semi circular bands taken around the experimental plants and then covered with soil carefully. Nitrogen was supplied as urea where as phosphorous and potassium was applied respectively in the form of rock phosphate and *muriate* of potash. Only 25% and 50% of the fertilizer nutrients as per the treatment schedule were given in the first and second year of planting respectively. Nutrients were given in two splits one in the month of June and the second split during the gap between SW and NE monsoon. The data collected on yield and other biometric characters were analysed statistically through ANOVA (Analysis Of Variance) (Panse and Sukhatme, 1985). Soil analysis for nutrient concentration was carried out as per the standard procedure (Jackson, 1973). All the cultural operations such as weeding, spraying chemicals, shade lopping, post harvest processing was given uniformly to all treatments as per Kerala Agricultural University Package of practices (1996).

Collection of Rainfall data

Annual rainfall data for the whole period of experimentation were collected from the cardamom research station, Kerala Agricultural University, Pampadumpara, which is the representative station for cardamom hill reserves. The seasonal rainfall data were calculated from the annual data as per the IMD classification of seasons. [(South West Monsoon (SWM): June, July, August and September) (North East Monsoon (NEM): October, November December) (Summer Rainfall (SR): January, February, March, April and May)]. Normal, excess and drought years of rainfall were classified based on the literature information of long-term rainfall analysis for that cardamom ecosystem (Murugan et al., 2000). The average annual rainfall for the cardamom hills was available as 2000 mm (1956-1997 average), any amount less than 1850mm per year is considered drought year and amount

above 2150 mm in a year regarded as excess. Ten per cent variability has not been taken as standard since the tropical rainy climate rainfall is relatively reliable. Therefore this criterion was selected, as cardamom was highly sensitive to drought. Any small alteration in the distribution of rainfall will drastically affect the growth of plant and yield of capsule. Nonlinear least-squares data fitting by the Gauss-Newton method (MATLAB function '*nlinfit(.)*') was used to study the interaction of variables on the yield of cardamom.

RESULTE AND DISCUSSION

Effect of Fertilizer levels on yield

The pooled average yield of cured capsules increased with the application of nitrogen, phosphorous and potassium [table (1) fig (1)]. A linear trend of yield was observed for the increase in NPK levels up to 125:125:200 kg ha⁻¹, the response of nutrients after this level was decreasing and the yield was reduced. The increasing levels of N, P and K had increased the yield of cardamom.

The maximum yield of 587kg ha⁻¹ was registered in those plots applied with 125:125:200 kg NPK ha⁻¹ during the year 2000. The lowest yield of 75.6 kg ha⁻¹ was recorded for application of NPK @ 75: 75: 150 kg ha⁻¹ during the year 1997. The yield during 1997 was very low in all the treatments due to severe drought. In the year 1999 maximum yield of 578 kg ha⁻¹ was registered in T5 (150:150:225 Kg NPK ha⁻¹) followed by T4 (125:125:200 Kg NPK ha⁻¹), which were statistically superior to other treatments. This trend on yield was followed in the succeeding years up to 2002. The pooled average data revealed that the lowest yield (156 kg ha⁻¹) of capsule was reported in control (T1) while the highest capsule yield (306.5 kg ha⁻¹) was recorded for the application of 125:125:200 kg NPK ha⁻¹ followed by T5 (NPK@ 150:150:225 Kg ha⁻¹) (281 kg ha⁻¹). The treatment T6 (NPK@ 75:75:150 + neem cake 0.5 Kg pt-1 yr-1) gave a yield of 161.5 kg ha⁻¹.

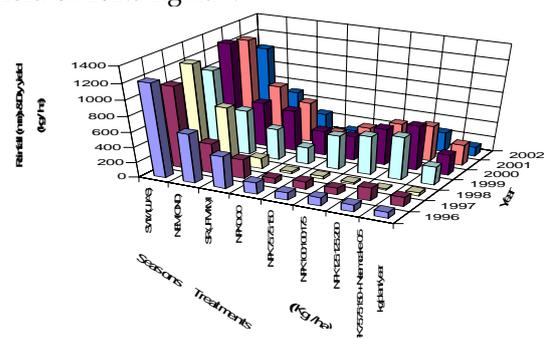


Fig 1: Effect of different doses of NPK and neem cake on dry yield of cardamom variety PV-1.

Similar type of experiments conducted elsewhere also revealed that for cardamom clones grown under controlled shade and supplied fertilizer level @ 100:25:100 kg NPK ha⁻¹ yr⁻¹ had recorded optimum yield in Karnataka (Korikanthimath *et al.*, 2000) condition.

The poor yield reported from T6 where neem cake @ 0.5 kg plant⁻¹ yr⁻¹ applied along with fertilizer at present level of recommendation could be attributed to the unknown biological metabolism that exist in tropical rainforest ecosystem soils in which the ecosystem responses like atmospheric nitrogen fixation, P solubilisation mineralization etc. through micro organism. Similar types of results were also reported by Sunderashwar *et al.* (2003) in coastal ecosystems.

The result of an experiment conducted from 1986-1989 (Korikanthimath, 1989) using variety PV 1 under uniform shade condition with 27 treatment combination of primary nutrients also showed no significant difference in yield under Karnataka condition. Therefore it is understood that the yielding behavior of same variety in different ecosystems will differ depending on the soil biochemical properties which is the basis for soil nutrient dynamics in any ecosystem.

Influence of Rainfall on yield

Conventionally, the most obvious agro meteorological variable to predict is rainfall. However, the total amount of rainfall received in a season or year may be above average but poorly distributed so that cardamom growth and production for that season or year is below average. For cardamom planters, a major management decision is the fertilizer application rate because of the quick response of the crop. From the table (1 and 2) and figure (1)

it is clear that the yields were low in three years, which received scanty rainfall during the summer months. Among the summer months February and March are critical months. Even though the annual rainfall was more than the average in 2002, because of the little no rain fall during the summer months of that year the yield was affected considerably. On the contrary in the year 1998, though the annual rainfall was fairly high the yield was very low owing to the rainless months of February and March.

Interestingly, the number of rainy days also played crucial role in increasing the yield, this was very vividly manifested in the years of 1998 and 2002. Therefore, this experiment explicitly showed that quantity and number of rainy days during summer months had greatest influence in the yield of cardamom as that of fertilizers do in normal years.

Since these two climatic variables can be considered as important parameters for the rainfall forecast for the region for this crop. Reliable forecast can help avoiding fertilizers during the drought season, which means loss of money, and yield while applying little fertilizers in normal or excess years means lost opportunity or crop loss again. Normally, the all India drought has very little influence on the rainfall climatology of cardamom hill reserves for example the recent drought years 2002, 1998 and 1997 had very high rainfall in July months which was the highest amount of rainfall in these years during the experimentation. The reason for the recent drought in India had been attributed to the Madden-Julian Oscillation (MJO) caused by the eastward extension of the West Pacific Warm Pool (Saith and Slingo, 2006) which had not influenced the annual summer monsoon rainfall to decrease in cardamom hill reserves of Kerala.

Table 1: Effect of different doses of NPK and neem cake on yield of dry cardamom capsule variety PV-1.

Treatments (kg ha ⁻¹ yr ⁻¹)	Capsule Yield (kg ha ⁻¹) (Dry)							
	1996	1997	1998	1999	2000	2001	2002	Average
NPK 0:0:0	156.8	75.6	30.9	225.0	328.5	185.0	90.4	156.03
NPK 75:75:150	99.6	100.5	34.8	450.0	314.5	310.0	110.4	217.11
NPK 100:100:175	109.2	90.0	26.7	508.8	481.3	428.3	170.0	259.19
NPK 125:125:200	94.8	167.5	13.8	563.3	587.0	463.8	255.7	306.56
NPK 150:150:225	83.2	89.0	23.6	578.0	382.5	528.0	283.0	281.04
NPK 75:75:150 + Neem cake 0.5 kg plant ⁻¹	80.2	124.1	37.4	245.5	273.8	285.5	124.1	161.51
CD (P=5%)	NS	76.3	21.7	20.8	23.53	42.50	28.10	

Table 2: Rainfall distribution in cardamom hills during the period of experimentation.

Months	Rainfall (mm)						
	1996	1997	1998	1999	2000	2001	2002
January	9.5	0.4	8.4	19.5	113.2	98.3	0.0
February	35.1	0.0	1.0	45.3	89.1	54.8	0.0
March	86.8	24.8	0.0	116.8	49.7	58.4	34.2

Table 2. Continued.

April	188.2	93.3	52.0	128.2	169.4	123.8	88.3
May	108.6	133.6	83.0	98.3	113.7	195.3	143.4
June	275.4	187.5	345.3	215.4	315.2	297.5	166.4
July	348.5	493.3	376.8	318.4	395.4	334.5	387.2
August	327.5	290.0	291.0	317.5	267.1	295.9	299.0
September	260.6	98.8	219.0	200.8	310.2	311.1	190.5
October	248.2	264.7	319.0	198.3	284.1	249.2	278.5
November	264.4	38.7	237.2	289.4	198.7	234.7	119.7
December	135.6	92.0	191.2	105.7	98.5	210.5	112.0

Interaction of nutrients and seasonal rainfall on the yield

Among SWM, NEM and SR, the SR plays a more important role increasing the cardamom yield. The cross terms are quite small with the exception of NEM-SR and SWM-SR terms. The reason for the higher yield by summer rainfall could be attributed to increased growing season soil moisture which is essential for the growth of panicle initiation and subsequent development flowers and capsule setting. Higher than the average SR (366mm) followed by SWM (1162mm) found to influence the yield significantly (table 3).

The poor yield reported from T6 where neem cake @ 0.5 kg plant⁻¹ yr⁻¹ applied along with fertilizer at present level of recommendation could be attributed to the repellent effect of neem cake on the foraging honey bees. In fact the repellent action of neem cake on the honey bees foraging on the flowers of prostrate panicles is maximum in this variety because of the close proximity and mixing of neem treated soil with flowers. In other varieties the panicles don't touch the soil and at least two feet distance is maintained between soil surface and panicles thereby the repellent effect of neem is minimum in these *Mysore* and *Vazhuka* varieties. Hence pollination is affected by neem application in this particular variety.

Therefore further studies on the crop-pollinator relationships are warranted to unravel the mechanism among the different types of cardamom types and varieties. The cardamom yield is influenced more by SR as well as number of rainy days than the fertilizer

nutrients. In the absence of well-distributed SR the yield of cardamom cannot be increased significantly by fertilizer application. It is therefore hypothesized that the yields of cardamom are increased in which year the SR and its distribution would be normal and above average irrespective of fertility of the soils. During the experimentation it was observed that SR and NEM have positive and significant effect on the major nutrients availability and yield than the SWM.

The response of cardamom to climate is nonlinear that changes over time (nonstationarity) However, trends in yield may also attributed to trends in climate, cardamom is highly sensitive to sub seasonal weather variability also, therefore the prospects for yield-climate prediction, particularly in the context of climate change, in part rely, on the understanding of crop-climate system.

The key question for this is how much of the nonstationarity in the weather-yield relationship can be accurately simulated. It should be noted that the above non-linear equation could in principle be used to predict the average yield of small cardamom given the values of N, P, K, neem and the rainfall (expected or actual) for a particular year.

However, a note of caution with such a prediction is that it may not be accurate. In fact, with a non-linear equation, even small deviations in any of the given values can result in widely different yield values. Long-term datasets therefore are needed both on the climate variables and yield for accurate prediction and forecast.

Table 3: Seasonal distribution of rainfall in cardamom hills, Kerala, India.

Season	Rainfall (mm)							Average
	1996	1997	1998	1999	2000	2001	2002	
SWM	1212.0	1069.6	1232.1	1052.1	1287.9	1239.0	1043.1	1162.2
NEM	648.2	395.4	747.4	593.4	583.1	694.4	510.2	595.7
SR	428.2	252.1	144.4	408.1	535.1	530.6	265.9	366.3
Total	2288.4	1717.1	2123.9	2053.6	2404.3	2464	1819.2	2124.3

SWM: South West Monsoon (June, July, August, September).

NEM: North East Monsoon (October, November, December).

SR: Summer Rainfall (January, February, March, April, May).

CONCLUSION

The cardamom soils are found to be distinctly acidic, rich in organic matter and low in available phosphorous and potassium depicting the characteristics of the humid tropics. It is estimated that an average of 5-8 tones of dry leaves fall from shade trees annually in a hectare of land in cardamom plantations adding 100-160 kg N, 5-8 kg P, 100-160 kg potassium, 10-16 kg calcium and 25-40 kg Magnesium per hectare. The nutrient addition through natural litter fall may have profound impact on soil fertility maintenance and ecosystem processes. Up to now, based on the factors affecting the availability of nutrients in soils, a fertilizer dose of 75:75:150kg NPK ha⁻¹ was recommended for normal (average) crop yield of 100 kg ha⁻¹yr⁻¹. In our experiment maximum yield of 306.5kg ha⁻¹ (average of seven years) was registered for the application of 125:125:200 kg NPK ha⁻¹ yr⁻¹. Therefore, fertilizer dose of 125:125:200 kg NPK ha⁻¹yr⁻¹ could be recommended for realizing maximum yield under normal rainfall year. Nevertheless, the cardamom yield is influenced more by summer rainfall as well as number of rainy days than the fertilizer nutrient. In the absence of well-distributed summer rainfall the yield of cardamom cannot be increased significantly by fertilizer application. It is therefore hypothesized that the yields of cardamom are increased in which year the summer rainfall distribution would be normal and above average irrespective of fertility of the soils. Since cardamom is very sensitive to climatic elements such as air temperature, relative humidity, sunshine hours and wind, understanding the variations within season would unravel the exact climatic critical variables that influence the yield of cardamom in a larger way. Some of these variables tend to have negative effect on the yields; therefore the future research must focus on the identification of critical climatic variables and correct forecast of seasonal rainfall, which can maintain one of the most unique agro ecosystems in a sustainable way.

ACKNOWLEDGMENTS

The assistance in all forms given by the Indian Council of Agricultural Research, New Delhi during the period of experimentation is gratefully acknowledged. The work was carried out at the cardamom research station, Kerala Agricultural University, Pampadumpara, during 1994 - 2002 under All India Coordinated Research Projects on Spices for which Cardamom Research Station, Pampadumpara

was the lead centre for major spices. The authors are thankful to Nithin Nagaraj, Researcher, Mathematical Modeling unit, National Institute of Advanced Studies, Bangalore for valuable help.

REFERENCES

- Goswami, N.N. 1998. Some thoughts on the concept, relevance and feasibility of IPNS under Indian conditions. In *Integrated Plant Nutrient Supply system for sustainable productivity*. Acharya C L et al. (ed). Indian Institute of soil science, Bhopal. pp. 3-9.
- Jackson, M.L. 1973. *Soil chemical analysis*. Prentice Hall, Inc., USA.
- Juo, A.S.R. and Wilding, L.P. 1996. Soils of the low land forest of the West and Central Africa. In *Essays on the ecology of the Guinea-Congo rainforest*, Proceedings Royal Society of Edinburgh. Vol. 104B, Edinburgh, Scotland, UK. pp. 15-26
- Kerala Agricultural University (1996) *Package of Practices of crops*.
- Kerala Agricultural University press, Thrissur, Kerala, India
- Korikanthimath, V.S., Hiremath, G.M. and Hosmani, M.M. 2000. Requirement of labour in the mixed cropping system of coconut and cardamom and its relationship with productivity levels. *Crop Research* **20(3)**, 520-524.
- Korikanthimath, V.S. 1989. Annual Report. *National Research Center for Spices (NRCS)*, Calicut. pp.33-34.
- Lui, X. 1999. Perspective of food security in China. Major technical changes. In *World food security and crop production technologies tomorrow*. (ed) Horic, T., Geng, S., Imamura, T and Suiraiwa, T., Kyoto University, Kyoto. pp. 41-47.
- Moench, M. 1991. Soil erosion under a successional agro-forestry sequence: A case study from Idukki District, Kerala, India. *Agro forestry systems*. **15**, 31-50.
- Murayama, N.1982. *Conquest of Law of diminishing returns*. Yokendo, Tokyo. 139-186.
- Murugan, M., Miniraj, N. and Carmelrani, J. 2000. Changes in climatic elements and their impact on production of cardamom (*Elettaria cardamomum* M) in the cardamom hill reserves of Idukki district, Kerala. *J. Spices and Aromatic Crops*: **9(2)**, 157-160.
- Murugan, M., Josephraj Kumar, A., Sheela, B., Vasanthakumar, K. and Ambikadevi, K. 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.
- Panse, V.G. and Sukhatme, P.V. 1967. *Statistical methods for agricultural workers*, ICAR Publications, New Delhi.
- Saith, N and Slings, J. 2006. The role of the Madden-Julian Oscillation in the El Nino and Indian drought of 2002 *Int.J. Climatol.* **26**, 1361-1378.
- Sanchez P.A. 1976. *Properties and management of soils in the tropics*. John Wiley and Sons, New York, USA.
- Sunderashwar, P.V., Morris, J.T., Koepfler, E.K. and FornWalt, B. 2003. Phosphorous limitation of coastal ecosystem processes. *Science* **299**, 563-565.
- Swaroop, A. and Ganeshamurthy, A.N. 1998. Emerging nutrient deficiencies in intensive cropping systems and their remedial measures. *Fertiliser news* **43 (7)**, 37-50.
- Van Wabeke, A. 1991. *Soils of the Tropics: Properties and Appraisal*. McGraw-Hill, New York, USA.